Unit 3 Cycle 1

Beginnings: Pushing against another person

LESSON TARGET IDEA

- When two objects push against each other and they remain at rest, the strengths of the forces that each applies to the other are the same.

COMMON MISCONCEPTIONS

- *When two people push against each other and they remain at rest, the force applied by the larger, stronger person is greater than the force applied by the smaller, weaker person.* (It is not! The relative strengths of the people pushing do not determine whether the two forces are equal.)

- *When a person actively pushes against a person (or object) at rest that resists that push, the force applied by the active push is greater than the force of resistance to that push.* (It is not! Being "active" or "resistive" does not determine whether the two forces are equal.)

WHAT TO FOCUS ON

In this initial lesson about forces being applied by two objects on each other, we examine different scenarios in which the objects remain at rest. It is important that participants recognize for each scenario that there is a pair of forces to consider, but that each object applies a force to the other object. In other words, unlike scenarios in previous lessons, each force is acting on a different object rather than a pair of forces acting on a single object.

In the first part of this activity, participants make predictions about relative force strength for a series of scenarios. Participants should focus on the nature of the objects and their pushes (e.g., sizes of objects, and "active" vs. "resistive" push). Next participants are introduced to the function of the force plate and should see that it detects the strength of force being applied to its surface. Finally, force plates are used to measure the strengths of forces in each of the scenarios for which the participants made predictions. It is important to focus on the relative magnitudes of forces that are recorded for each pair of forces. Participants should recognize that the nature of the objects and their pushes make no difference in the relative strengths of the forces. That is, regardless of other aspects of the scenario, the strengths of forces applied by objects that push against each other and remain at rest are the same.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Two force-detection plates (available from Vernier or Pasco) and compatible data collection system	1 per class

Purpose

The instructor should introduce the lesson by highlighting the new focus on situations where two objects are applying forces to each other. It may be helpful to contrast this new focus with situations in the previous cycle where participants were asked to consider more than one force acting on a single object.

What do we think?

The instructor should explain the scenarios and remind participants that each scale measures the force being applied by the person holding that scale. If participants have difficulty accepting that the scales measure force strength, it may be helpful to pursue the analogy of a bathroom scale measuring weight. By asking participants to reflect on why the scale would read differently for a given person on Earth compared to being on the moon, participants will likely point to the difference in the strength of the gravitational forces on the person. From this idea, participants should realize that the scale reading depends on the magnitude of the force being applied to its surface, whether it is the weight of a person standing on it or the strength of the force applied to it by someone pushing on it. Participants need to decide whether the forces have equal strength or if one is stronger than the other, and describe how they know. If unequal, which force is stronger? As participants make their way through the different scenarios, it may be necessary to remind them that neither person begins to move in any scenario.

Unit 3 Cycle 1

Beginnings: Pushing against another person

Purpose

When one object interacts with another object it applies a force to that other object. But does the second object also apply a force to the first at the same time? If so, what would determine the strength of that force? In this Cycle we will examine the forces that objects exert on each other during contact push/pull interactions, to see if there is a general rule that can be applied to any such situation. To start we will consider situations in which people push on each other, but do not move.

For example, in a football game players at the line of scrimmage often push on each other but do not move. In this lesson we will examine situations like this, in which people push on another person, but neither of them moves. In particular we will focus on examining the strength of the forces involved in such situations.

When two people push on each other, how do the forces they apply compare?

What do we think?

Imagine a situation in which two people are holding bathroom scales. Assume the people use their scales to push against each other, ***but not hard enough to cause either of them to move***. As they push, each person notes the reading on their own scale, which we assume measures the strength of the force with which they are pushing against the other person.

For each of the situations described below, **predict** how you think the readings on the scales will compare—would they be equal, or would one be larger than the other, and if so, which would be larger? Briefly **explain how you decided** each case. (Remember, you are comparing

When considering each case, the instructor should monitor groups to make sure they are recording a brief explanation of their thinking.

Case A. All participants will likely agree that the strengths of the forces applied by people of the same size are equal. However, they are likely to reason this based on the people having the same size, or the forces not resulting in motion, or both. Many may not reason that the equal strength forces are independent of the size of the people or any resulting motion.

Case B. Participants may predict that the bigger person applies a stronger force than the smaller person. Some participants that predict the forces will still be of equal strength may reason this based on the forces not resulting in motion.

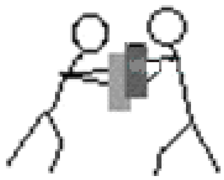
Case C. Participants may predict that the person designated as pushing applies a stronger force than the person that resists. Again, some participants that predict the forces will still be of equal strength may reason this based on the forces not resulting in motion.

Case D. Similar to Case C, participants may predict that the person designated as pushing applies a stronger force than the person that resists. In this case, reasoning may include a role for the wall in providing support for the person providing resistance. Again, some participants that predict the forces will still be of equal strength may reason so based on the forces not resulting in motion.

the two forces in each situation to each other, not to those in a different situation.)

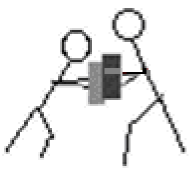
Case A. Same size people push hard on each other.

Prediction:



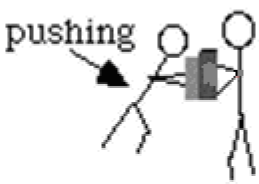
Case B. One person is bigger; people push hard on each other.

Prediction:



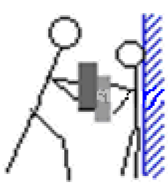
Case C. Smaller person pushes, the bigger person resists.

Prediction:



Case D. Bigger person pushes, the smaller person resists while braced against a wall.

Prediction:



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

Activity 1

In this activity, we address the relative strengths of forces when the objects applying the forces remain at rest. First, the function of the force plate is established and then the force plates are used to measure the strengths of the forces in the scenarios for which participants already made predictions.

Activity 1: Step 1

It should be evident to participants that the readings for force strength increase when the participant pushes the force plate harder against the wall. Likewise, it should be evident that readings for force strength decrease when the participant reduces the push. These changes should be emphasized to establish that the readings from the force plate indicate the strength of the force being applied at its surface.

Activity 1: Step 2

The strengths of forces applied to the force plates over time can be graphed on the data collection system.. By comparing the two graphs for each case, it should be evident to participants that the magnitudes of the forces are always very similar (even though one graph may indicate the force is positive while the other shows a negative force). It may be helpful to remind participants that the output measures the strength of force on each plate.

The instructor should monitor groups to make sure they are drawing force arrows that are consistent with their thinking.

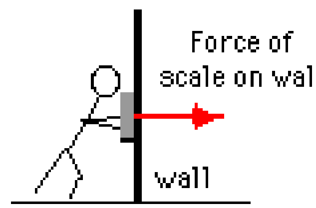
Activity 1: Pushing on each other

The whole class will work together on this activity. The class will need:

- Two force plates
- Data collection system

STEP 1: Bathroom scales are usually used to measure the weight of a person. However, in reality, they do this by simply measuring the supporting force exerted by the scale on the person needed to stop the person from falling. The force plates are like bathroom scales, except they can be connected to a data collection system and a record made of the force they are exerting on another object.

One person in your class will hold a force plate vertically against the wall and push while data are collected and displayed on a graph of force versus time.



As the person pushes harder on the scale, what happens to the reading on the computer graph? Does it increase, decrease or stay the same?

Let us assume throughout the rest of this activity that the reading from the plate indicates the **strength of the force (or push)** being applied to it.

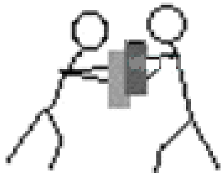
STEP 2: Using two force plates, your instructor will help you test the predictions you made in the *What Do We Think?* section. Each person in the class should be involved in at least one situation.

For each of the situations, record how the readings on the scales compare—are they approximately equal, or is one substantially larger than the other, and if so, which is larger? Also indicate the result by **drawing two arrows** for each case, representing the force that each

person exerts on the other. *The example arrow drawn for Case A is supposed to represent the force that the person on the right is applying to the person on the left.* (The actual force strengths do **not** need to be recorded.)

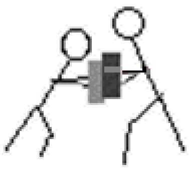
Case A. Same size people push hard on each other.

Observation:



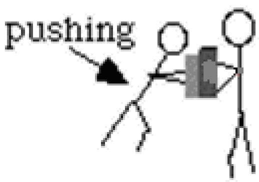
Case B. One person is bigger; people push hard on each other.

Observation:



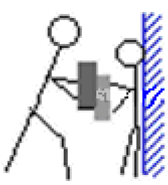
Case C. Smaller person pushes, the bigger person resists.

Observation:



Case D. Bigger person pushes, the smaller person resists while braced against a wall.

Observation:



Activity 1: Step 3

The instructor should encourage participants to compare the predictions they recorded in the "What do we think?" section to the force arrows they drew in Step 2, and to describe any differences.

After considering the results, participants should have little difficulty recognizing that the two objects apply forces of the same strength in each case.

Participants who recognize that the two objects apply forces with the same strength in each case should conclude that neither the sizes of the people pushing nor whether a person's role is "active" or "resistive" makes the forces unequal. If participants persist in thinking that either the size of the person pushing or the "active" or "resistive" role affects relative force strength, it may be helpful to review the results from Step 2 and focus on the consistency across all cases.

Making Sense Questions

Before discussing the questions, the instructor should re-emphasize that the class has examined situations where two objects apply forces to each other, which differs from previous situations where two forces were being applied to a single object.

Question 1:

We are looking for participants to generalize across the different cases presented to recognize that the forces have equal strength.

STEP 3: Answer the following questions based on the results of this investigation.

Did the results agree with your predictions? If not, how were they different?

Do you see any kind of pattern in your data? If so, what is the pattern?

Perhaps you noticed some differences in the various situations. In cases A and B, both people were actively pushing. In cases C and D, one person seemed to actively push, while the other person was trying to resist the push. However, in all cases, both people were applying a force against their scales. They certainly should have felt that in their muscles!

Does it make any difference whether one person seems to be actively pushing, while the other seems to just be resisting? Also, does the size or mass of the person seem to matter?

Making Sense

S1: For each of the situations you explored in this lesson, how does the strength of the force that one person applies to the other during an interaction compare with the strength of the force that the second person applies to the first?

Question 2:

This question is aimed at getting participants to compare their initial thoughts about force strengths applied by people of different sizes to their conclusion that a difference in the sizes of the people pushing does not affect the strength of the forces applied.

Question 3:

The scenario presented in this question asks participants to extend the idea that the strengths of forces applied by two objects to each other are equal, regardless of whether they are "active" or "resistive" pushes. Because the scenario describes the people as resting against each other rather than pushing, some participants may think that neither is applying a force to the other. In such a case, it may be helpful to ask what would happen to one of the "resting" people if the other suddenly moved away. It may also be helpful to remind these participants that the force plate showed that a force was present even when a participant pushed gently against a wall in Step 1. Finally, emphasizing the similarity between resisting a push (Step 2) and resting against another person (neither person is actively pushing) may help participants recognize that the support provided by one person for the other is a force.

Once participants recognize that resting against an object applies a force, they should readily recognize that the people apply a force to each other in this scenario. Based on the experiments conducted in this activity, participants can infer that the strengths of the forces must be equal. Many may still inappropriately include the lack of motion in their reasoning; and a question might arise about force strengths when objects that push each other move. If so, the instructor can inform participants that this question is addressed in a future lesson.

Question 4:

This question uses a specific, concrete context to revisit thoughts about force strengths applied by people of different sizes. This context may challenge a participant's conclusion from this activity that a difference in the sizes of the people pushing does not affect the strength of the forces applied. Because a bigger, stronger football player is generally able to push a smaller, weaker player backward, participants may be attracted to the incorrect conclusion that the forces applied by each to the other are not equal in strength. Reflection on the evidence collected in this lesson and the conclusions derived from that evidence may again be helpful.

S2: Does your answer to the previous question depend on whether the sizes or masses of the people are equal or unequal? Does this surprise you?

S3: Suppose you sit on the ground with your back against another person. Neither of you is *actively* pushing but simply resting against each other. Neither of you move. Do you apply a force to the other person? Does the other person apply a force to you? If so, how do these forces compare?

S4: Two football players block each other at the line of scrimmage so that they are not moving. One player weighs 230 lbs while the other weighs 270 lbs. Which one applies the stronger force to the other?

Unit 3 Cycle 1

Exploration #1: Forces during collisions

LESSON TARGET IDEA

- When two objects collide, the strengths of the forces applied by the objects to each other are the same.

COMMON MISCONCEPTIONS

- *When two objects collide, the force applied by the more massive object on the less massive object is greater than the force applied by the less massive object on the more massive object.* (It is not! The relative masses of the objects do not determine whether the two forces are equal.)

- *When an object at relatively high speed collides with an object at relatively low speed (including at rest), the force applied by the faster object on the slower object is greater than the force applied by the slower object on the faster object.* (It is not! The relative motion of the objects does not determine whether the two forces are equal.)

WHAT TO FOCUS ON

This lesson extends the examination of force pairs from the previous lesson to situations in which objects collide.

Like the first lesson in this unit, participants initially make predictions about the forces present in a series of scenarios; participants should pay attention to the motion of the carts before collision, and the relative sizes of the carts. Next, participants observe a demonstration of colliding carts and should focus on the carts' motions before and after the collision. The changes in motion of the carts as a result of the collision should help participants recognize that each cart experiences a force during the collision which had to be applied by the other cart. Participants then make a second set of predictions about the relative strengths of the forces two carts apply to each other when they collide in scenarios where the initial motion and masses of the carts vary. Finally, force probes are used to measure the strengths of forces in these scenarios. It is important to focus on the relative magnitudes of forces that are recorded for the pair of forces in each scenario. Participants should recognize that the relative motion of the carts and their sizes make no difference in the relative strengths of the forces. That is, regardless of other aspects of the scenario, the strengths of forces applied by each cart on the other are the same.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Two force-detection plates (available from Vernier or Pasco) and compatible data collection system	1 set per class
Two low-friction carts, track, and attachable force probes with compatible data collection system	1 set per class
Blocks or similar items for use as extra mass to add to cart	1 set per class

Purpose

The instructor should remind participants that in the previous lesson they saw that forces applied by two objects that did not move to each other were equal in strength. In this lesson we will turn our focus to the strengths of forces that objects apply to each other when they collide. Will the force strengths be different if one, or both, objects are moving before the collision? Will they be different if the objects have different masses?

What do we think?

Participants need to indicate whether the forces in each scenario have equal strength or if one is stronger than the other, and describe their rationales. If unequal, which force is stronger? As participants make their way through the different questions, they may ask for information about the motion of the carts after the collision. Rather than answering this question directly, the instructor should encourage participants to use their own knowledge and experiences (including previous units) when considering if/how motion after the collision is important for each question. The recording of participants' thoughts is designed to encourage them to make connections among object motion, object size and strengths of forces explicit. This explicitness will likely be helpful later in the lesson (Making Sense Question 2) when participants compare their predictions to the conclusions based on data from the activities.

Many participants will likely agree that the moving cart applies a force to the stationary cart, and reason correctly that the stationary cart must experience a force if it moves as a result of the collision.

Because the stationary cart appears passive in the collision, some participants may not see it as applying a force. However, some may recall their observations from the previous lesson of active vs. passive roles not affecting force strength and apply this reasoning to the collision scenario. Some participants may also reason that the moving cart must experience a force if its motion changes as a result of the collision.

Some participants may indicate that the force applied by the moving cart is larger. Again, this view may stem from the moving cart appearing more active and the stationary cart appearing more passive. In addition, participants may previously have seen in similar collisions that the moving object comes to a stop (or nearly does) and the stationary object suddenly moves. Because some participants may associate a stronger force with the start of an object's motion than with the stopping of an object's motion, they might indicate that the stationary cart experiences the larger force. However, some participants may recall from observing collisions of billiard balls, marbles or similar objects that the loss of speed by one object is similar to the gain in speed of a second object and reason that the forces are the same strength.

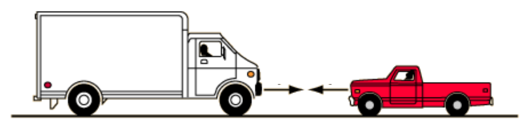
Unit 3 Cycle 1

Exploration #1: Forces during collisions

Purpose

In the previous lesson you saw that when people push on each other, but do not move, the forces they exert on each other are equal in strength. In this lesson we will examine the forces that objects exert on each other when they collide together.

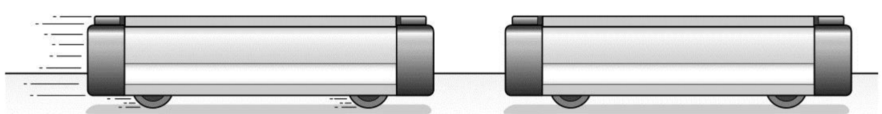
For example, suppose a small pick-up truck collides with a large van. Which vehicle do you think applies the stronger force to the other and why?



When two objects collide, how do the forces they apply compare?

What do we think?

Consider a situation in which a small moving cart collides with an identical stationary cart.



During the short period of the collision, do you think the moving cart applies a force to the stationary cart? How would you know if it did?

During the short period of the collision, do you think the stationary cart applies a force to the moving cart? How would you know if it did?

How do you think these forces compare? To show your thinking, draw arrows on the pictures below to represent the forces you think the carts

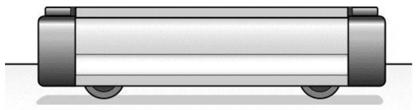
Using the reasoning stated above, some participants may believe that the relative motion of the carts affects the strength of the forces they apply to each other. Many participants will likely believe that the masses of the carts affect the relative strength of forces applied to each other. However, some may recall their observations from the previous lesson of mass not affecting force strength and apply them to the collision scenario.

The goal here is to have participants relate their own observations and ideas to the question of what affects the strengths of the forces that objects apply to each other.

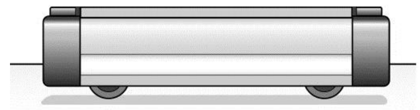
Discussion and clarification of differing views should be encouraged so that participants can compare their ideas with alternatives. Participant engagement here may be promoted by letting the participants know that they will be conducting activities that address these questions.

The demonstration should match the scenario that the participants have been asked to consider: a moving cart colliding with a stationary cart. This demonstration allows participants to see how the carts' motions change as a result of the collision. Observation of the changing motions may cause some participants to change their predictions. In this case, encourage participants to explain/record why they changed their minds.

are applying to each other at a moment in time **<u>during the collision</u>**. Also, briefly explain why you drew your force arrows as you did.



Launched Cart



Target Cart

Would your answer be different if the carts had different masses, or if their motions were different from those in this situation?

What factors do you think determine the relative strengths of the forces that objects exert on each other during a contact push/pull interaction?

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

Your instructor will demonstrate what happens when two identical carts collide.

What do the results of this demonstration indicate about whether each cart applies a force to the other during the collision between them?

Activity 1: Step 1

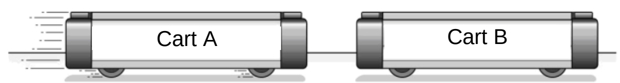
The evidence indicating that each cart in collision scenarios applies a force to the other (their motion changes) has now been made explicit. The focus, therefore, should go from whether the pair of forces exists to the issue of their relative strengths under varied circumstances. As was the case with predictions made in the “What do we think?” section, some participants may hold ideas that relative speed or direction of travel, or mass affect the relative strengths of these forces. When making predictions in step 1, participants should be encouraged to explain their thinking because, as the activity unfolds, we want their rationale rather than just their predicted results to be re-examined in light of the evidence. As the different scenarios are considered, it may be necessary to remind participants that relative force strengths are compared *within* each scenario rather than across scenarios.

Activity 1: Forces during collisions

The whole class will work together on this activity. The class will need:

- Two low-friction carts and track
- Two force probes
- Metal blocks
- Data collection system

STEP 1: Because the motion of both carts changed during the collision between them you know they are both applying a force to each other. In this experiment you will examine the strengths of these forces in different types of collisions.



Consider the following different situations and predict how you think the strengths of the forces involved would compare.

Suppose the collision were between two identical carts, one moving and one at rest. How do you think the strength of the forces these two carts apply to each other would compare? Explain your thinking.

If Cart A were moving substantially faster (than in the previous situation) when it collided with Cart B, how do you think the strength of the forces the two carts apply to each other would compare? (Remember you are just considering how the forces compare in strength to each other, NOT how they compare to those in the previous question.) Explain your thinking.

If one of the carts was more massive than the other, how do you think the strength of the forces would compare? Explain your thinking.

Activity 1: Step 2

Be sure that the data from the force probes are plotted such that one has negative values and one has positive values. Otherwise they will overlap and be difficult to recognize as separate plots. Labeling each half of the paper graph to correspond with a specific cart may also help solidify participants' association of each force plot to a particular cart.

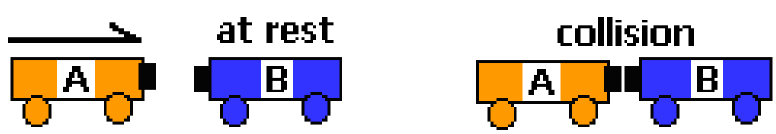
Focus participants on the relatively short time period when the force probes detect forces of substantial strength (readily visible "spikes" on the graph). It may be helpful to explicitly direct participant attention to how far above the "0" line and how far below the "0" line the force plots extend.

If both carts were moving toward each other, instead of one being at rest, how do you think the strength of the forces would compare? Explain your thinking.

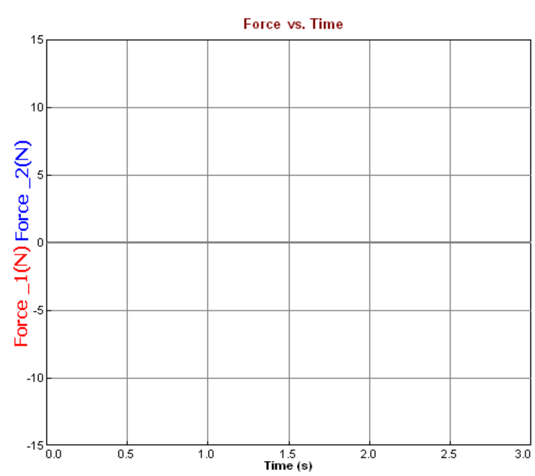
Finally, what if one cart were moving slowly and the other cart ran into the back of it in a "rear-end" collision? How do you think the strength of the forces would compare now? Explain your thinking.

STEP 2: Your instructor will now help you test your thinking by using carts and force probes. The force-time graphs are set-up so that one force-time graph will be positive and the other will be negative, so you can tell the two apart.

Start with a situation (Case 1) in which a moving cart collides with a cart of equal mass that is at rest. Start collecting data, and push Cart A (the arrow in the diagram below indicates motion, not a force) so it collides with Cart B which is at rest.



Using two different colored pencils, sketch the force-time graph. (Note that one force is shown as being positive and the other as negative.)



How does the strength (ignoring the + or – sign) of the force that Cart A (the moving one) applies to Cart B (the stationary one) during the collision compare to the force that Cart B applies to Cart A?

The idea we want to get at here is that the two forces are applied in opposite directions. If participants have difficulty deriving this idea from the opposite sign of the force values recorded, ask questions to focus them on exactly what force each probe is detecting. Repeating the collision and having participants draw force arrows may also be helpful in emphasizing force direction.

Activity 1: Step 3

For clarity, have participants record their descriptions and results after the collision in each case before moving to the next case. As new cases are considered, remind participants that relative force strengths are compared within each case rather than across cases. Considering several different cases is important because it discourages participants from viewing any result as an exception, ultimately lending credence to the generalizations participants are encouraged to make in the Making Sense section. Be sure to include different initial motions of the carts (e.g., only one cart moving, both carts moving, varied speeds) as well as varied cart mass in the cases conducted. The metal blocks can be used to increase cart mass.

Aside from being able to tell the two forces apart, what else might the positive or negative indicate about the forces acting on the two carts?

STEP 3: Now suggest some other cases to be tested, corresponding to some of the different situations you considered when making predictions in STEP 1.

In each case briefly describe the motion and relative masses of the two carts and record your results for how the strength of the force that Cart A applies to Cart B **during the collision** compares to the force that Cart B applies to Cart A.

Case	Description	Result
B		
C		
D		
E		
F		

Activity 1: Step 4

Monitor participant responses to be sure they address how their results differed from their predictions. Specifically, encourage participants to make connections between the particular conditions (i.e., initial cart motion and mass) and any discrepancies between predicted and observed results.

Most participants will recognize that the two forces had the same strength in each of the cases considered. Some participants may be tempted to look for other patterns of force strength across cases by comparing the force strengths of one case to those of another. For instance, participants may observe that the greater the speed at collision, the greater the force strengths recorded. If such observations are voiced, you may want to point out that addressing one question in science often leads to new questions to investigate, and then redirect participants' attention to whether this affected the relative strength of the forces each cart applied to the other.

Making Sense Questions

Before discussing the questions, the instructor should emphasize that the class has focused on situations where two objects apply forces to each other during a collision.

Question 1:

Again, most participants will recognize that the two forces had the same strength in each of the different cases considered.

Question 2:

This question serves to reiterate the idea that neither motion nor mass of objects affects the relative strengths of the two forces. The instructor should encourage participants to compare this finding with the predictions they made in the "**What do we Think?"** section and in **Step 1**. Having participants record specific instances (e.g., unequal mass) where their findings contradict their predictions may help solidify the new idea.

STEP 4: Answer the following questions based on the results of this investigation.

Did the results agree with your predictions? If not, how were they different?

Do you see any kind of pattern in your data? If so, what is the pattern?

Making Sense

S1: For each of the situations you explored in this lesson, how does the strength of the force that one cart applies to the other during collision compare with the strength of the force that the second cart applies to the first?

S2: Does your answer to the previous question depend on whether the masses of the carts are equal or unequal? Does how they are moving make a difference? Does this result surprise you?

Question 3:

By presenting an extreme case, this question is intended to challenge the correct general conclusion that neither motion nor mass of objects affect the relative strengths of the forces they apply to each other during a collision. By presenting an extreme case (i.e., the car has much more mass than the bug and the car is travelling much faster than the bug) where only one object seems to be affected by the collision, this scenario appeals to the tendency to conflate consequences for the object with the strength of the force experienced. Some participants may respond to this appeal and state that the bug experiences a larger force. If so, the instructor should draw participant attention back to the evidence they collected that contradicts this view, making sure that parallels are drawn between carts of differing mass/speed, and the differing mass/speed of the car and bug.

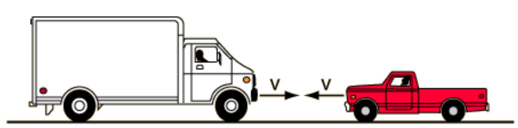
Addressing the question of why the bug suffers more damage is important because it supplies a rationale (other than unequal force strength) that can account for the impressive discrepancy in damage that participants readily imagine. Something similar to "a force of a certain strength will have a much greater effect on a tiny object than a massive object" is likely sufficient.

Question 4:

This question provides another, less extreme, example where participants can reconcile unequal consequences (damage) with equal force strengths.

S3: As you are driving down the highway, you hit a bug with your windshield. How does the strength of the force your car applies to the bug compare to that of the force the bug applies to your car? Why does the bug suffer more damage than your car?

S4: Suppose a small pick-up truck collides head on with a large van. How do the forces these two vehicles apply to each other compare? Why does the small pick-up truck suffer more damage?



Unit 3 Cycle 1

Exploration #2: Forces during a continuous push

LESSON TARGET IDEA

- When one object is being pushed continuously by another object, the strength of the force that each object applies to the other is the same.

COMMON MISCONCEPTIONS

- *When one object is being pushed by another object at constant speed, the strength of the force applied by the "pushing" object to the "pushed" object is greater than that applied by the "pushed" object to the "pushing" object.* (It is not! The perception of "pushing" versus "pushed" (likely resulting from the direction of motion) does not indicate that the two forces are unequal.)

- *When one object is being pushed by another object and their speeds are increasing, the strength of the force applied by the "pushing" object to the "pushed" object is greater than that applied by the "pushed" object to the "pushing" object.* (It is not! The increasing speed does not indicate that these two forces are unequal.)

WHAT TO FOCUS ON

This lesson extends the examination of force pairs in collisions from the previous lesson to scenarios when one object is continuously pushing another.

Like previous lessons in this unit, participants initially make predictions about the forces present in a series of scenarios; participants should focus on the motion of the objects during the pushes. Next, participants use force probes and force plates to measure the strengths of forces in scenarios similar to those for which they made predictions. It is important to focus on the relative magnitudes of forces that are recorded for the pair of forces in each scenario. Participants should also pay attention to the motion of the objects (constant speed or increasing speed) during the pushes. Participants should recognize that the motion of the objects is not related to the relative strengths of the forces. That is, regardless of the motion, the strength of the force the objects apply to each other is the same.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Two force-detection plates (available from Vernier or Pasco) and compatible data collection system	1 set per class
One low-friction cart with fan attachment, one low-friction cart with adjustable friction attachment, track with a motion sensor, and an attachable force probe for each cart with compatible data collection system	1 set per class
Chair with wheels/casters	1 per class

Purpose

The instructor should remind participants that in the previous lesson they saw that forces applied by two objects to each other in a collision were equal in strength. In this lesson we will turn our focus to the strengths of forces that objects apply to each other when they continue for longer times. Will the force strengths be different if the objects move at a constant speed? Will they be different if the objects experience a change in motion while the forces are being applied?

What do we think?

Participants need to decide whether the forces applied by the pusher and the chair have equal strength or if one is stronger than the other, and provide a rationale for their assertion. If unequal, which force is stronger?

Some participants will likely state that the force applied by the pusher to the chair is larger than the force applied by the chair to the pusher. This view may arise from confusion with the scenario of unbalanced forces acting on a single object because in both cases a change in motion occurs. This association of unbalanced forces with a change in motion may lead participants to think that the forces applied to each other by the pusher and the chair must also be unbalanced. Because the chair appears passive in this scenario, some participants may not see it as applying a force at all. Others may apply their observations in the previous lessons and hold that the forces must be of equal strength. In any case, the instructor should encourage participants to describe their reasoning.

Unit 3 Cycle 1

Exploration #2: Forces during a continuous push

Purpose

In collisions between objects, the forces they apply to each other last only a very short time. But what if one object pushes another for a longer period? How would the forces the objects apply to each other compare then; and would it depend on how they were moving while they did so?

For example, suppose you started pushing a stationary grocery cart so that its speed gradually increased for a few seconds and then you pushed so it moved at a constant speed. How would the force that the cart applies to you compare to the force you apply to it during both parts of this motion?

When one object pushes another along, how do the forces they apply to each other compare?

What do we think?

When someone pushes a person in a wheelchair they must first start the chair moving from rest, and increase its speed gradually. When they get to the desired speed, they then push such that it moves at a constant speed from then on.

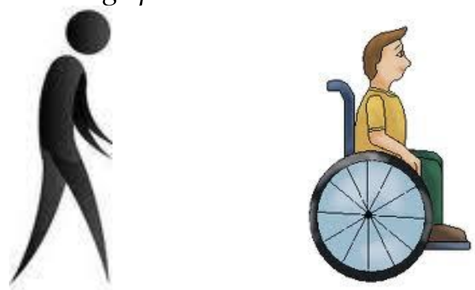
While the speed of the wheelchair is increasing, how do you think the force that the "pusher" is applying to the chair compares to the force the chair is applying to the "pusher"? Why do you think so?

Fewer participants may assert that the force applied by the pusher to the chair is larger than the force applied by the chair to the pusher when they move at a constant speed. However it is again important to reveal participants' reasoning. Some assertions of equal strength forces may be based on confusion of this scenario with balanced forces acting on a single object because in both cases no change in motion occurs.

Drawing force arrows on the diagrams provided allows participants to revisit their predictions when the context of forces between two objects is made explicit. This may relieve some confusion with balanced and unbalanced forces acting on a single object. The diagrams and subsequent discussion should also clarify any inclusion of other forces some participants may consider (e.g., friction of wheels on surface). If such other forces become a distraction, the instructor should assure participants that they will consider other forces later, but need to focus now on the forces that the "pusher" and the chair exert on each other.

While the speed of the wheelchair is constant, how do you think the force that the "pusher" is applying to the chair compares to the force the chair is applying to the "pusher"? Why do you think so?

To illustrate your thinking, draw arrows to represent the forces the "pusher" and chair exert on each other in the two situations on the pictures below.

Increasing speed	*Constant speed*
	

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

Activity 1: Forces during a longer push

The whole class will work together on this activity. The class will need:

- Fan-cart and friction cart
- Track
- 2 force probes with bumper attachments
- Motion sensor
- Chair on wheels
- Two force plates
- Data collection system

Activity 1: Step 1

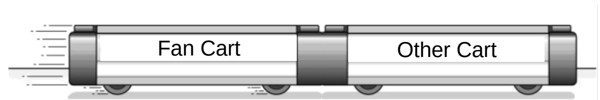
Although it likely will be apparent to most participants, the instructor should make sure that participants recognize the fan cart as the pushing object and the regular cart as the object being pushed. Knowing that the carts roll with extremely low friction may change some participants' interpretation of this scenario compared to the wheel-chair based scenario. The instructor should ensure that participants consider the strengths of the forces the two carts apply to each other and record predictions for both increasing and constant speed.

Activity 1: Step 2

Although the friction attachment may not be necessary for this experiment, the instructor will likely find it most convenient to have it in place prior to beginning the activity. For this experiment, it is important that the friction attachment is set so that the fan causes the speed of the carts to noticeably increase at a constant rate. The instructor should display the speed versus time graph as well as the force strength versus time graph for each cart. Observing the three plots simultaneously allows participants to consider the motion of the carts as they compare force strengths. The instructor should focus participants on the portion of the force strength graph where the speed of the carts was increasing. Participants should see that the forces are of equal strength during this time.

For this experiment it is important that the friction attachment is set so that the fan causes the speed of the carts to remain constant following the gentle push of the carts by hand. A few test runs may be required to establish an initial push and friction setting that produce a constant speed. The instructor should focus participants on the portion of the force strength versus time graph where the speed of the carts was constant. Again, participants should see that the forces are of equal strength during this time.

STEP 1: In the previous lesson the interactions between two colliding carts lasted only a very short time. Suppose you used a fan-powered cart to push another cart along the track so that they were in contact for a period of a few seconds.



If the carts were moving at a **<u>constant speed</u>**, how do you think the strength of the forces that they exert on each other would compare? What if the carts were moving with an **<u>increasing speed</u>**?

STEP 2: Your instructor will again help you test your thinking using carts and force probes. S/he will first arrange for the fan-powered cart to push the other cart toward a motion sensor (with the "bumpers" touching) and collect data as it does so, taking care to keep the connecting wires from interfering. There should be at least a short period when the speed of the carts was clearly increasing.

During the period that speed of the carts was increasing, were the strengths of the two measured forces the same, or different?

S/he will now repeat the experiment, but this time very carefully adjust a friction attachment so that, after being given a gentle push to start them moving, the carts should move along the track at a constant speed, at least for a short period.

During the period that speed of the carts was constant, were the strengths of the two measured forces the same, or different?

Activity 1: Step 3

In this step, participants apply forces that result in a person rolling across a floor in a chair. The instructor should caution participants to take sufficient care in applying pushes to avoid over-turning the chair or causing any collisions.

During the push, it is important that the face of the force plate being held by the person in the chair contacts only the face of the force plate held by the person who is standing. It is also necessary to maintain the contact during the push to continue to see non-zero force values. However, if contact between force plates is lost during the activity, participants should still see that the two forces are equal (both zero). Pushes should be applied such that the chair goes from being stationary, to rolling at a safe speed, and then slowing to a stop.

Participants should see that the strength of the force applied by the pusher equals the strength of the force applied by the person in the chair throughout the push.

Making Sense Questions

Before discussing the questions, the instructor should emphasize that the class has focused on situations where two objects apply forces to each other over an extended time.

Question 1:

By now, most participants should recognize that the strengths of the two forces are always equal and should be able to cite several different situations from this and previous lessons of this cycle:

- Two people "actively" pushing against each other
- One person "actively" pushing and the other resisting the push
- Pushes provided by people of different size
- Collision of a moving object with an object at rest
- Collision between moving objects
- Collision between objects of different mass
- Objects that change speed during a push
- Objects at a constant speed during a push
- Fan providing a constant push
- Person providing a constant push

It may be helpful to explicitly ask participants to recall several of these situations and ask them about the relative strengths of the forces.

Question 2:

Participants should recognize that the force strengths were always equal, regardless of relative masses, motion etc. Again, encourage participants to cite the evidence they collected to address each of the characteristics specified.

STEP 3: Your instructor will now help you test a situation much closer to that of the wheelchair you considered in the *What We Think* section.

One person will sit in a chair on wheels while another person pushes the chair. The forces they apply to each other will be measured using force plates. Data will be recorded using a portable device and then displayed for the class to see.

Was there any period during which the two measured forces had different strengths, or were they always the same?

Making Sense

S1: For all of the situations you have explored in this Cycle, how does the strength of the force that one object applies to another compare with the strength of the force that the second object applies to the first?

S2: Does your answer to the previous question depend on any other characteristics, such as the relative mass of the two objects, their relative motions, or whether the motion is changing or is constant?

Question 3:

This question is intended as an opportunity to apply the general conclusion, that the opposing forces are always equal in size, from the previous question. It includes one of the more challenging aspects of previous scenarios (person "actively" pushing against an inanimate, "resistive" object). The new context may also be challenging in that in order to move, the object must slide, rather than roll. Again participants are prompted to consider cases of collision, continuous force with increasing speed, and continuous force with constant speed. Application of the generalized conclusion to this new context is intended to provide a sense of its comprehensive nature prior to the formal introduction of Newton's third law.

S3: A football player practices by running at a tackle dummy that is mounted on a sled, pushing it across the grass. At first its speed increases, but then it moves across the grass at a constant speed.

How does the strength of the force the dummy applies to the player compare to the force he applies to it while he is:

a. Colliding with the dummy.

b. Pushing the dummy so its speed increases.

c. Pushing the dummy at a constant speed.

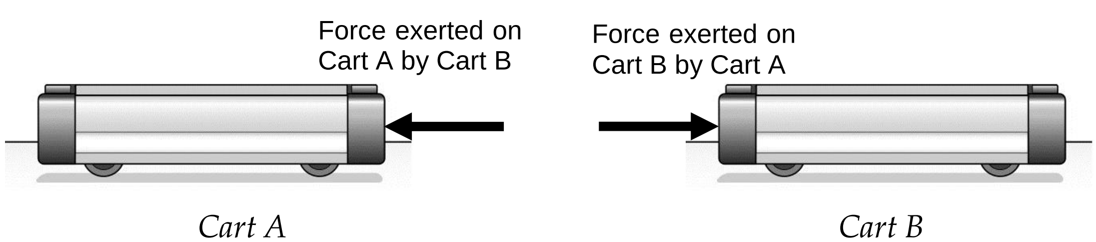
Newton's Third Law

The surprisingly simple idea you have been developing in this Cycle was first proposed by Sir Isaac Newton and is now known as Newton's Third Law of Motion. It can be stated as:

> ***If Object A exerts a force on Object B, then Object B exerts a force on Object A that is equal in strength and opposite in direction.***

However, Newton originally stated this idea in a way you may be more familiar with: "*To every action there is an equal and opposite reaction.*" (Note that to Newton the words "action" and "reaction'" referred specifically to what we now call forces.)

Thus, during any contact push pull interaction, there are two equal strength forces involved, only one of which acts on each object involved. Because of Newton's original wording for this idea, we call these forces an ***action-reaction pair***. For example, in a collision between two carts (A and B) the action-reaction pair of forces would be represented on two force diagrams as shown below.



It is important to note that Newton's Third Law does not mention any conditions on the mass or motion of objects. As far as we know, this simple statement is always true, for any interaction between any two objects during which they exert forces on each other.

Unit 3 Cycle 1

Exploration #3: How can it move?

LESSON TARGET IDEA

- When determining whether an object will experience a change in motion, one needs to consider *all* the forces acting on that object.

- When determining whether an object will experience a change in motion, one needs to consider *only* the forces acting on that object.

COMMON MISCONCEPTIONS

- *Because two objects in a contact-push interaction apply forces of equal strength and opposite direction to each other, no change in their motion is produced.* (The equal and opposite pair of forces applied to each other do not cancel or balance because they act on different objects. In addition, one must examine all the forces acting on each object to determine if (how) its motion will change.)

WHAT TO FOCUS ON

This lesson addresses the distinction between two different sets of forces: the equal and opposite pair of forces two objects apply to each other (Newton's third law and the subject of unit 3), and the forces acting in opposite directions on a single object, resulting in a net force on that object (Newton's second law, addressed in unit 2). Specifically, the lesson is intended to clarify that the equal and opposite forces due to Newton's third law act on different objects, and thus do not result in a net force of zero.

A difficulty that can arise when confusing the two sets of forces is used as a foundation for the lesson. Participants are asked to consider an apparent dilemma: how can an object begin to move if it is applying a force of the same size and in the opposite direction to the object that is pushing on it? The "What do we think?" activity instructs participants to draw only this pair of forces in the case of one person pushing another in a wheelchair. Many participants will likely struggle with the second prompt in the "What do we think?" portion of the lesson—explaining how an object can move if pairs of forces are always equal and opposite—as they are not paying attention to the fact that the two forces act on different objects.

In Step 1 of the activity, participants first identify each component of the equal and opposite pairs of forces present when two people push on a chair in opposite directions. Participants then express their thinking about which of these four forces would affect the motion of the chair.

In Step 2, force plates are used to monitor each of the forces in cases where pushes are applied and the chair does, and does not, move. Participants should focus on the relative strengths of individual forces measured for different force pairs as pushes are applied. Participants should compare force strengths and see that the two components of two pairs of forces are the same strength regardless of chair motion. Participants should also see, in contrast, that the strengths of the two forces applied to the chair are equal when the chair is at rest (or has a constant speed), but are unequal as the chair's speed increases or decreases. By reflecting on the equality, or inequality, of the force strengths and what they have already learned about net force and motion, participants should see that considering only the forces applied to the chair satisfactorily account for the chair's motion: a zero net force when the chair's motion does not change, and a non-zero net force when the chair's motion does change. Participants should conclude that the pair of forces that are applied to the chair account for the chair's motion, and that the pairs of forces that are always equal are the action-reaction pairs associated with Newton's third law.

Finally, participants revisit the concept of net force in Step 3. In answering the questions posed, participants should reinforce their understanding that multiple forces may act on an object without changing the object's motion, and that it is the net force on an object that determines whether the object's motion changes.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Four force-detection plates (available from Vernier or Pasco) and compatible data collection system	1 per class
Chair with wheels/casters	1 per class

Purpose

The instructor should inform participants that in this lesson they will explore how the action-reaction force pair they have learned about relates to changes in motion when one object pulls or pushes another.

What do we think?

Participants need to use their knowledge of action-reaction pairs to draw force arrows. Most participants will likely recall that the strength of the forces applied by the pusher and the chair are equal and draw force arrows accordingly.

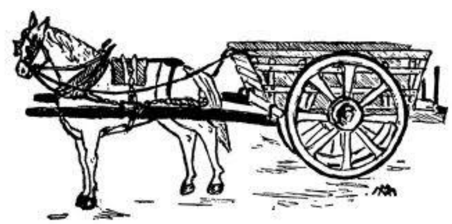
Unit 3 Cycle 1

Exploration #3: How can it move?

Purpose

In the previous lessons you developed an idea you now know to be Newton's Third Law of Motion. Namely, that whenever two objects interact the forces they exert on each other are always equal in strength and opposite in direction.

For example, consider a horse harnessed to a cart, both standing at rest. When the horse pulls on the cart it applies a force to it, but Newton's Third Law tells us that the cart always applies an equal and opposite force to the horse.



Does this mean that the forces are balanced and so however hard the horse pulls, the cart will never move?

> ***If pairs of forces are always equal, how can anything at rest ever start to move?***

What do we think?

In the previous lesson you considered one person pushing another person in a wheelchair. Consider this situation while the pusher and the chair are both **<u>at rest</u>**.

Draw arrows on the pictures above to represent the forces the pusher and the chair apply to each other.

Participants know that a horse can pull a cart, or person can push a wheel chair, but will not yet be able to apply force ideas to explain how. Many participants will likely think that the equal and opposite forces of an action/reaction pair of forces "cancel each other out" or are "balanced" (and thus no change in motion can occur). What many people overlook is that the forces in an action/reaction pair act on different objects, and it is only the forces acting on an object that determine whether its motion changes. It is okay for participants to have this confusion at this point in the lesson.

Many participants will likely not be able to correctly explain how the wheelchair can move at this point in the lesson, largely because they are not yet paying attention to which object each force in an action/reaction pair is acting on. Let participants know that this lesson is intended to help them examine this kind of scenario. Let them know that they should pay careful attention to which object each force acts on.

Activity 1: Step 1

When considering the scenario, it is important to emphasize that the chair is at rest as the two people begin to push, but may begin to move while they are pushing. With this understanding, the use of "**always**" in the upcoming questions includes both instances when the chair's motion changes and when it does not.

Explain how, with the forces you have drawn, it is possible for the chair to start moving.

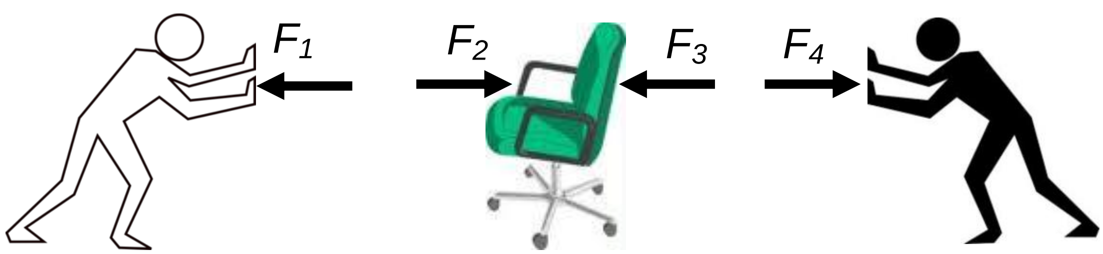
Participate in a group discussion about this question. Make a note of any idea or reasoning that differs from your own.

Activity 1: Pushing on a chair

The whole class will work together on this activity. The class will need:

- Chair on wheels
- Four force plates
- Data collection system

STEP 1: Consider a chair on wheels that is initially at rest. Two people push on the chair in opposite directions. We can represent the forces being applied between the chair and two pushers using arrows (labeled F_1 to F_4) as shown below.



- F_1 is the force that the chair is applying to pusher A
- F_2 is the force that pusher A is applying to the chair
- F_3 is the force that pusher B is applying to the chair
- F_4 is the force that the chair is applying to pusher B

Based on the work done to develop Newton's third law in this unit, most participants should recognize that F_2 and F_1 are an action-reaction pair and thus will always be equal in strength. In instances when the chair's motion is not changing, it is also true that F_3 (and F_4 because it is equal and opposite to F_3) will be equal in strength to F_2. Therefore, if participants point to F_3 (or F_4) in answer to this question, the instructor should ensure that participants consider cases when there is a change in motion and when there is no change in motion.

Again, most participants should recognize that F_3 and F_4 are an action-reaction pair and thus will always be equal in strength. And like the above question, in instances when the chair's motion is not changing, it is also true that F_1 and F_2 will be equal in strength to F_3, making it important that participants consider cases with and without a change in motion.

The challenge here is to recognize that only the forces acting on the chair determine the chair's movement. Unit 2 lessons addressing balanced and unbalanced forces provide the basis for answering this question.

Again, Unit 2 lessons addressing balanced and unbalanced forces provide the basis for answering this question. Some participants likely will recall that the net force acting on an object determines if and how the object's motion changes. Others may simply associate unbalanced forces with a motion change and balanced forces with no motion change. The key here is to apply these ideas using the appropriate forces: only those that act on the object. If the forces are equal in strength, participants should indicate that either the chair won't move or the chair will be moving at a constant speed. If the forces are unequal, participants should indicate that the chair will move with changing speed.

Activity 1: Step 2

In this step, participants apply forces that result in a person rolling across a floor in a chair. The instructor should caution participants to take sufficient care in applying pushes to avoid over-turning the chair or causing any collisions.

While one force plate can be held by the person seated in the chair, another should be attached to the back of the chair using bungee cords or similar means that do not obstruct the face of the force plate. Each of the two people standing should position the force plate they hold such that its face aligns with the face of one of the chair force plates. During the application of pushes, it is important that the face of each force plate contacts only the face of its partner force plate. It is also necessary to maintain contacts during the push to continue to see non-zero force values. However, if contact between force plates is lost during the activity, participants should still see that the two forces of the pair are equal (both zero). Interpreting results from the force plates may be best facilitated by displaying F_1 (positive) and F_2 (negative) on one graph and F_3 (positive) and F_4 (negative) on another. The instructor should orient the participants to ensure they understand which forces correspond to which plots. The instructor should also ensure that the graphs have the same scale so that participants can readily compare force strengths. To successfully address all of the questions in this step, the pushes on the chair need to be varied such that there is a period when the chair remains at rest and a period when the speed of the chair changes.

By comparing the distances of the plots from the zero lines at multiple times, participants should see that the strengths of F_1 and F_2 appear as mirror images and thus always have the same strength.

Likewise, participants should be able to see that the strengths of F_3 and F_4 are always the same.

Which of the other forces (if any) will **always** be equal in strength to F_2? How do you know?

Which of the other forces (if any) will **always** be equal in strength to F_3? How do you know?

Which forces will determine how the chair moves (if at all)? Explain why you chose these particular forces.

If the forces you identified in the previous question were equal in strength what would happen to the chair. What if they were not equal in strength?

STEP 2: Your instructor will again help you test your thinking. While two people push on a wheeled chair, with a person sitting in it, the four forces identified above will be measured using force plates. The results will be displayed for you to consider in answering the following questions.

How do the strengths of F_1 and F_2 compare? Are they always the same or are they sometimes different?

How do the strengths of F_3 and F_4 compare? Are they always the same or are they sometimes different?

Providing that the chair's speed changed for a period when forces were recorded, participants should be able to identify times when F_2 and F_3 did not have equal strength. Participants may need to compare the distances from the zero lines at several times to find instances when there is a noticeable difference.

Based on experiences in Unit 2, many participants are likely to respond that forces acting on the chair must be balanced if the chair is at rest. These participants should recognize that the net force would be zero.

Participants should recognize that F_2 and F_3 are equal when the chair is not moving. They should also see that this equality is consistent with their response to the previous question. The goal here is for participants to explicitly associate the forces acting on the chair, and being balanced when the chair is at rest, with the forces labeled F_2 and F_3.

Based on experiences in Unit 2, many participants are likely to respond that forces acting on the chair must be unbalanced if the speed of the chair is changing. These participants should recognize that the net force would *not* be zero.

Participants should recognize that F_2 and F_3 are different when the speed of the chair is changing. They should also see that this difference is consistent with their response to the previous question. Because it is difficult to cause the chair to increase or decrease speeds for an extended time, the participants may need to consider very brief portions of the activity when the speed of the chair clearly changed. So the goal here is for participants to explicitly associate the forces acting on the chair, and being unbalanced as the speed of the chair changes, with the forces labeled F_2 and F_3.

How do the strengths of F_2 and F_3 compare? Are they always the same or are they sometimes different?

Consider a period of time while the chair is not moving.

Would you expect the forces acting on the chair to be balanced or unbalanced? What would be the strength of the net force acting on the chair?

How do the strengths of F_2 and F_3 compare when the chair is not moving? Are they the same or are they different? Is this consistent with your answer to the previous question?

Now consider a period of time while the speed of the chair is changing.

Would you expect the forces acting on the chair to be balanced or unbalanced? Would the strength of the net force acting on the chair be zero, or something other than zero?

How do the strengths of F_2 and F_3 compare when the speed of the chair is changing? Are they the same or are they different? Is this consistent with your answer to the previous question?

This question is simply intended to have participants reiterate their understanding from previous unit 3 lessons by naming (F_1 and F_2), and (F_3 and F_4), as the action-reaction pairs of forces.

Participants should identify F_2 and F_3 as the forces that they need to take into account when determining whether forces on the chair are balanced or unbalanced. Because these two forces do not act on different objects, and do not always have the same strength, participants should recognize that they are *not* action-reaction pairs.

If participants are having difficulty recognizing that only F_2 and F_3 are relevant when considering any motion of the chair, it may be helpful to:

- rephrase the question as "which forces are acting on the chair?"
- review the *Unit 2 cycle 2 Beginnings* target ideas and the evidence that supported them.

Activity 1: Step 3

Again, based on experiences in Unit 2, many participants are likely to choose participant 2, recalling that an object at rest will stay at rest if multiple forces are acting on it as long as the forces are balanced. Others may cite the application of forces in this activity when the chair was stationary. If necessary, prompt participants to explain how the forces on the chair they observed in this activity support this idea. Participants should identify times when F_2 and F_3 have the same strength, and the chair is at rest, as evidence that supports the claim of participant 2.

Revisiting the idea of net force here is intended as a foundation for addressing the "making sense questions." We want participants to explicitly recall their understanding of net force to highlight the contrast that will be made between the net force on a single object versus the action–reaction pair of forces for two objects that interact. To help solidify the understanding of net force, the participants are asked about the underlying similarity for situations with no forces or balanced forces on a single object. Once participants acknowledge that no force on an object and balanced forces on an object both result in no change in motion, they should connect each with zero net force. Participants should see that net force is useful in explaining why these different force situations produce the same result, reconciling the views of Participant 1 and Participant 2.

Which two pairs of forces in this situation are action-reaction pairs associated with Newton's Third Law?

Which two forces in this situation should we consider when discussing whether the forces acting on the chair are balanced or unbalanced? Are these two forces an action-reaction pair or not?

STEP 3: Two participants are discussing what they can say about the chair while it is not moving.

Participant 1: *"We know that a force is needed to start an object moving, so if the chair is not moving, that must mean there are no forces acting on it."*

Participant 2: *"I agree that if the chair were to start moving, a force must be responsible. But it is also possible for two or more forces to be applied to the chair, yet it does not start to move."*

Which participant's thinking is supported by the evidence from this activity?

Explain how the idea of **net force** could reconcile these two participants' ideas.

Making Sense Questions

Before discussing the questions, the instructor should have participants revisit the "purpose" section that illustrates the horse and cart, and remind the class about the key features of this scenario:

- The horse and cart are connected together
- When the horse pulls on the cart it applies a force to it
- The cart always applies an equal and opposite force to the horse.

Question 1:

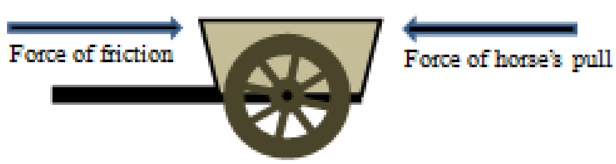
Separating the horse from the cart simply provides an opportunity for participants to explicitly and clearly designate what object is being acted upon by each force of the action-reaction pair. Participants should show that each force is being applied to a different object: one force acts on the horse and the other on the cart. It may be necessary to remind some participants of the convention that the object the arrow points to is the object that the force acts on.

Question 2:

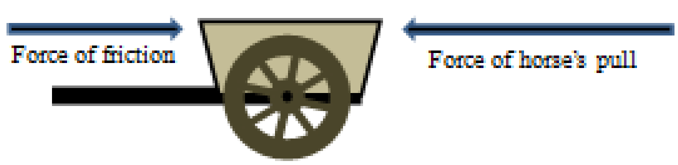
First, participants need to establish that only the forces on the cart are relevant for determining the motion of the cart. This step may be accomplished by having participants apply what they observed for the chair-pushing activity to the cart scenario. Some participants will likely point out that motion of the chair was determined by F_2 and F_3. It may be helpful to then prompt participants about the similarities in the two situations. For instance, participants might benefit from identifying what forces on the cart are similar to the F_2 and F_3 forces on the chair. One push on the chair can be related to the horse's pull, and the push on the chair in the opposite direction might be related to friction between the cart's wheels and the ground.

Once the appropriate forces are identified, participants need to recognize that the relative strengths of the forces affect the cart's motion. Again, encouraging participants to draw on parallel observations for F_2 and F_3 during the chair push activity will likely be helpful. In this case, participants need to focus on how the relative sizes of the forces affected motion and construct their diagrams accordingly. As shown below, the diagram for the cart at rest should show that the sum of forces applied in one direction equal the sum of the forces applied in the opposite direction. The diagram for the cart starting to move should show that the sum of forces applied in one direction is greater than the sum of the forces applied in the opposite direction.

Cart Staying at Rest



Cart Starting to Move



Making Sense

For these questions we will return to the case of a horse harnessed to a cart.

S1: For the action-reaction pair of forces associated with this situation, are both of these forces applied to the same object, or are they each applied to two different objects? To show your thinking, draw a picture of the horse and a separate picture of the cart. Draw and label arrows on your pictures to represent where you think these two force are being applied.

S2: When considering whether the cart moves or not, we need to know whether the forces acting on it are balanced or unbalanced. In this case do we need to think about the forces being applied to the cart only, or do we also need to consider the forces being applied to the horse? Draw two diagrams for the cart, one showing an arrangement of forces that would result in the cart staying at rest, the other showing an arrangement of forces that would result in the cart starting to move. (You may consider friction as one force that is applied to the cart.)

Question 3:

Because the pairs of forces in action-reaction pairs have equal strength and opposite direction, it is easy for participants to consider these pairs of forces as balanced. This thinking is largely why action-reaction pairs are often confused with balanced forces. The activities of this lesson provided the basis for contrasting action-reaction pairs and balanced forces. At this point it may be helpful to have participants point to these contrasts specifically:

- F_1 and F_2, and F_3 and F_4 are action-reaction pairs, but F_2 and F_3 are balanced forces (when equal in size).
- The force applied by the horse to the cart and by the cart to the horse are action-reaction pairs, but the force applied to the cart by the horse and the force applied to the cart through friction are balanced forces (when equal in size).

Prompting participants to explicitly reiterate fundamental descriptions of these sets of forces may also help cement the contrast in participants' thinking:

- Balanced forces act on a single object, action-reaction pairs do not.
- Balanced forces cause an object's motion to remain constant, action-reaction pairs do not.
- Even when forces on an object are not balanced, the strengths of action-reaction forces are equal.

Question 4:

Appropriate answers to the first part of this question could take many forms. Participants may simply respond that the difference is that "no forces" means that forces are absent whereas "balanced forces" means that forces are present. Some participants might state that no forces means an object is not interacting with other objects, and that balanced forces means that it is.

Although the effects of no force and balanced forces are the same with respect to motion of the target object, the distinction may be important when considering how the situation might change. In the case of "no forces" acting on a target object, an interaction with a new object would need to occur in order for the target object to experience a net force. However, in the case of "balanced forces," no new object is required. Instead, a slight change in the strength of a force applied by an existing object could cause a non-zero net force.

S3: When describing Newton's Third Law it is common for people to describe an action-reaction pair of forces as being an example of "balanced forces." Explain why this is not an appropriate use of the term "balanced forces" as we use it in studying force and motion.

S4: What is the difference between "no forces" and "balanced forces"? If the effect of both is the same, why is it important to make this distinction? Describe an example of each case.