Unit 2 Cycle 3

Extension 1: Changing the strength of the forces (Intended for Professional Development only)

Note: this extension (along with the remainder of U2C3) is intended to be used only in professional development for teachers, not in the classroom with elementary students. It involves conceptual complexities and representations that students may not be ready to grasp.

TARGET IDEAS

- The magnitude of the net force acting on an object determines the rate at which the object's speed changes.
- When a non-zero net force acts on a moving object in the same direction as its motion, the magnitude of the net force will determine the rate at which the object's speed increases.
- When a non-zero net force acts on a moving object in the direction opposite to its motion, the magnitude of the net force will determine the rate at which the object's speed decreases.

COMMON MISCONCEPTIONS

- *When a non-zero net force acts on an object at rest, the object's speed will increase at the same rate regardless of the magnitude of the net force.* (In other words, all net forces applied to an object at rest cause the same change in motion. They will not! The larger the net force, the greater the rate of speed increase.)
- *When a net force acts on an object at rest, only the magnitude of the force acting in the resulting direction of motion determines the rate at which an object's speed increases.* (Not necessarily! The magnitudes of any backward forces also need to be taken into account because it is the net force that determines the rate of speed increase.) This misconception is often stated as: The greater the magnitude of a forward force, the greater an object's increase in speed.
- *When a non-zero net force acts on an object in the direction opposite its motion, the object's speed will decrease at the same rate regardless of the magnitude of the net force.* (It will not! The larger the net force, the greater the rate of speed decrease.) This misconception is often stated as: Any net force in the direction opposite motion causes the same change in motion.
- *When the net force acting on a moving object is in the direction opposite to its motion, only the magnitude of the force opposing motion determines the rate at which an object's speed decreases.* (In other words, only the opposing force matters. In actuality, the rate of decrease in speed also depends on the strength of any forces acting in the same direction as motion. It is the magnitude of the <u>net</u> force that determines rate of speed change.)

WHAT TO FOCUS ON

Note: In this extension, it is especially important to be careful about the use of language when describing speed and changes in speed. Participants may interpret statements about changes in speed to be about speed itself, and may make statements about speed when they intend to address change in speed. This issue is likely exacerbated if changes in speed are referred to using the terms “slower” and “faster” (e.g., the object’s speed increased faster) because we so often use those terms to compare speeds. Thus, we recommended that phrases such as “the toy’s speed increases faster” be avoided and that phrases such as “the toy’s speed increases at a greater rate” be used instead.

This extension addresses the idea that different strength net (unbalanced) forces will make an object’s speed change at different rates. Participants examine the results of different strength forward and backward forces acting on objects. They use their own observations of pushes applied to small objects, and simulation results, to investigate the relationship between the magnitude of the net force acting on an object and the rate at which the object’s speed changes.

Participants will conduct a series of activities that provide evidence for the idea that the magnitude of the net force acting on an object determines the rate at which the object’s speed *changes*. Initially, participants apply constant forces, first gentle (but stronger than friction) and then strong, to a toy car. (Note, they will likely find it difficult to maintain a constant push as the car will move faster and faster. Also, they may mistakenly equate “constant push” with “constant speed.” Be on the lookout for this issue and address if necessary.) From this extension, they should recognize that the speed of the car increases at a greater rate with the strong push.

The hands-on activity is followed by a pair of simulations that reinforce this idea by providing additional evidence. The first simulation shows two cars starting at rest that are subjected to forces of different magnitudes acting in only one direction. The second simulation is more realistic because it includes a backward (frictional) force and provides evidence that forces other than those acting in the direction of motion affect the change in motion.

Before each simulation runs, participants should be focused on the direction and magnitude of the forces acting on the cars as indicated by the adjacent (black) arrows labeled with force strength. As each simulation runs, participants should recognize that the motion of the cars is represented by the cars’ position on the screen and in the corresponding graphs. Participants should also be made aware of the red “half-arrow” above each car whose size represents the speed of the car at any given time.

In the first simulation, the differing growth of speed arrow sizes and corresponding slopes of the graphs provide evidence that different forward forces result in different rates of speed increase. The simulation provides evidence that counters the misconception that *when a non-zero net force acts on an object at rest, the object’s speed will increase at the* *same rate regardless of the magnitude of the net force* because the speeds of the cars increase at different rates.

In the second simulation, two cars again start at rest, but frictional forces are added. Participants should focus on the presence of both forward and backward forces and the combination of forces to calculate the net force on each car. Again, the differing growth of the speed arrows and corresponding slopes of the graphs provide evidence that different non-zero net forces result in different rates of speed increase. The car experiencing the smaller net force accelerates more slowly (in this case, even though one car experiences a stronger forward force than the other car, it also experiences a stronger backward frictional force, and the net force is smaller). The simulation provides evidence that counters the misconception that *when a net force acts on an object at rest, only the magnitude of the force acting in the resulting direction of motion determines the rate at which an object's speed increases* because the car with the stronger forward force experiences less acceleration.

Next, participants observe what happens when they apply a quick push to a block first on a smooth surface and then again on a rough surface. They should recognize that the speed of the block decreases at a greater rate on the rough surface. It is important that they recognize that the rough surface subjects the block to a greater frictional (backward) force than the smooth surface.

In the third simulation, two blocks start in motion at the same speed. Participants again should focus on the presence of both forward and backward forces and use the combined force arrows to calculate the net force on each block. The differing decreases of the speed arrows and corresponding slopes of the graphs provide evidence that different backward non-zero net forces result in different rates of speed decrease. The speed of the block experiencing the smaller net force in the direction opposite its motion decreases at a lower rate (in this case, even though one block experiences a stronger backward (frictional) force than the other block, it also experiences a stronger forward force and the net force is smaller). The simulation provides evidence that counters the misconception that *when a non-zero net force acts on an object in the direction opposite its motion, the object's speed will decrease at the same rate regardless of the magnitude of the net force.* It also counters the misconception that *when a net force acts on an object at rest, only the magnitude of the force acting in the resulting direction of motion determines the rate at which an object's speed increases* because the car with the stronger forward force experiences less acceleration.

MATERIALS NEEDED FOR THIS EXTENSION

Material	**Quantity**
Toy car	1 per small group
Wooden block	1 per small group
Sheet of sandpaper	1 per small group

Masking tape	2-4 rolls per session
Computer with internet access	1 per PD session
Motion and Force Simulator The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The three simulations for this extension are the Extension 1 simulations within Unit 2, Cycle 3.	1 per PD session

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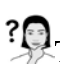
Purpose

Explain that participants have experienced how non-zero net forces cause changes in motion and that the purpose of this extension is to investigate how different size non-zero net forces affect motion.

Emphasize that this extension (along with the remainder of U2C3) is intended for teachers only, not for use in the classroom with elementary students. It involves conceptual complexities and representations that students may not be ready to grasp.

What do we think?

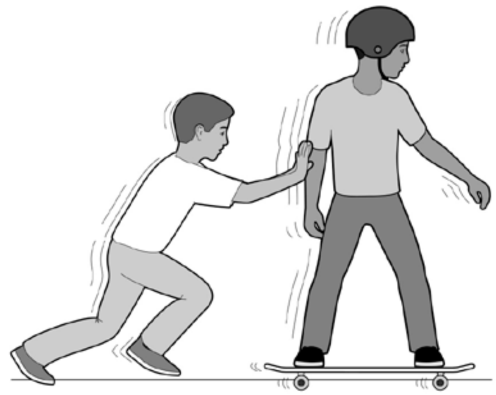


The "What do we think?" task introduces participants to a scenario including different strength net forces and how the resulting motion is represented graphically. Though most participants are likely to realize that the skateboarder's increase in speed will become smaller when the strength of the push is reduced, it is not important that participants portray the scenario accurately at this point (some may not draw a reduced slope, or may draw a smooth curve rather than two distinct sections with different slopes, or may indicate a constant speed when the push strength is reduced). However, it is important that they are familiar with the use of speed-time graphs for representing motion. This type of graph will be used repeatedly in later simulations. Have each group of participants reach consensus and create a representative group graph (using small whiteboards facilitates this).

Extension 1: Changing the strength of the forces (Intended for Professional Development only)

Purpose

In the previous cycles you have seen that when unbalanced forces act on an object, its speed either increases or decreases, depending on whether the net force acts in the same direction as the motion, or opposite to it. In this *Extension* activity you will examine whether changing the strength of the forces acting on an object will change any aspect of its motion?



For example, if you were to continuously push your friend on his skateboard, would any aspect of his motion change if you pushed harder? If so, what?

The big question we will address in this activity is:

When an unbalanced combination of forces acts on an object, how is its motion affected by the strengths of the forces?

What do we think?

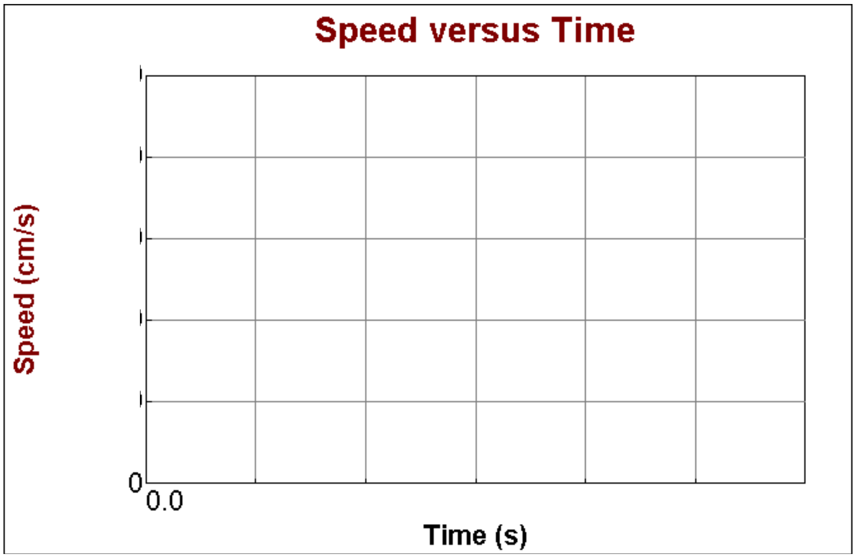
Suppose a child is standing on his well-oiled skateboard, which is not moving, and you start to push him. After a short time you reduce the strength of your pushing force to half its value. Assuming the effects of friction are negligible, would he continue to move in exactly the same manner after you reduce the strength of your push, or would his motion change in some way?

Discuss your thinking with your neighbors, and on the next page sketch what you think a speed-time graph for the skateboarder would look like. Make a note of your reasoning below the graph.

Have participant groups display their graphs so that all participants can see graphs created by other groups. Encourage participants to describe similarities and differences they see across the graphs. Reiterate, or point out, the indications of changing speed and constant speed. Have spokespersons for groups with differing graphs explain why they drew the graph as they did. If present, include a correctly drawn graph (two segments of increasing speed with the slope of the first segment being greater than that of the second segment). Review the rationales for the representative graphs (e.g., reduction in force caused constant speed, reduction in force caused speed to increase at a slower rate, reduction in force caused speed to decrease) and state that this extension will allow investigation of what happens with different strength forces.

Activity 1
STEP 1

Participants need to focus on attempting to maintain a gentle constant push rather than using a quick push. They should apply the push to the back of the car rather than the top. Most participants will easily recognize that the speed of the car gradually increases. (Note: they will have to move their hand faster and faster to maintain a constant push; be on the lookout for participants confusing “constant push” with “constant speed.”)



Participate in a class discussion about this question. Make a note of any ideas or reasoning that differs from others in your group.

Activity 1: Force strength and increasing speed

You will need:

- Toy car
- Access to the **Motion and Force Simulator**

STEP 1: Place the toy car on a table, or on the floor. Use your finger to push on the car with a continuous **gentle** push for a few seconds. Try to keep the strength of your push the same strength the whole time.

Describe the motion of the car while you were pushing it. Did its speed stay constant or did it increase gradually?

Participants may find that maintaining a stronger push for more than a couple seconds was quite difficult because the speed of the car increases at a great rate. Nonetheless, they should recognize that the speed of the car increased as they pushed and that the speed increased at a greater rate with the stronger push than with the gentle push.

The objective here is to have participants generalize the difference they identified for gentle and strong pushes of the car to different magnitude forces causing different rates of increase of speed for an object.

STEP 2

The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). The simulations for this extension are in the Unit 2, Cycle 3 Simulations section. For this portion of the extension, use "Extension 1 First Setup."

The simulations can be projected so that all participants view them together. Depending on the availability of computers and internet access, smaller groups or individuals may view the simulations separately.

Now return the car to the starting point and repeat what you did, but this time try to maintain a **stronger** push on the car.

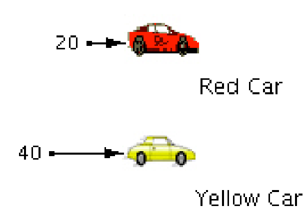
Describe the motion of the car while you were pushing it this time. What, if anything, was different about how its speed behaved?

You have seen in earlier activities that when a single force is applied to an object at rest, the object will start to move, with its speed continuously increasing as long as the force is applied.

What aspect of the behavior of such an object seems to be affected by changing the strength of the force that is applied to it?

In the next step, you will use a simulator to check your thinking, but before doing so we need to know how the strength of a force is specified. The strength of a force is measured in units of newtons (N), named in honor of Sir Isaac Newton, a famous English scientist you have probably heard of. To give you a feeling for these units, it takes a force of about 1 N to lift a four-pack of AA batteries, whereas it would take a force of about 10 N to lift a 2 lb bag of sugar.

STEP 2: Open the first simulator setup for this activity. This setup shows two otherwise identical toy cars that will each be pushed across a smooth surface by a single force. The red car will be pushed with a force of 20 N, while the yellow car will be pushed by a force of 40 N. Speed-time graphs for both cars will be displayed. Run the simulator and answer the following questions based on the results.



Whether the simulations are viewed as a whole group together or separately by small groups or individuals, have the participants share and record their responses to the questions posed in these materials.

Most participants will likely note that the speed of both cars increased. Some participants might point out that the scenario is unrealistic because there would also be frictional forces that oppose the cars' motion. If this occurs, point out that the simulator allows the examination of a hypothetical, simple case, and that friction will be dealt with in subsequent scenarios.

Again, most participants will recognize that the speed of the yellow car increases at a greater rate than the speed of the red car. This idea may be expressed as the yellow car moved farther in the same time. Continue to prompt participants so that the difference in motion is put in terms of increased speeds.

The time for each car to reach 10 m/sec is determined from the speed-time graphs. Encourage participants to explain how they used the graphs to find that the time for the red car was 5 sec. and the time for the yellow car was 2.5 sec.

Many participants will readily be able to identify the yellow car as experiencing the higher acceleration. When explaining how they know this, participants may point to evidence in terms of the graphs and the distance travelled in a set time. Encourage participants to relate these descriptions to the rates of speed increase. Some participants may simply respond that the yellow car was faster. If so, emphasize that the simulation provides more than just speed data—point out that the graphs show the change in speed throughout the time segment and it is this change in speed, or acceleration, which is of interest.

STEP 3
Use the "Extension 1 Second Setup" simulation for this part of the extension.

What is similar about the motion of the two cars, even though different strength forces are being applied to them?

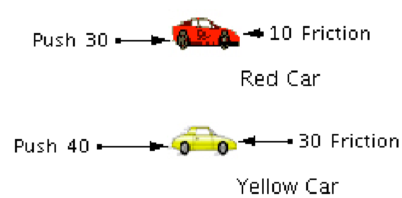
What is different about the motion of the two cars while different strength forces are being applied to them?

How long did it take the red car to reach a speed of 10 m/s? What about the yellow car? What does this tell you about the rate at which the speed of the cars was changing?

You saw in Unit 1 that scientists use the term *acceleration* to refer to the rate at which an object's motion is changing? Which of the toy cars, red or yellow, had the highest acceleration? How do you know?

STEP 3: In reality, the toy car you used in STEP 1 also had a frictional force acting on it while you were pushing it. This means that there was not a single force acting on it, but an unbalanced combination of forces.

Open the second simulator setup for this activity now. It shows two cars that have unbalanced combinations of forces acting on them. When run, the red car will be pushed with a 40 N force, while a frictional force of 10 N also acts on it.



The yellow car will be pushed by a 40 N force while a 30 N frictional force acts on it. <u>**DO NOT RUN THE SIMULATOR YET!**</u>

Have participants discuss the scenario and their thoughts about what motion they expect to see. Ask participants to share predictions and explanations with the whole group and prompt them to make any alternatives public as well.

Be sure that the outcome of the scenario (the speed of both cars increases, but the rate of increase is greater for the red car than it is for the yellow car) is recognized by all before they discuss how it relates to their predictions.

At this point, many participants will readily be able to identify the red car as experiencing the greater rate of speed increase. When explaining how they know this, participants may point to evidence in terms of the graphs and the distance travelled in a set time. Encourage participants to relate these descriptions to acceleration.

This scenario may be difficult for some to accept because it counters the misconception that the strengths of the forward forces determine the rates of speed increase. Participants now need to consider the relative effects of the two different net forces acting on the cars. As this situation is examined and discussed, it should become clear to participants that the determining quantity for rate of speed increase is the net force rather than the forward force.

Do you think the speed of the two cars will behave in exactly the same way, or will they be different in some way? If so, how will they be different, and why?

NOW RUN THE SIMULATOR

Did the speeds of the two cars behave as you predicted? If not, discuss with your group and try to understand their behavior.

Which of the toy cars, red or yellow, had the highest rate of change in its speed? How do you know?

How is it possible that the speed of the car with the weaker force pushing it forward changed at a higher rate?

Activity 2: Force strength and decreasing speed

You will need:

- Wood block
- Sandpaper and tape
- Access to the **Motion and Force Simulator**

Activity 2

STEP 1

When applying a push to the block, participants need to use a quick push, as opposed to maintaining a push like they did in Activity 1 with the toy car.

Participants should have observed that the speed of the block decreases at a greater rate when it was pushed on the sandpaper.

Encourage participants to express their thoughts about:

- the differences in friction based on the nature of the two surfaces, and
- how these surfaces affected block motion differently.

The objective here is to use the evidence elicited by the two previous questions to draw the tentative conclusion that a stronger backwards force (friction) seems to cause a greater rate of decrease in speed. Prompt participants to explicitly cite their observations that the block speed decreased at a higher rate on the sandpaper surface and that the sandpaper surface provides a greater backwards, frictional force. Participants may object to accepting this idea as a general conclusion because objects can also be subjected to different forward forces that need to be taken into account. If this occurs, tell the participants that they will examine that situation next.

STEP 2

Before viewing the third simulation ("Extension 1 Third Setup"), point out that the blocks in the simulation are moving at the same speed when the simulation begins. It may also be helpful to point out (particularly if a participant raises the issue) that unlike their own pushes, the simulation includes a constant forward force on the blocks. Explain that applying a constant forward force is extremely difficult for humans to do, especially when encountering friction-based resistance, but that using the simulator allows them to include this aspect in the scenario.

STEP 1: In the first part of this activity you examined how the rate at which an object's speed increases is affected by the strength of the forces acting on it. We will now turn to examining the case of decreasing speed.

Place the wood block on a smooth table top and give it a quick, firm push to start it moving. Now tape a sheet of sandpaper to the table, place the block on it at one end, and give the block the same strength tap as before.

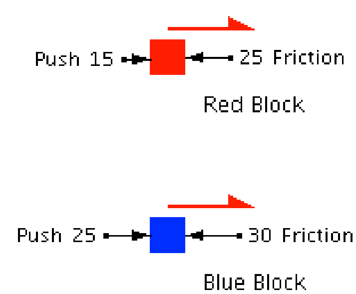
On which surface did the block's speed decrease at a higher rate, the smooth table top or the sandpaper?

On which surface do you think the frictional force acting on the block was stronger?

What does this result seem to imply about how the rate at which an object's speed decreases depends on the strength of the backwards force being applied to it?

STEP 2: Again, we will check our thinking using a simulator. Open the third simulator setup for this activity. It shows two otherwise identical blocks that will initially be moving to the right at the same speed. (The red half-arrows indicate speed, not force!)

The red block will be pushed forward with a force of 15 N, while a frictional force of 25 N will act on it in the opposite direction. The blue block will be pushed forward with a force of 25 N, while a 30 N frictional force acts on it. **DO NOT RUN THE SIMULATOR YET!**



Have participants discuss the scenario and their thoughts about what motion they expect to see. Ask participants to share predictions and explanations with the whole group and prompt them to make any alternatives public as well.

Be sure that the outcome of the scenario (the speed of both blocks decreases, but the rate of decrease is greater for the red block than it is for the blue block) is recognized by all before they discuss how it relates to their predictions.

At this point, many participants will readily be able to identify the red block as experiencing the greater rate of speed decrease. When explaining how they know this, participants may point to evidence in terms of the graphs and the distance travelled in a set time. Encourage participants to relate these descriptions to rate of speed change.

This scenario may be difficult for some to accept because it counters the misconception (and the tentative conclusion reached in the previous step) that the strength of the backward forces is what determines the rates of speed decrease. Participants now need to consider the net forces acting on each block and the relative effects of the two different net forces acting on the cars. As this situation is examined and discussed, it should become clear to participants that the determining quantity for rate of speed decrease is the net force rather than just the backward force.

Do you think the speed of the two blocks will behave in exactly the same way, or will they be different in some way? If so, how will they be different, and why?

NOW RUN THE SIMULATOR

Did the speeds of the two blocks behave as you predicted? If not, discuss with your group and try to understand their behavior.

For which of the blocks, red or blue, did the speed change at a higher rate? How do you know?

How is it possible that the speed of the block with the weaker frictional force acting backwards decreased at a higher rate?

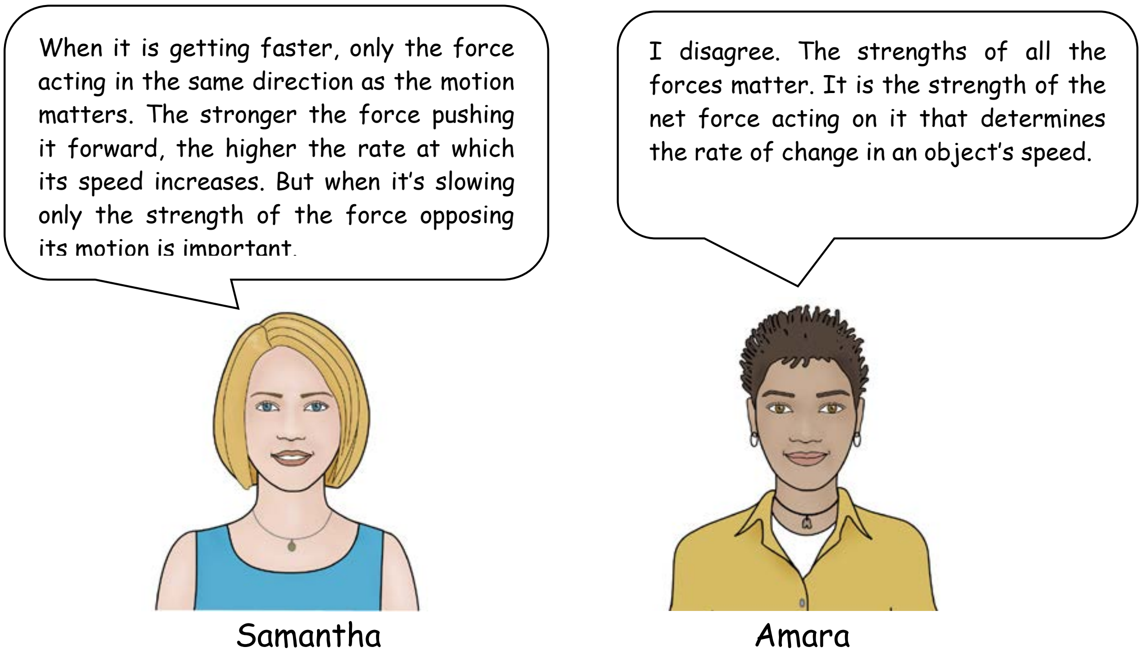
Making Sense Questions

Question S1: This question may be difficult for some participants to "digest" because Samantha's statement addresses forward forces in determining rate of speed increase and backward forces in determining rate of speed decrease. Nonetheless, participants should draw from the evidence produced in the extension to identify and explain the flaw in Samantha's thinking—that only forces in the direction of motion have an effect on motion. If needed, have the participants address one situation at a time (i.e., forward forces and speed increase, then backward forces and speed decrease) before linking them together as representing the same general issue. Participants should see that Amara's response is correct and be able to put this general idea in their own words (e.g., all forces on an object contribute to any change in motion the object experiences).

Question S2: Participants may struggle with not knowing the current speed of the objects included in this question. If so, emphasize that the question does not ask about the relative speeds of the objects, but instead asks about the relative changes in the speeds of the objects. Most participants will likely know that they need to calculate the net forces acting on each object. Encourage participants to record these calculations. Some participants may not know how to use the calculated net force values to answer the question. Prompt participants to consider that they examined the rate of speed change in relation to net force in the simulations and that this is what the question is asking about. Once participants accept that the current speed of an object is not important for determining the extent to which a net force changes the speed, they should be comfortable using their net force calculations to simply order the rates of speed change: D (net force = 0), B (net force = 30), and A and C (each have net force = 40). In the event that possible differences in the starting speeds of the four objects appears to be an insurmountable conceptual obstacle, the participants can assume that all of the objects start at the same speed.

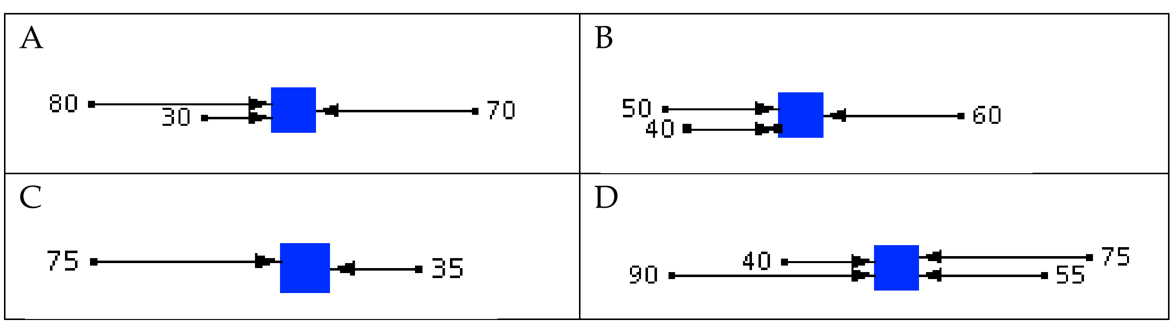
Making Sense

S1: Two people are discussing what it is that determines how quickly an object's speed changes when an unbalanced combination of forces acts on it.



Do you agree with Samantha or Amara? Explain why.

S2: Shown below are four otherwise identical objects that have different combinations of forces acting on them. Order them in terms of the rate of change in their speeds, from lowest to highest. Explain your reasoning.



Unit 2 Cycle 3

Extension 2: Objects of different mass

(Intended for Professional Development only)

TARGET IDEAS

- The mass of an object determines the rate at which the object's speed changes when a non-zero net force acts on it.
- When a non-zero net force acts on a moving object in the same direction as its motion, the mass of the object will determine the rate at which the object's speed increases.
- When a non-zero net force acts on a moving object in the direction opposite to its motion, the mass of the object will determine the rate at which the object's speed decreases and when its direction of motion changes (as well as the rate of speed increase following the direction change).

COMMON MISCONCEPTIONS

- *Mass and weight are the same thing.* (They are not! Mass is the amount of material that comprises an object. Weight is a measure of the gravitational force exerted on an object.)
- *When a non-zero net force acts on an object at rest, the object's speed will increase at the same rate regardless of the mass of the object.* (It will not! The smaller the mass, the greater the rate of change in the speed; in this situation, a greater rate of increase in speed.) This misconception may be stated as: A particular net force will cause the same change in speed for any object at rest.
- *When a non-zero net force acts on an object in the direction of its motion, the object's speed will increase at the same rate regardless of the mass of the object.* (It will not! The smaller the mass, the greater the rate of change in the speed; in this situation, a greater rate of increase in speed.).
- *When a non-zero net force acts on an object in the direction opposite its motion, the object's speed will decrease at the same rate regardless of the mass of the object.* (It will not! The smaller the mass, the greater the rate of change in the speed; in this situation, a greater rate of decrease in speed.)
- *A net force that causes a change in motion for an object of small mass may fail to cause a change in motion for an object of greater mass.* (Not so! As long as there is a non-zero net force acting on an object, a change in motion will result. It is the rate of the change in motion that is affected, which will be lower with the more massive object.)

WHAT TO FOCUS ON

Note: In this extension, it is especially important to be careful about the use of language when describing speed and changes in speed. Participants may interpret statements about changes in speed to be about speed itself, and may make statements about speed when they intend to address change in speed. This issue is likely exacerbated if changes in speed are referred to using the terms "slower" and "faster" (e.g., the object's speed increased faster) because we so often use those terms to compare speeds. Thus, we recommend that phrases such as "the toy's speed increases faster" be avoided and that phrases such as "the toy's speed increases at a greater rate" be used instead.

This extension focuses on the idea that a particular strength non-zero net (unbalanced) force will make objects of differing mass change speed at different rates. Participants examine the results of equal strength net forces acting on objects of different masses. They use their own observations of pushes acting on familiar objects of similar size but differing mass, as well as simulation results, to investigate the relationship between an object's mass and the rate at which its speed changes when a net force is applied.

Initially, participants apply a constant, gentle push to a toy car, then add a mass to the car and apply the same push. (Note, they will likely find it difficult to maintain a constant push as each toy will move faster and faster. They may also inadvertently use a stronger push when the added mass is present because of a habit of taking the mass of an object into account when applying a force to move it. Finally, they may mistakenly equate "constant push" with "constant speed." Be on the lookout for these issues and address if necessary.) From this activity, they should recognize that the car's speed increases at a greater rate without the added mass.

This hands-on activity is followed by a simulation that reinforces this idea by providing additional evidence. The simulation shows two cars of different masses starting at rest and subjected to the same non-zero net force in the same direction. Before the simulation runs, participants should note the mass of each object and that the direction and magnitude of the forces acting on the objects are equal. As the simulation runs, participants should recognize that the motion of the objects is represented by the objects' position on the screen and the corresponding graphs. Participants should also be made aware that the size of the red "half-arrow" above each object represents the speed of the object at any given instant. Participants should attend to the speed arrows and graphs showing that both cars' speeds increase. The differing growth of speed arrow sizes and the corresponding slopes of the resulting graphs provide evidence that different car masses result in different rates of speed increase. This result also provides evidence that counters the misconception that *when a non-zero net force acts on an object at rest, the object's speed will increase at the same rate regardless of the mass of the object* because the speeds of the cars increase at different rates. It also provides some evidence that counters the misconception that *a net force that causes a change in motion for an object of small mass may fail to cause a change in motion for an object of greater mass.*

Next, participants maintain gentle pushes of the same strength in the direction opposite the motion of two balls of similar size but different masses. They should recognize that the speed of the ball with less mass decreases at a greater rate. They may also observe that the direction of motion changes (or changes sooner) for the ball with less mass. Again, this hands-on activity is followed by a simulation that reinforces the idea by providing additional evidence. In this simulation, two balls start in motion at the same speed and in the same direction. Participants should note the different masses of the balls and the presence of equal magnitude forces acting in the direction opposite the balls' motion. The differing sizes of the speed arrows and corresponding slopes of the graphs provide evidence that different masses result in different rates of decrease in the balls' speeds. The simulation provides evidence that counters the misconception that *when a non-zero net force acts on an object in the direction opposite its motion, the object's speed will decrease at the same rate regardless of the mass of the object.* In this case the rate of change in speed for the ball with less mass is great enough that a change in its direction is also observed during the simulation. Although incidental to this portion of the extension, participants might recognize that this ball's speed increases following the change in direction because the force is then acting in the direction of motion, yielding a situation represented in the first simulation.

MATERIALS NEEDED FOR THIS EXTENSION

Material	**Quantity**
Toy car	1 per small group
Lump of modeling clay or similar payload for toy car	1 per small group
Balls of similar size but differing masses	1 pair per small group
Computer with internet access	1 per PD session
Motion and Force Simulator The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The two simulations for this extension are the Extension 2 simulations within Unit 2, Cycle 3	1 per PD session

Purpose

Explain that participants have experienced how the magnitude of a non-zero net force affects changes in motion and that the purpose of this extension is to investigate how the mass of an object affects changes in motion.

Reiterate that this extension (as a part of U2C3) is intended for teachers only, not for use in the classroom with elementary students. It involves conceptual complexities and representations that students may not be ready to grasp.

What do we think?

The "What do we think?" task introduces participants to a scenario in which different masses experience the same magnitude net force, asking how the motion will be different (the speed will still be increasing, just at a lower rate, after the second child jumps on the skateboard because there is still a non-zero net force acting in the direction of motion,). Though most participants will likely realize that the skateboarder's increase in speed will become smaller when the mass is increased, it is not important that participants' graphs be completely accurate at this point (some may not draw a reduced slope; some may draw a smooth curve rather than two distinct sections with different slopes; some may indicate a constant, or even decreasing, speed when the mass is increased). However, it is important that participants be familiar with the use of speed-time graphs for representing motion because this type of graph will be used in the simulations. Have each group of participants reach consensus and create a representative group graph (using group whiteboards facilitates this process).

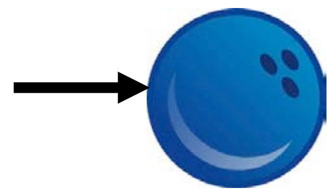
Unit 2 Cycle 3

Extension 2: Objects of different mass

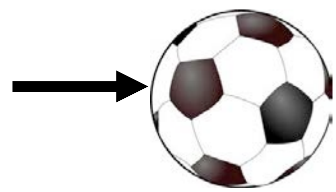
(Intended for Professional Development only)

Purpose

In the previous activity you saw that when unbalanced forces act on an object, the rate at which its speed changes depends on the strength of the net force acting on it. In this activity we will investigate whether the mass of an object also has an effect on its motion, and if so, what?



Suppose you pushed a soccer ball and a bowling ball with the same strength force, would anything about the way they move be different?



The big question we will address in this activity is:

> ***When the same net force acts on objects of different mass, is their motion different in any way?***

What do we think?

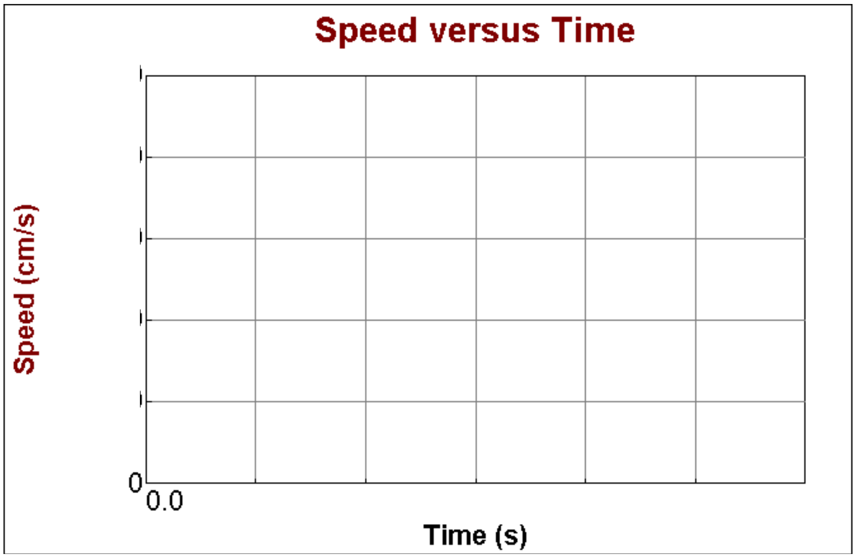
Suppose a child is standing on his well-oiled skateboard, which is not moving, and you start to push him. After a short time a friend comes along and also jumps on the skateboard. Assuming the effects of friction are negligible, and you maintain the same strength push, would the motion of the skateboard stay the same when the friend jumps on, or would it change in some way?

Discuss your thinking with your neighbors, and on the next page sketch what you think a speed-time graph for the skateboard would look like before and after the friend jumps on. Make a note of your reasoning below the graph.

Have groups display their graphs so that all participants can see the graphs created by other groups. Encourage participants to describe similarities and differences they see across the graphs. Reiterate, or point out, how one can tell from speed-time graphs whether the speed is constant or changing. Have spokespersons for groups with differing graphs explain why they drew their graphs as they did. If a group has drawn the graph correctly, (two straight-line segments of increasing speed with the slope of the first segment being greater than that of the second segment), be sure to have that group share. After groups are done presenting, review the rationales for the different graphs (e.g., increased mass caused constant speed, increased mass caused speed to increase at a slower rate, increased mass caused speed to decrease) and state that this extension will allow investigation of what happens when different masses experience net forces with the same magnitudes.

Mass and Weight

Before moving on, the PD facilitator should highlight the distinction between mass and weight. Emphasize that it is the effect of an object's mass that we will be considering in this extension.



Participate in a discussion about this question. Make a note of any ideas or reasoning that differs from others in your group.

Mass and Weight

Before continuing with this activity we need to make sure we understand what is meant by the mass of an object. **Mass and weight are not the same.** ***An object's mass is a measure of the amount of material it comprises*** and, as such, is the same anywhere in the universe. Common units of mass used by scientists are kilograms (kg) and grams (g). ***'Weight' is the name scientists give to the strength of the gravitational force exerted on an object by a planet***, such as Earth. As such, an object's weight would be different on different planets, and would be zero in interstellar space. Because weight is a force, it has the same units as other forces: newtons (N).

It is important to remember that **mass is a property of an object** that does not change if you take it somewhere else, like its shape or its color. However, **weight is a force that acts on an object** when it is near (or on) a planet and can change from place to place. (Indeed, very sensitive instruments that can detect very small changes in weight are used to determine geological information about specific locations here on Earth – such as where oil-bearing rocks might be.)

Activity 1

STEP 1

Participants need to focus on attempting to maintain a gentle constant push rather than using a quick push. They should apply the push to the back of the car (pushing forward parallel to the ground) rather than to the top (pushing down on the car). Most participants will recognize that the speed of the car gradually increases with and without the added mass. (Note: they will have to move their hand faster and faster to maintain a constant push; be on the lookout for participants confusing "constant push" with "constant speed." It may be necessary to direct participants' attention to the first moments of the push, particularly when mass is added to the car, in order to consider the motion when a constant force is most readily applied.)

The objective here is to have participants explicitly express that, although the speed kept increasing in each case, the rate of increase in the speed was lower when the car had the added mass. It is often difficult to judge rates of change in speed, particularly when comparing objects that are not viewed "side-by side" when their speeds are changing. As a result, participants may tend to focus on relative speeds of the car at a given time, or distance from the starting point, to make comparisons. For example, participants may state that the car had a lower speed in the trial using the added mass than it did in the initial trial. If so, prompt them to express a chain of logic that turns the focus to the difference in the rate of increase in speed: because the car had a greater speed in the first trial than it did in the second trial, and because the car started at rest in both trials, and because we pushed the cars for the same amount of time, the rate at which the speed increased must have been greater in the first trial.

Activity 1: Mass and increasing speed

You will need:

- Toy car
- Large "lump" of modeling clay (or object of similar mass)
- Access to the **Motion and Force Simulator**

STEP 1: Place the toy car on a table, or on the floor. Use your finger to push on the car with a continuous **gentle** push for a few seconds. Try to keep the strength of your push the same the whole time.

Now return the car to the starting point and add the modeling clay so that the car has significantly more mass than it did before. Repeat what you did above, using the same strength push as you did before.

Describe the motion of the car while you were pushing it, both with and without the modeling clay added. Did its speed stay constant or did it increase gradually?

You know that when unbalanced forces are applied to an object at rest, the object will start to move, with its speed continuously increasing as long as the force is applied.

What aspect of the behavior of such an object seems to be affected by changing the mass of the object?

STEP 2

⚠ The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). The simulations for this extension are in the Unit 2, Cycle 3 Simulations section. For this portion of the extension, use "Extension 2 First Setup."

The simulations can be projected so that all participants view them together. Depending on the availability of computers and internet access, smaller groups or individuals may view the simulations separately.

Whether the simulations are viewed as a whole group together or separately by small groups or individuals, have the participants share and record their responses to the questions posed in these materials.

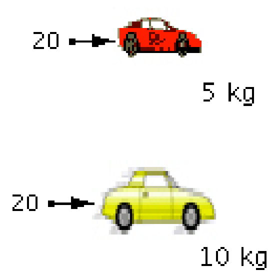
Most participants will likely note that the speed of both cars kept increasing.

Again, most participants will recognize that the speed of the red car increases at a greater rate than the speed of the yellow car. This idea may be expressed as the red car moved farther in the same time or had a greater speed at a given time. Continue to prompt participants so that the difference in motion is put in terms of rate of increase in speed and the difference in rate is tied to the difference in mass.

The time for each car to reach 10 m/sec is determined from the speed-time graphs. Encourage participants to explain how they used the graphs to find that the time for the red car was 2.5 sec. and the time for the yellow car was 5 sec.

The objective here is to have participants generalize the difference they identified for cars of smaller and larger mass to any objects of different mass that experience the same magnitude net force. In this case the focus is on different rates of increasing speed.

STEP 2: Open the first simulator setup for this activity. This setup shows two toy cars of different masses that will both be pushed with a force of 20 N. The red car has a mass of 5 kg, while the yellow car has a mass of 10 kg. Speed-time graphs for both cars will be displayed. Run the simulator and answer the following questions based on the results.



What is similar about the motion of the two cars, even though they have different masses?

What is different about the motion of the two cars even though they have the same strength force acting on them?

How long did it take the 5 kg car to reach a speed of 10 m/s? What about the 10 kg car? What does this tell you about the rate at which the speed of the two cars was changing?

When the same force is applied to two different objects, which one's speed will increase at a higher rate, the one with less mass, or the one with more mass?

Activity 2

STEP 1

Depending on the size of the balls being used, the gentle backward force may be most reliably and evenly applied by conducting the runs with one ball at a time, or with the two balls rolling side-by-side. In any case, it is important that the starting speeds of the balls be approximately the same.

Have participants discuss the scenario and their thoughts about what motion they expect to see. Ask participants to share predictions and explanations with the whole group and prompt them to make any alternatives public as well.

Participants should observe that the speed of the ball with the smaller mass decreased at a greater rate. In the event that this result is not observed, have participants repeat the ball rolling runs and emphasize the importance of the balls having the same initial speeds and their applying equal strength forces to the balls. Be sure that the outcome of the scenario (the speed of both balls decreases and the decrease happens at a greater rate for the smaller-mass ball than it does for the larger-mass ball) is recognized by all before they discuss how it relates to their predictions.

Again, the objective here is to have participants generalize the difference they identified for the balls of smaller and larger mass to any objects of different mass that experience the same magnitude net force. In this case, the focus is on different rates of decreasing speed.

Activity 2: Mass and decreasing speed

You will need:

- Two small balls of similar size but different mass (golf ball and ping-pong ball, or similar)
- Access to the **Motion and Force Simulator**

STEP 1: In the first part of this activity you examined how the rate at which an object's speed increases is affected by its mass. We will now turn to examining the case of decreasing speed.

Imagine two balls of the same size, but different masses, were rolling across a level table at the same speed. Suppose you applied the same strength force to both balls in the opposite direction to their motion.

Which of the two balls do you think would slow to a stop and reverse direction first, or would they both behave in the same way? Explain your thinking.

Use the two small balls to check your thinking. Apply the "backward" force by blowing very gently on them as they roll toward you.

Which ball slowed to a stop and reversed direction first, the one with more mass, or the one with less mass?

What does this result seem to imply about how the rate at which an object's speed decreases depends on its mass (when the same strength force is being applied to it)?

STEP 2
Use the "Extension 2 Second Setup" simulation for this part of the extension.

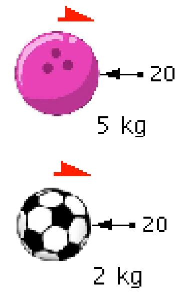
Before viewing the second simulation, emphasize that the balls in the simulation are moving at the same speed when the simulation begins. It may also be helpful to point out that unlike the force produced by their own blowing in the previous step, the simulation includes a perfectly constant backward force on the balls. Explain that applying a constant force is extremely difficult for humans to do, but that using the simulator allows them to examine what would happen in an ideal scenario.

Have participants discuss the scenario and their thoughts about what motion they expect to see. Ask participants to share predictions and explanations with the whole group and prompt them to make any alternative ideas public as well.

Be sure that the outcome of the scenario (the speed of both balls decreases, but the rate of decrease is greater for the soccer ball than it is for the bowling ball) is recognized by all before they discuss how it relates to their predictions. Participants may focus on the direction change experienced by the soccer ball. If so, steer the discussion to emphasize that it is the greater rate of decrease in speed that allows the direction change to occur within the time frame of the simulation (if the simulation ran for more time, eventually the bowling ball would also reverse direction). Participants may also notice that the rate of increase in speed following the change in direction equals the rate of speed decrease prior to the change in direction. Again, steer the discussion to emphasize that because neither the strength of the force nor the mass of the ball change, the rate of speed change is also the same before and after the change in direction.

At this point, many participants will readily be able to identify that the soccer ball experiences the greater rate of decrease in speed. Encourage participants to express this result in relation to mass. When explaining how they identified different rates of decreases in speed, participants may point to evidence from the graphs and the distance travelled in a set time. Encourage participants to relate these descriptions to rate of change in speed.

STEP 2: As usual, we will check our thinking using a simulator. Open the second simulator setup for this activity. It shows two balls that will initially be moving to the right at the same speed with a 20 N force acting on each of them in the opposite direction to their motion. One ball has a mass of 5 kg, while the other has a mass of 2 kg. **DO NOT RUN THE SIMULATOR YET!**



Which of the two balls do you think will slow to a stop and then reverse direction first, or will they behave in exactly the same way? Explain your thinking.

NOW RUN THE SIMULATOR

Was the result as you predicted? If not, discuss with your group and try to understand what happened.

While their speeds were decreasing, for which of the balls did the speed change at a higher rate, the one with less mass, or the one with more mass? How do you know?

Making Sense Questions

Question S1: One objective here is to have participants generalize the difference they identified for the cars and balls of smaller and larger mass to any objects of different mass that experience the same magnitude net force. Another is that participants understand that the effect of the mass of an object on the rate at which its speed changes holds true for both speed increases and speed decreases. Participants should now be able to cite examples from the extension to support these ideas.

Question S2: Participants may struggle with not knowing the masses of the balls included in this question. If so, point out that the graph does not show an absolute scale for speed, and that they should focus on the relative masses, and relative speeds of the balls. It may also be necessary, particularly with respect to the beach ball, to specify that the forces are applied in such a way that the balls remain in contact with the floor rather than flying into the air.

Most participants will likely be able to indicate that in the 1st second, the upward slope of the line for the beach ball is greater than that for the bowling ball. Encourage participants to express why there is this difference in slope (e.g., the 5 N force causes the speed of the beach ball to increase at a greater rate because it has less mass than the bowling ball). The extent to which the slopes differ is not important (and would depend on the difference in mass between the two balls).

Most participants will likely indicate that the speeds are constant for each ball during the 2nd one-second period; however, it may be necessary to remind participants that the scenario excludes the effects of friction, and ask participants what happens to an object's speed when no forces are applied.

Most participants will also likely indicate that the speeds of the balls decrease during the final second. It is important that participants draw a line for the beach ball that has a greater downward (negative) slope than the line for the bowling ball. Again, encourage participants to express why there is this difference in slope (e.g., the 5 N force causes the speed of the beach ball to decrease at a greater rate because it has less mass than the bowling ball). Although it is not essential that the lines drawn for this final second of motion reflect the exact opposite slope from those drawn for the initial second, this feature of the graph can be discussed if any participants raise the issue.

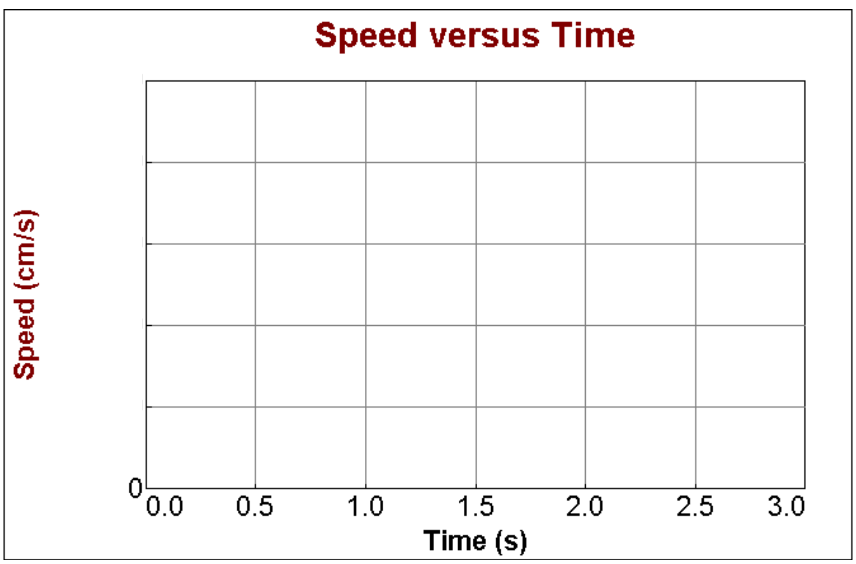
Making Sense

S1: How does the mass of an object affect the rate at which its speed changes while a particular strength net force acts on it? Is this true for both increasing speed and decreasing speed? What evidence supports your answer?

S2: A beach ball and a bowling ball are sitting at rest on a level floor. Forces are applied to each of them as follows. (The effects of friction can be ignored.)

- A 5 N force is applied to each for a period of 1.0 second.
- They then move for another 1.0 second period with no forces acting on them.
- Finally, a 5 N force is applied to each in the direction opposite its motion for a further period of 1.0 second.

Sketch and label speed-time graphs for both balls on the blank axes below. Briefly explain why your graphs look as they do.



Unit 2 Cycle 3

Extension 3: Putting it all together

(Intended for Professional Development only)

TARGET IDEAS

- The rate at which an object's speed changes is proportional to the magnitude of the net force acting on the object and inversely proportional to the object's mass.
- When objects of different mass fall, their speeds increase at the same rate because the magnitude of gravitational force acting on an object is proportional to the object's mass.

COMMON MISCONCEPTIONS

- *The rate at which an object's speed changes is determined* ***only*** *by the magnitude of the net force acting on the object.* (Not true! Both the mass of the object and the net force it experiences affect the rate at which its speed changes.)
- *The rate at which an object's speed changes is determined* ***only*** *by its mass.* (Again, both the mass of the object and the net force it experiences affect the rate at which its speed changes.)
- *The more massive an object, the greater the rate at which its speed increases as it falls.* (As a general rule, this is not true! Although the increase in speed of falling objects is sometimes lower for objects of less mass than it is for objects of greater mass, it is due to the effects of air resistance. In the absence of such a frictional force, objects of different masses fall with the same rate of increasing speed.)
- *Objects of different mass fall at the same rate of increasing speed because the strength of the gravitational force acting on all objects is the same.* (Objects of differing mass do fall at the same rate of increasing speed when experiencing only a gravitational force, but the strength of the gravitational force acting on all objects is not the same. The same rate of increase in speed is observed because the gravitational force acting on an object is proportional to the object's mass.)

WHAT TO FOCUS ON

This extension addresses the idea that both the mass of an object and the net force applied to the object determine the rate at which the object's speed changes. After the two previous extensions, participants should now recognize that each of these factors (mass and net force) individually affects the rate at which the speed of an object changes. The new challenge presented in this extension is to understand the combined effect of these factors, including the quantitative relationship among net force, mass and rate of change in speed. Participants examine the results of different strength net forces acting on objects that also differ in mass. They then use their own observations of falling objects to investigate the relationship between an object's mass and the gravitational force it experiences.

Participants also engage with simulations involving objects of different masses subjected to different net forces. Before each simulation runs, participants should note the masses of the objects and the magnitudes of the net forces acting on them. As each simulation runs, participants should recognize that the motion of the objects is represented by the objects' position on the screen and in the corresponding graphs. Participants should also be made aware that the size of the red "half-arrow" above each object represents the speed of the object at any given instant.

In the first activity, a simulation shows three cars of different masses starting at rest with different net forces acting on them (all in the same direction). Participants should attend to the cars' relative positions, as well as the speed arrows and graphs showing that the speeds of the cars increase at different rates. The relatively low rate of increase in speed of the car with the lowest mass provides evidence that counters the misconception that *the rate at which an object's speed changes is determined only by its mass.*. The differing rates of increase in speed for the cars of different mass experiencing the same net force provide evidence that counters the misconception that *the rate at which an object's speed changes is determined only by the magnitude of the net force acting on the object.*

Next, participants examine the relationships among mass, net force, and rate of change in speed as they explore how they can modify the net forces in the simulation to produce equal rates of speed change for all three cars. From this part of the activity, they should recognize that mass and net force have opposite effects on the rate of change in speed (i.e., the rate at which a car's speed changes is proportional to the magnitude of the net force acting on the car and inversely proportional to the car's mass).

Finally, participants compare the changes in motion for two similarly sized objects of differing masses as they fall to the floor. Participants should note the different masses of the objects and pay attention to how much time it takes for each object to reach the floor. They should see (or hear) that the objects hit the floor at the same time, indicating that there is no difference in the rate at which the objects' speeds change. This activity also provides evidence that counters the misconception that *the more massive an object, the greater the rate at which its speed increases as it falls.* Because the relationship among mass, net force, and change in speed has already been established, participants should conclude that the two objects of different masses with the same rate of change in speed must have experienced net forces of differing magnitudes. They should further reason that the object with the lower mass must have experienced a proportionally smaller force. This activity provides evidence that counters the misconception that *objects of different mass fall at the same rate of increasing speed because the strength of the gravitational force acting on all objects is the same.* The role of friction due to air resistance in countering the gravitational force (and thus affecting the magnitude of net forces on falling objects on Earth) is also addressed.

MATERIALS NEEDED FOR THIS EXTENSION

Material	**Quantity**
Similarly sized objects with different masses (e.g., volley ball and “medicine” ball)	1 of each per small group
Computer with internet access	1 per PD session
Motion and Force Simulator The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The simulation for this extension is the Extension 3 simulation within Unit 2, Cycle 3.	1 per PD session

Purpose

Explain that participants have investigated how the magnitude of net forces and mass individually affect changes in speed, and that the purpose of this extension is to investigate how these factors combine to affect speed.

Reiterate that this extension (as a part of U2C3) is intended for teachers only, not for use in the classroom with elementary students. It involves conceptual complexities and representations that students may not be ready to grasp.

What do we think?

The “What do we think?” task is intended to remind participants that when two objects experience the same net force, the rate of increase in speed is greater for the less massive object. Participants are likely to conclude that the red car’s speed will increase faster and would win a race.

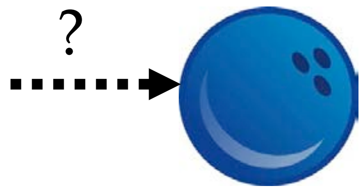
Unit 2 Cycle 3

Extension 3: Putting it all together

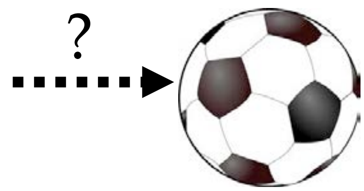
(Intended for Professional Development only)

Purpose

In the previous two activities you saw that the rate at which an object's speed changes depends both on the strength of the net force acting on it, and on its mass. In this activity we will put these two factors together to see how we can make two objects with different masses behave in the same way.



Suppose you wanted a soccer ball and a bowling ball to move in exactly the same way, what would you have to do? Would you need to apply the same strength force to both balls, or would the forces you apply need to be different?

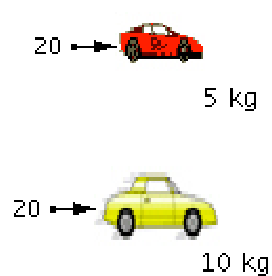


The big question we will address in this activity is:

> ***How can you combine net force and mass to determine the rate at which an object's speed changes?***

What do we think?

In the previous activity, you saw that when two toy cars of different masses had the same force applied to them, their speeds increased at different rates.



If these two cars were in a race, which one would win? Why is this?

Suggestions for making each car experience the same increase in speed may include changes to mass (increasing the mass of the red car and/or decreasing the mass of the yellow car) or changes to the net force (increasing the net force applied to the yellow car and/or decreasing the net force applied to the red car). Some participants might also suggest combinations of these changes (e.g., reducing the mass of the yellow car and the force on the red car). Note: The mass was chosen to differ by a factor of 2 to keep the math from getting in the way of understanding how net force and mass relate to rate of change in speed.

Have participants describe why they think the car they selected would win the race and how the changes they proposed would cause the race to be a tie. Encourage them to express their ideas in terms of mass, net force, and change in speed. Conclude the discussion by stating that in this extension, participants will investigate how the strength of the net force and mass together affect changes in objects' speed.

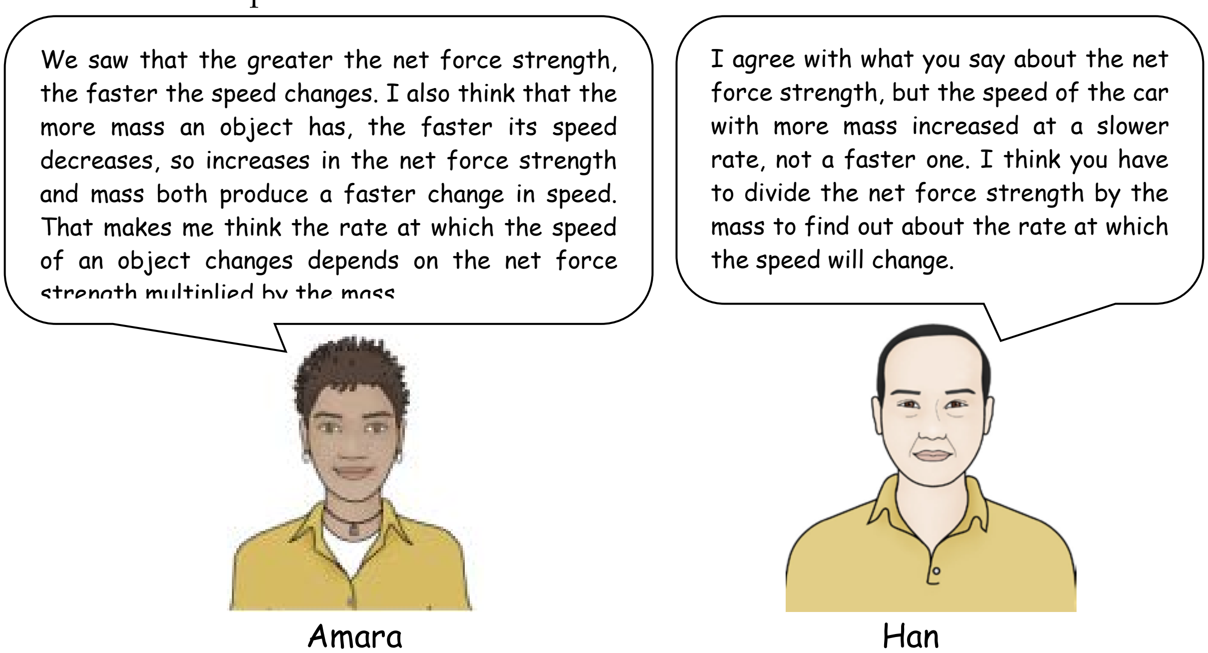
Now suppose you wanted the race between these two cars to end in a tie. Suggest some different ways you could accomplish this. Why do you think your suggestions would work?

Participate in a discussion about these questions. Make a note of any ideas or reasoning that differs from others in your group.

Putting force and mass together

You should now be comfortable with the ideas that the rate at which an object's speed changes depends on **both** the strength of the net force **and** the mass of the object. But what if you had two objects that had **different masses,** acted on by net forces of **different strengths**? How could you predict which object's speed would change at a faster rate?

Two people were discussing their ideas about a relationship that they could use to help them decide:



Participants have seen that the greater the net force acting on an object, the greater the change in speed, while the greater the mass of an object, the smaller the change in speed. These observations support Han's claim. Based on their observations, some participants may reason that the rate of change in speed will be directly proportional to the strength of the net force and inversely proportional to mass. Others may realize that the strength of the net force and mass have opposite influences on the rate of change in speed and conclude that because the strength of the net force is in the numerator, mass must be in the denominator. Still others may recognize that a larger mass means a smaller rate of change in speed, but not readily translate this idea into a mathematical expression.

During the discussion, prompt participants such that all of the different participant ideas and rationales are made public, then explain that they will now be checked by using data from simulations in which both mass and net force strength are varied.

In terms of a mathematical relationship, Amara thinks:

$$\text{Rate of change in speed} \sim \text{Strength of net force} \times \text{Mass of object}$$

(where the "~" sign means "is related to" or "depends on") while Han thinks:

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

Do you agree with Amara, Han, or neither of them? What evidence from previous activities supports your thinking?

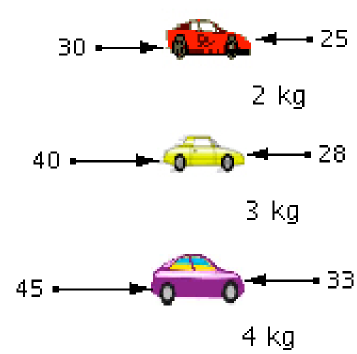
Participate in a discussion about this question.

Activity 1: Who will win the race?

You will need:

- Access to the **Motion and Force Simulator**

STEP 1: Suppose you were to arrange for a race between three toy cars, as shown here.



- The red car has a mass of 2 kg and will have forces of 30 N and 25 N acting on it in opposite directions.
- The yellow car has a mass of 3 kg and will have forces of 40 N and 28 N acting on it acting on it in opposite directions
- The purple car has a mass of 4 kg and will have forces of 45 N and 33 N acting on it in opposite directions.

Activity 1
STEP 1

By now, most participants will realize that they need to determine the net force acting on each car and then compare the net forces and masses to determine which car will experience the greatest rate of increase in speed, and therefore win the race. Comparing the yellow and purple cars will likely be most straightforward because they have different masses but experience the same net force. Because neither the net force nor the mass for the red car match with either of the others, participants will likely use the mathematical expression described above to predict rates of speed change. Encourage participants to explain the rationales for their predictions in terms of relationships among rate of change in speed, mass, and the magnitude of the net force (e.g., directly proportional to, inversely proportional to) as well as in terms of mathematical operations (e.g., rate of change equals net force divided by mass).

STEP 2

The simulator can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). The simulations for this extension are in the Unit 2, Cycle 3 Simulations section. For this portion of the extension, use "Extension 3 First Setup." The simulations can be projected so that all participants view them together. Depending on the availability of computers and internet access, smaller groups or individuals may view the simulations separately.

Participants should recognize that the positions of the cars show that the yellow car won the race, followed by the purple car and then the red car. When comparing the results to their predictions, encourage participants to also interpret the three graphs provided to describe the relative rates of change in speed for the three cars.

Whether the simulations are viewed as a whole group together or separately by small groups or individuals, have the participants share and record their responses to the questions posed in these materials.

The main goal here is for participants to recognize that both the strength of the net force and the mass determine the rate of change in speed. Most participants will likely note that although the red car has the smallest mass, it experiences the smallest net force, and use this information to explain its last place finish. Prompt participants to use the graphs or mathematical expressions to more specifically characterize the red car's change in speed compared to the other cars (e.g., the slope of the graphs for the red car is the smallest, showing that its rate of increase in speed is the smallest).

Participants should first recognize that although the forward force is strongest for the purple car, the net force acting on the yellow car is the same as that acting on the purple car. Second, participants should reason that because the mass of the yellow car is smaller, its speed increases at a greater rate than that of the purple car. Prompt participants as needed to have these ideas expressed.

Assuming all three cars start from rest, and the forces do not change, in which order do you think they will finish the race? Explain your reasoning.

STEP 2: Open the first simulator setup for this activity. This setup shows precisely the situation you considered in STEP 1 Run the simulator and then answer the questions below.

Do the cars finish the race in the order predicted? If not, discuss with your group why this is.

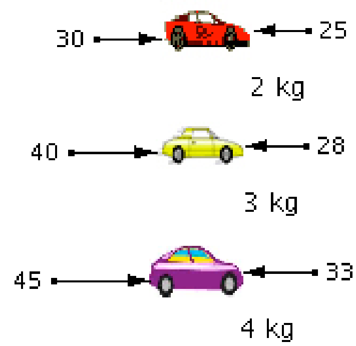
How is it possible that the car with the smallest mass finished the race last?

How is it possible that the car with the strongest forward force acting on it did not win the race?

STEP 3

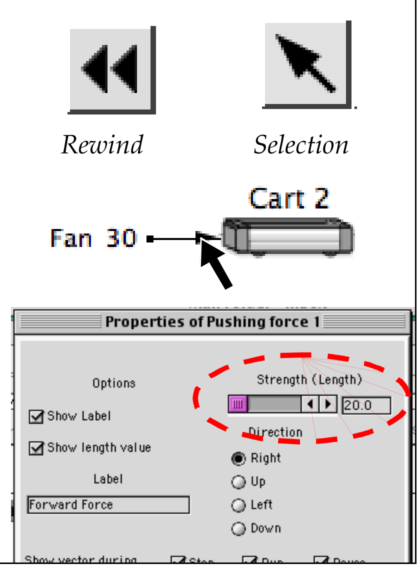
The key here is that the ratio of the net force to mass must be the same for all three cars. Some participants may simply use trial and error to find strengths of forces that produce equal rates of increase in speed for the three cars. Other participants may determine the net force to mass ratio for one car and then calculate the net forces needed to produce this same ratio for the other cars. In either case, ask participants to try to explain their reasoning in terms of net force and mass.

STEP 3: Now suppose you wanted this race to end in a three-way tie. To do this you would need to arrange for the speed of all three cars to increase at the same rate, so that they move along side-by-side.



Suggest how you could adjust the strength of the forces acting on two of the cars, so that their motion matches that of the third car. Explain your reasoning.

You will now check your thinking by changing the strengths of the relevant forces in the simulator setup.

To change the strength of a force, first rewind the simulator, then click on the Selection Tool. *Now double-click on the head of the relevant black force arrow itself to bring up the “‘properties box”’ of the force. (If the “‘Properties of Background”’ box appears close it and try again.)* *You can now change the strength of the force using the control at the top right. You can either adjust the value using the slider control, or type in the new value*	

Change the strengths of the relevant forces to the values you suggested above, and then run the simulator again.

Does the race end in a three-way tie now?

Whatever approach is used, have participants check the combinations they create using the simulator. Participants will likely focus on the positions of the cars for the simulation runs, but also direct their attention to the graphs to reinforce the connection between finishing the race at the same time and having equal rates of increase in speed.

Activity 2
STEP 1

Predictions for this scenario are likely to include a mixture of the following:
1) (Correct) *The two balls will reach the floor at the same time because the ball with the greater mass also experiences a greater gravitational force.* This prediction indicates an understanding that although the object with greater mass has more resistance to a change in motion (more inertia), the greater mass also means that the gravitation force acting on the object is larger (the force of gravity is proportional to the mass of an object).

2) The bowling ball will reach the floor first because heavier objects fall faster than lighter objects. This prediction may be based on experiences with objects that are not affected much by air resistance (an upward force acting on the object) such as a dropped book, and objects of low mass that are greatly affected by air resistance during a fall such as a leaf or piece of paper). Others may give this answer because they think that gravity must be stronger for the more massive object (it is!) but not realize that the larger mass means a stronger force is needed to have the same change in speed.

3) The two balls will reach the floor at the same time because the force of gravity is the same for each ball and therefore will affect each ball in the same way. It is likely that those making this prediction are not considering the role of mass that has been demonstrated in previous activities. This response may reflect a difficulty in translating the importance of mass in horizontal motion to vertical motion.

4) The soccer ball will reach the floor first because gravity is a constant force and the soccer ball has less mass. When equal forces act on two objects, the object with the smaller mass changes speed at a faster rate. This prediction indicates an understanding of the relationship between the mass of an object and change in speed, but a lack of understanding that the strength of the gravitational force acting on an object is proportional to the mass of the object.

Encourage participants to describe their predictions and rationales and prompt them such that all of the different viewpoints are made public. Then explain that they will now be checked by conducting experiments with objects that have different masses.

If the race was not a three-way tie, work with your group to find some combination of forces that does produce a tie. Then explain why these force strengths work, whereas your previous values did not.

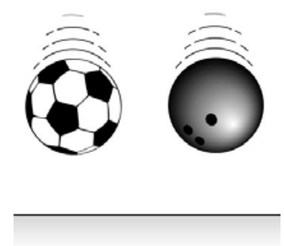
Activity 2: A race straight downward

You will need:

- Various objects

STEP 1: Imagine you were to drop a bowling ball and a soccer ball from the same height at the same time.

Which ball do you think would reach the floor first? Explain your reasoning in terms of the forces acting on the balls and how they affect their motion. (Assume the effects of the air are negligible.)



STEP 2

In choosing objects to drop in this experiment it is important to avoid objects of very low mass and objects with a large surface area (e.g., sheet of paper) because these will be significantly affected by air resistance (air resistance is a force that acts opposite to the gravitational force and makes the net force smaller). Note: a tennis ball and a baseball make an appropriate pair.

Participants should be able to detect (see and/or hear) that the objects hit the floor at the same time when dropped from the same height. Because sources of error in this type of experiment (e.g., object release times, visual/auditory perceptions) may be substantial, it is likely that multiple trials will be required to produce convincing evidence that the objects reach the floor at roughly the same time.

Participants should recognize that many objects of varying masses impact the floor at the same time when dropped from the same height.

STEP 3

Based on the previous activity, participants should understand and readily express that the object with less mass will win the race. Encourage participants to express the conclusion in terms of changes in speed in addition to describing the race outcome. Because the questions in STEP 3 are inter-related, it is important to conduct brief discussions for each to build consensus understandings before moving to the next.

This question is tied to the previous question because the same objects are considered. The goal here is for participants to reason that if the object of small mass wins a race against the object of large mass when equal net forces are applied, then a new race between these same objects ending in a tie must mean that the object of large mass experienced a greater net force. The intended conclusion for this question is key to a logic flow that will help participants form an answer to the next question. Therefore, it is important that participants clearly establish that if two objects of different mass experience the same change in speed, the object with more mass must experience a stronger net force.

STEP 2: Select two similarly sized objects of different mass. **It would be preferable not to use any very light objects, for reasons we will examine later.** Hold your selected objects (one in each hand) at the same height (about head high) above the floor. Release them at the same time and have all your team members **watch** and **listen** carefully as they hit the floor.

Does the object with more mass or the one with less mass clearly hit the floor first, or do they both appear to hit at the same time? (You may want to repeat the experiment several times to check.)

Now, repeat the experiment using different pairs of objects, of varying masses.

Describe your observations about which object hits the floor first (if any).

STEP 3: Let us now try to understand this behavior in terms of what we now know about how force strength and mass affect the motion of objects.

Suppose you had a race between two objects with **different masses** but applied the **same strength** force to both, which one would win the race, and why?

Suppose you had another race between the same two objects, but this time the race ended in a tie. What could you say about the strength of the forces being applied to each object?

Some participants will likely see that the falling object experiments they performed represent the same situation as in the previous question and readily conclude that the objects with greater mass experienced greater gravitational forces. For others, making this connection may be difficult. Encourage participants to follow the logic flow that is intended for two objects of different mass: the same strength of force causes an object with less mass to have a greater change in speed; so the same change in speed must mean an object of larger mass experiences a stronger force; because the objects fall with the same rate of increase in speed, the object of larger mass must experience a greater gravitational force.

This question requires participants to apply the conclusion that if the same net force is applied to objects of different masses, they will experience different changes in speed. Prompt participants to recall from their activities that if the net force is the same on the two objects, then the speed of the object with less mass will increase at a greater rate. Participants should see that this idea counters the assertion that the reason objects of different mass fall at the same rate is because the force acting on them has the same strength. In the discussion of this question, it may be helpful to have participants explicitly state what would happen if the gravitational forces were equal: the speed of the soccer ball would increase at a greater rate than the speed of the bowling ball.

Effect of the air on falling objects

The section describing the effects of air resistance should help participants reconcile the conclusions reached in this extension with what they observe in everyday experience. The effects of air resistance need not be pursued in great depth, but are described here to provide a framework that allows participants to sustain scientific views of the relationship among mass, strength of net force, and change in speed while observing everyday events that would appear to contradict what they are learning. It may be helpful to explicitly point out this intent and emphasize that their observations of various falling objects (e.g., leaf and rock) do provide evidence for the target ideas of the extension so long as all the forces are considered.

In your experiments in this activity you have seen that objects of different mass all fall at the same rate of increasing speed. What does this result imply about the strength of the gravitational force acting on each of them? Is the strength of the force the same on each object, or is it different? Explain your reasoning?

Many people are aware that objects of different mass fall at the same rate of increasing speed and, when asked, will attribute this to the idea that the strength of the gravitational force acting on all objects is the same.

If the strength of the gravitational force acting on a soccer ball and a bowling ball were really the same, which one would reach the ground first if they were dropped together from the same height? Explain your reasoning.

Effect of the air on falling objects

As you are probably aware, and as may have been pointed out in your class, here on Earth, objects do not always fall at the same rate of increasing speed. For instance, if you were to drop a hammer and a feather at the same time, the hammer would clearly reach the ground first, while the feather would "float" down much more slowly. However, this is not because of any change in the way the gravitational interaction affects these objects, but because of the influence of another interaction; that of the falling objects with the air.

Participants should easily see that the "scrunched" paper falls faster than the flat sheet. They may offer a variety of explanations for this (e.g., the "scrunched" sheet takes up less space, the flat sheet does not drop straight down, the scrunched sheet is more aerodynamic). Prompt participants to explain the observation in terms of interaction of the paper samples with air. It may be helpful to point out that the flat sheet of paper has more surface area that makes contact with air as it falls.

A video clip for the hammer and feather being dropped on the Moon's surface where there is no air (and thus no air resistance) can be accessed here: http://www.youtube.com/watch?v=5C5_dOEyAfk

As an object moves through the air, it has to push the air in front of it out of the way. As it does so, the air then exerts a force back on the object in the opposite direction to its motion. Scientists call this force "air resistance" or "drag" and its strength depends on two factors; the surface area of the part of the object that is actually pushing on the air, and how fast the object is moving through the air.

To think about the effect of speed on the strength of air resistance, imagine traveling in a car and holding your hand out the window, with your palm facing the direction the car is moving. As the car is moving, you would feel the force of the air pushing against your hand, and as the car increases speed, the air would press harder against your hand, suggesting that the strength of the drag force increases with speed.

You can easily demonstrate the influence of surface area with a simple experiment. Take two identical sheets of paper and "scrunch" one of them up into a small ball. Now hold both pieces of paper at the same height above the ground and release them simultaneously.

Which piece of paper reaches the ground first, the flat sheet or the "ball"? Why do you think this is?

The force of air resistance has a much more significant effect on objects that are both very light **and** have a large surface area, such as feathers, leaves, and "unscrunched" sheets of paper. It is the influence of this force that causes such objects to "float" downwards as they fall. In an environment in which there is little or no air, a hammer and a feather would fall at the same rate of increasing speed, and reach the ground together. (Your instructor may show you a demonstration or movie to illustrate this.)