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?

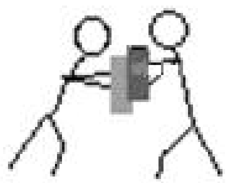
What we think

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

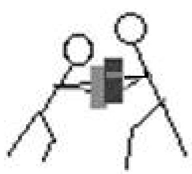
Case A. Same size people push hard on each other.

Prediction:



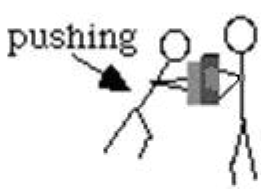
Case B. One person is bigger; people push hard on each other.

Prediction:



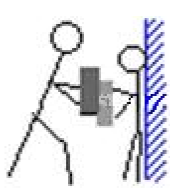
Case C. Smaller person pushes, the bigger person resists.

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.

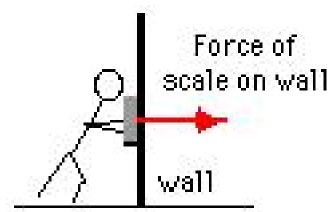
Activity 1: Pushing on each other

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?

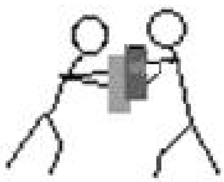
Let us assume throughout the rest of this activity that the reading from the plate indicates the **strength of the force (or push)** being applied to it.

STEP 2: Using two force plates, your instructor will help you test the predictions you made in the *What 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 **<u>drawing two arrows</u>** 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.)

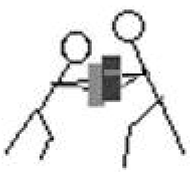
Case A. Same size people push hard on each other.

Observation:



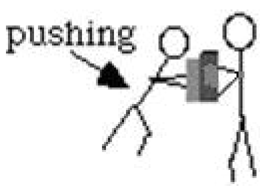
Case B. One person is bigger; people push hard on each other.

Observation:



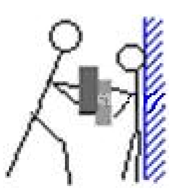
Case C. Smaller person pushes, the bigger person resists.

Observation:



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

Observation:



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?

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?

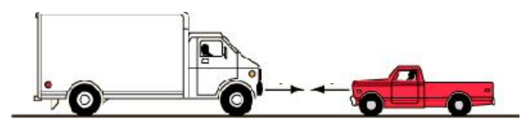
Unit 3 Cycle 1

Exploration #1: Forces during collisions

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.

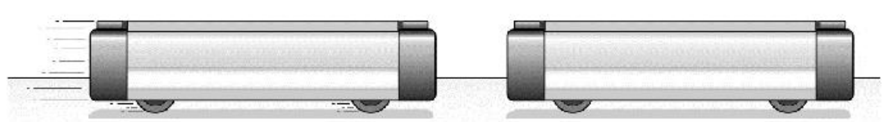
For example, suppose a small pick-up truck collides with a large van. Which vehicle do you think applies the stronger force to the other and why?



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

What we think

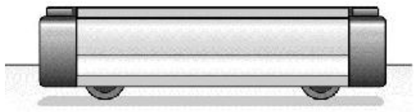
Consider a situation in which a small moving cart collides with an identical stationary cart.



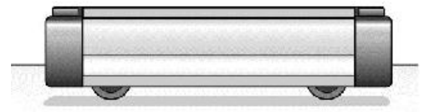
During the short period of the collision, do you think the moving cart applies a force to the stationary cart? How would you know if it did?

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 are applying to each other at a moment in time **during the collision**. 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.

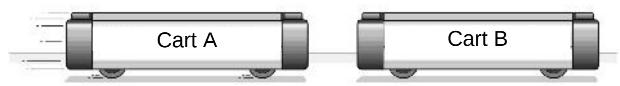
What do the results of this demonstration indicate about whether each cart applies a force to the other during the collision between them?

Activity 1: 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.

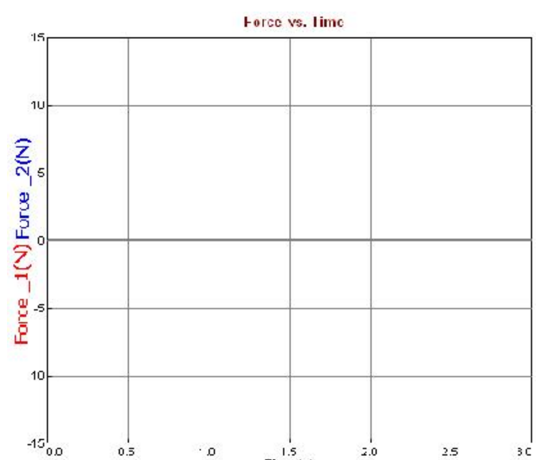
If both carts were moving toward each other, instead of one being at rest, how do you think the strength of the forces would compare? Explain your thinking.

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?

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		

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?

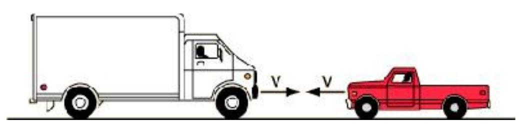
Making Sense

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?

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

Purpose

In collisions between objects the forces they apply to each other last only a very short time. But what about 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 we think

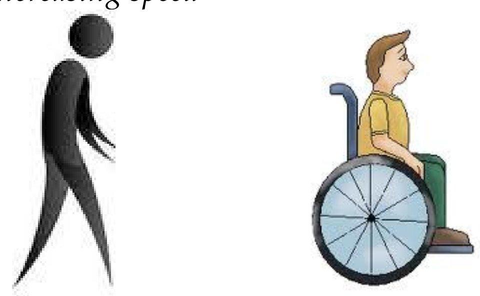
When someone pushes a person in a wheelchair they must first start the chair moving from rest, and increase its speed gradually. When they get to the desired speed, they then push such that it moves at a constant speed from then on.

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?

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

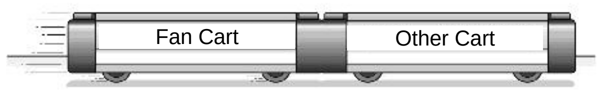
Participate in a group discussion about these questions. Make a note of any ideas or reasoning that differs from those of yours.

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

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?

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?

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.

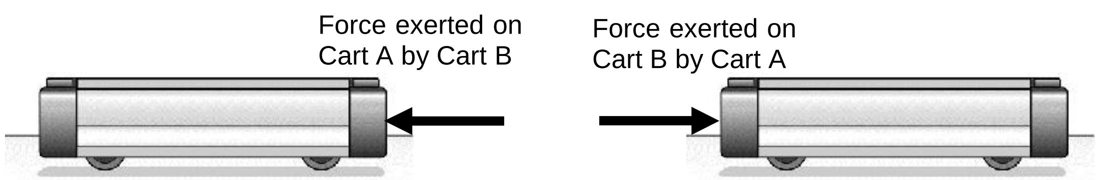
Newton's Third Law

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 an 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.



Cart A *Cart B*

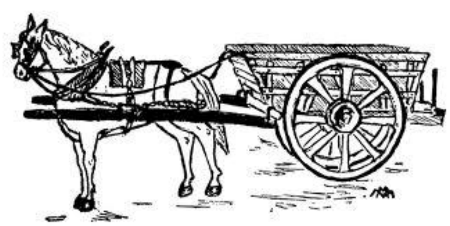
It is important to note that Newton's Third Law does not mention any conditions on the mass or motion of objects. As far as we know, this simple statement is always true, for any interaction between any two objects during which they exert forces on each other.

Unit 3 Cycle 1

Exploration #3: How can it move?

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.

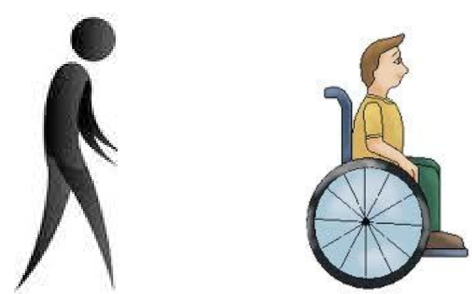


For example, consider a horse harnessed to a cart, both standing at rest. When the horse pulls on the cart it applies a force to it, but Newton's Third Law tells us that the cart always applies an equal an opposite force to the horse.
Does this mean that the forces are balanced and so however hard the horse pulls the cart will never move?

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

What 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.

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

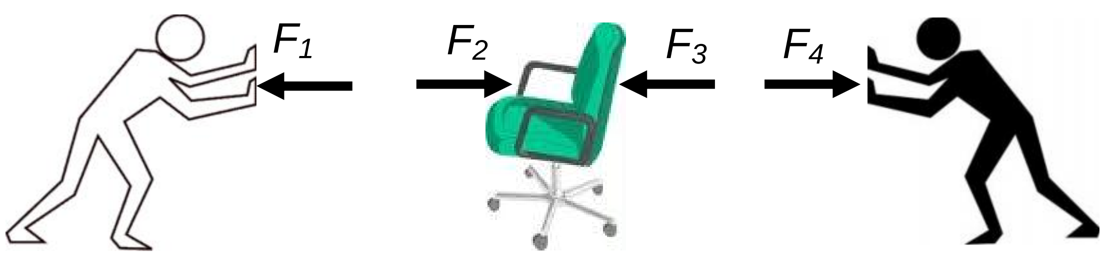
Participate in a group discussion about this question. Make a note of any idea or reasoning that differs from your own.

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

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

If the two 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?

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?

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 students are discussing what they can say about the chair while it is not moving.

Student 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."*

Student 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 student's thinking is supported by the evidence from this activity?

Explain how the idea of **<u>net force</u>** could reconcile these two students' ideas.

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.)

S3: When describing Newton's Third Law it is common for students 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.