

## Purpose

In Chapter 1 you developed some ideas about how to describe contact push/pull interactions between objects in terms of a transfer of mechanical energy between the objects. For example, for a soccer player kicking the ball, previously we might have said:

*“There is a contact push/pull interaction between the player’s foot and the ball. Mechanical energy is transferred from the foot to the ball”*



However, scientists often use a different way of describing the **same** interactions, not in terms of energy transfers and changes, but in terms of the pushes and pulls (which they call **forces**) that the objects exert on each other. So, for the example above, we could also say:

*“There is a contact push/pull interaction between the player’s foot and the ball. The foot pushes the ball” or “The foot exerts a force on the ball.”*

In this cycle you will be investigating the effects that forces have on the motion of objects. We will start by examining how we can recognize when a force is acting on an object, and when it is not.



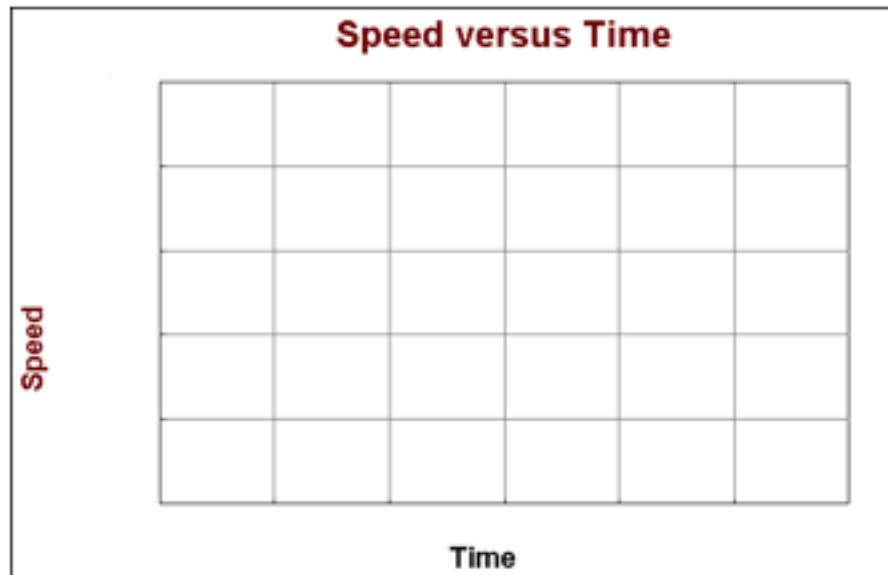
*How does an object move when a force is acting on it?*

## Initial Ideas

Think about a soccer player kicking a stationary ball. As he interacts with it, by kicking it, the ball starts to move. After the kick, the ball rolls across the grass and gradually comes to a halt.



Sketch a speed-time graph for the motion of the ball, from the moment the player's foot first contacts it until it comes to a halt again.



Using a colored pencil, indicate the period on the graph during which the foot was in contact with the ball. Explain your reasoning.



Using a different colored pencil, indicate the period on the graph during which there was a force pushing the ball forward. Again, explain your reasoning.



Draw a picture of the ball and use arrows to show what **forces** (if any) you think are acting on the ball **after** the foot has lost contact with it, but before it stops



Participate in a whole class discussion about these questions. Make a note of any ideas or reasoning that are different from those of your team.

## Collecting and Interpreting Evidence

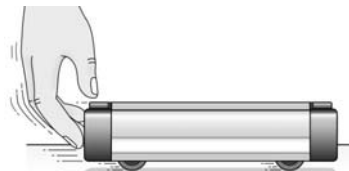
**Experiment #1: Is the motion of the cart after it has been pushed the same as during the push?**

You will need:

- ▶ Low-friction cart
- ▶ Track
- ▶ Access to a Motion Sensor connected to a computer

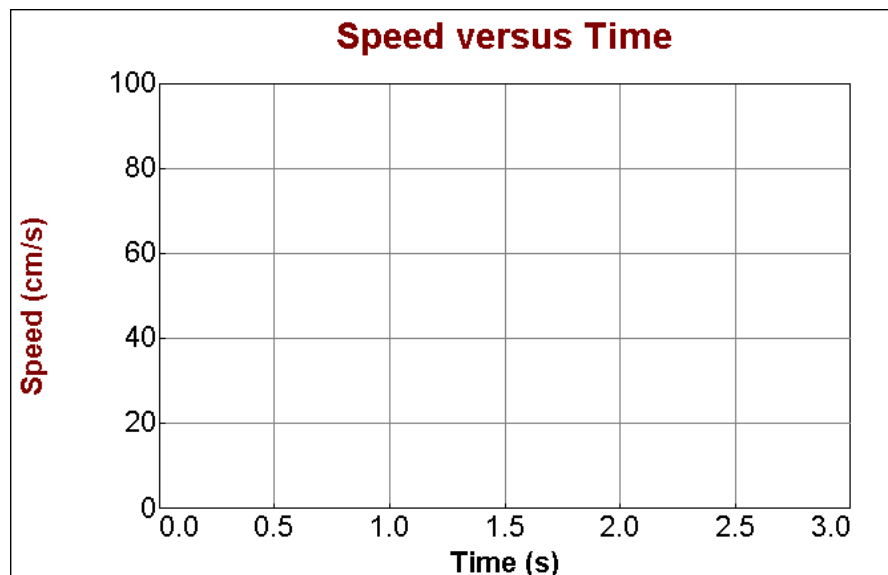
**STEP 1:** Open the Motion Sensor data collection file for this activity. Place your cart at rest on the track about 20 - 30 cm in front of the Motion Sensor.



Start collecting Motion Sensor data and then have one of your team members give the cart a **gentle** push away from the sensor with their hand.




While the cart is moving, and before the data collection stops, give the cart two or three more pushes, in the **same direction** as the first push. (Stop the cart when it reaches the other end of the track.)

-  Sketch the speed-time graph for the motion of the cart.



-  Each time the hand interacts with the cart, what happens to the cart's speed? Does it speed up quickly, slow down quickly, or move at a reasonably constant speed?
-  During the periods when the hand is not interacting with the cart what happens to the cart's speed? Does it speed up quickly, slow down quickly, slow down slowly, or move at a reasonably constant speed? Why do you think this is?

-  What evidence would you look for to tell you that a force is acting on the cart? To illustrate your thinking, use a colored pencil to indicate on the speed-time graph above the sections of the graph during which you think there is a force pushing the cart forwards. Explain your reasoning below.

**STEP 3:** Three students are discussing the motion of the cart and the force acting on it. They all agree that while the hand is pushing it there is a force acting on the cart, but have different ideas about what happens during the periods when the hand is not in contact.

The force of the hand is transferred to the cart and is carried with it. That's why the cart keeps moving after the push.

The force of the hand stops when contact is lost, but some other force must take over to keep the cart moving

After contact is lost there are no longer any forces acting on the cart. That's why it moves differently.



Samantha

Victor

Amara



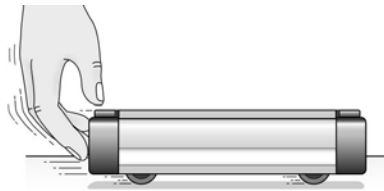
Do you agree with Samantha, Victor, or Amara, or with none of them? Explain your thinking.

### Experiment #2: What happens to the cart when it is given a continuous push?

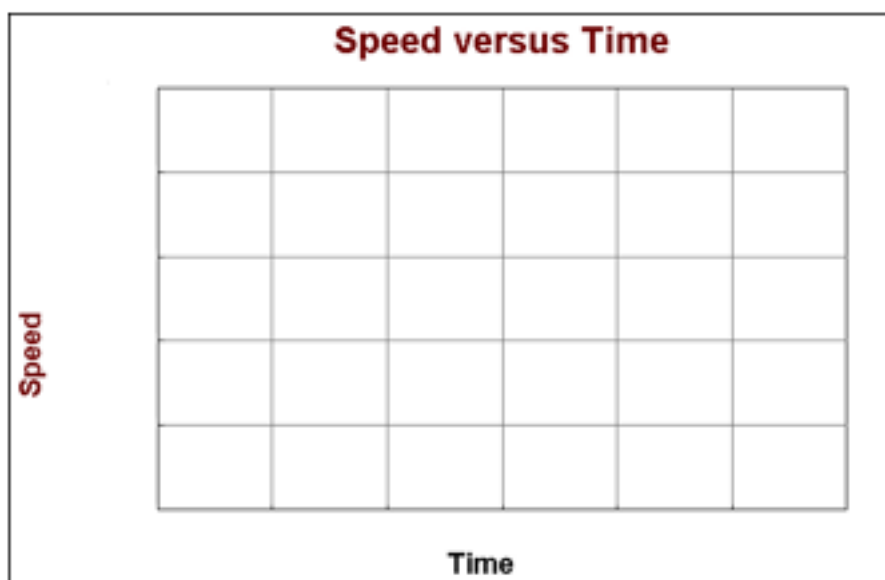
You will need:

- ▶ Low friction cart
- ▶ Track
- ▶ Fan unit
- ▶ Access to a Motion Sensor connected to a computer

**STEP 1:** In the previous experiment you started a cart moving by giving it a quick push. Now, suppose instead you were to keep pushing the cart continuously with a **constant strength**.

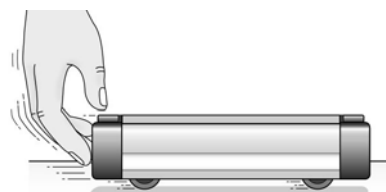




What do you think the motion of the cart would be like under these circumstances? Sketch a speed-time graph to illustrate your thinking.



Briefly explain your reasoning.

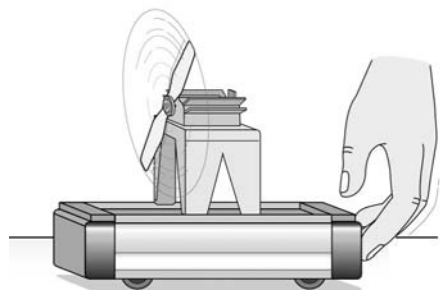
**STEP 2:** Place the cart near one end of the track (or table). Each member of your team should try using **one finger** to push the cart along the track. (Make sure you push the cart from behind; do not grip it with your fingers.) Try to maintain a constant strength push as the cart moves.






-  How does the cart seem to behave as you push it?
-  How easy did it seem to maintain a continuous, constant-strength, push?  
Why do you think this is?

Most people find it very difficult to maintain a continuous push of a constant strength. We will now check to see if there is a better way to arrange for such a force to act on the cart.

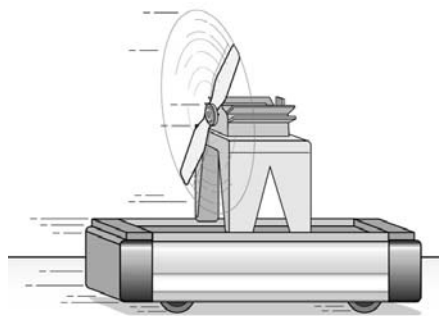
**STEP 3:** Fix the fan unit to the cart and place it, at rest, on the track (or table). Turn the fan unit on and have one of your team place a finger in front of the cart to stop it from moving. This person should concentrate on the push they feel from the cart while the fan is running.



At the same time another team member should listen to the sound the fan unit makes while it is running. Keep the fan running for several seconds and then turn it off.

-  How does the push of the cart seem to behave while the fan is running?  
Does the push seem to stay constant or does it seem to increase or decrease significantly?
-  Does the sound that the fan makes change as it is running, or does it sound about the same the whole time?
-  Do you think the fan unit exerted a constant strength force on the cart while it was running? What evidence supports your idea?

**STEP 4:** Open the Motion Sensor data collection file for this activity (if it is not already open). Place the cart about 20 – 30 cm in front of the Motion Sensor and turn the fan on. Start the data collection and then release the cart. (Do **not** give it any sort of push or pull with your hand.) One team member should listen carefully to the sound of the fan while the cart is moving.



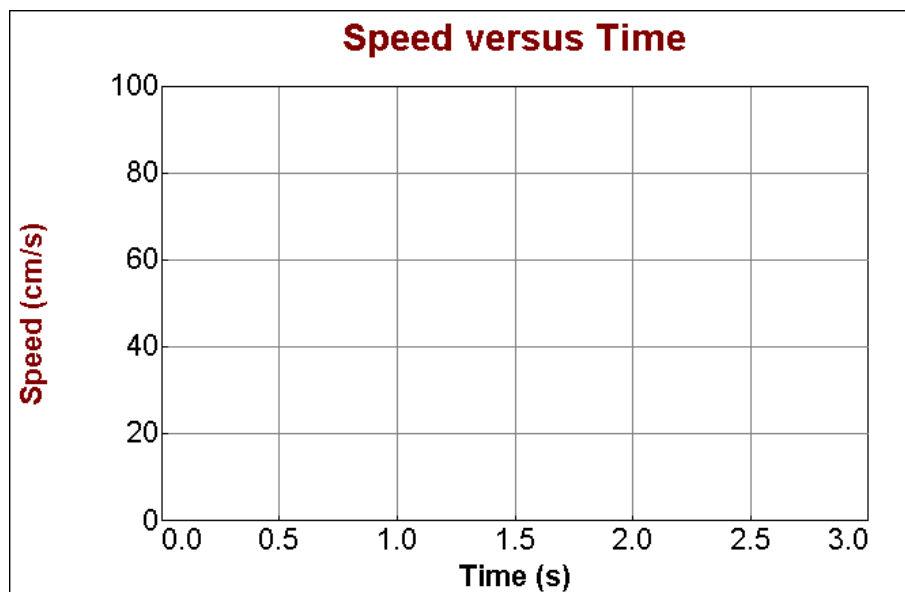
**Carefully** stop the cart before it reaches the other end of the track and turn the fan unit off.



Do you think the fan unit exerted a constant strength force on the cart as it moved along the track? What evidence do you have to support your answer?



Sketch the speed-time graph for the motion of the cart below.



What does the speed-time graph tell you about the speed of the cart while the fan unit was pushing it?

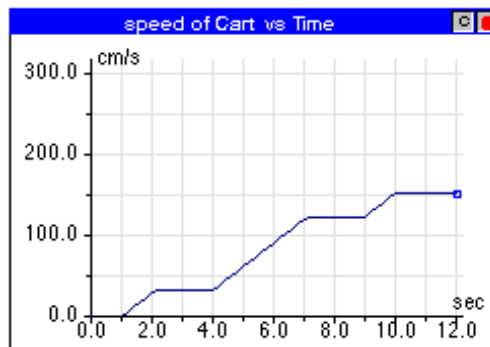




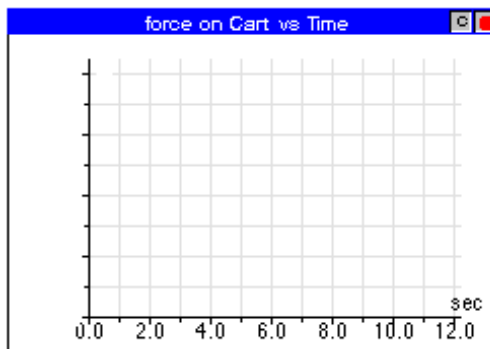
Does the behavior of the cart agree with the prediction you made at the beginning of this experiment?

**Simulator Exploration #3: How does your thinking compare to scientists' models?**

**STEP 1:** On the right is a speed-time graph taken from an *I&M Simulator* set-up that models the experiment in which you pushed the cart two or three times.



Indicate the periods on the speed-time graph when you think the cart in the simulator was being pushed. How do you know?



The *I&M Simulator* can also ‘measure’ the force acting on the cart in the simulator model. On the blank force-time graph above, sketch how you think the force acting on the simulator cart varies (if at all) during the same 12-second time period shown on the speed-time graph. (Note: It is only the shape of the graph that is important for now, so no values for the force are shown.)



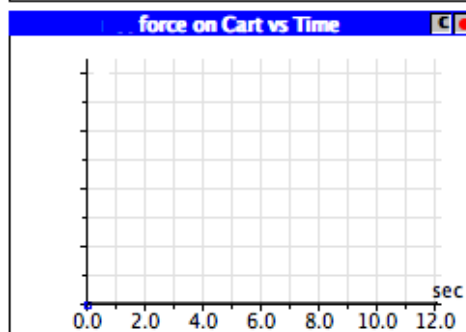
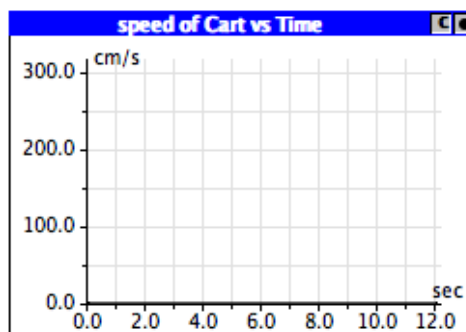
Explain the reasoning that led you to draw your force-time graph the way you did.


**STEP 2:** Open the simulator set-up file for this activity. The set-up shows a cart on a track, together with speed-time and force-time graphs.





While the simulator is running you can give the cart a 'push' by pressing on the spacebar of your computer keyboard. The push will continue (at a constant strength) as long as you hold the spacebar down. The simulator will stop on its own after 12 seconds.

Run the simulator a few times (remember to click 'rewind' to get back to the start) and check that you understand how the spacebar 'push' works. When you are ready, try to produce a speed-time graph as close to that shown in STEP 1 as you can.




 Sketch the speed-time and force-time graphs from the simulator.


 During the periods when the simulator cart was being 'pushed' was there a force acting on it? What evidence from the simulator graphs supports your idea?

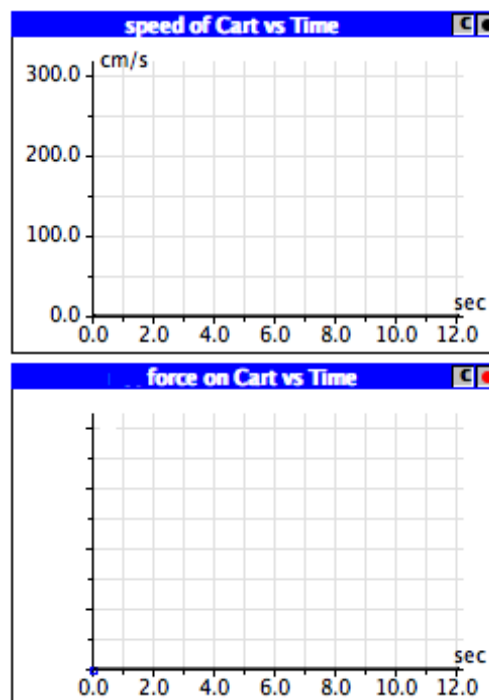
 During the periods in between the pushes, was there a force acting on the simulator cart? Again, what evidence from the graphs supports your idea?

**STEP 3:** Run the simulator again, but this time hold the spacebar down to apply a **continuous constant strength force** to the cart. (As the fan unit did to the real cart.)



 Sketch the speed-time and force-time graphs from the simulator.

 Based on the evidence you have gathered in this activity, what happens to the speed of an object while a single force is acting on it in the same direction as its motion?



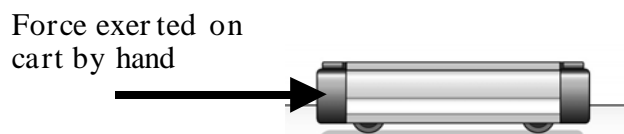
## Forces and Force Diagrams

The pushes you used in this activity are examples of forces. Whenever one object is pushing or pulling on another object we say it is exerting a force on the other object. This means that the pushes and pulls you used in Chapter 1 to investigate contact push/pull interactions could also be described in terms of forces exerted on the cart by a person or another cart.

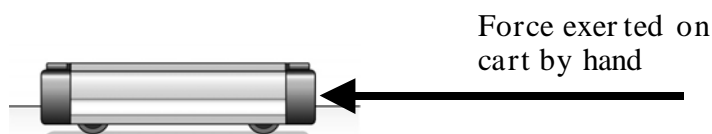
Just as with the energy description of contact push/pull interactions you developed in Chapter 1, we can also draw a diagram to help us analyze and explain the force description of the same interactions. In such a **force diagram**, we identify the object of interest and all the forces (pushes and pulls) being exerted on it by **other** objects at a **particular moment in time**. We represent these forces with 'force arrows' on the diagram, which are labeled

<sup>1</sup> Scientists often call such a diagram a **free-body diagram**.

to show what they represent. For example, the force of your hand pushing the cart could be represented like this:



As you might expect, the direction of these force arrows indicates the direction of the forces they represent. In addition, the length of the arrows indicates the relative strengths of the forces. So, for example, if you pushed the cart in the other direction, with a stronger push, the force diagram would look like this (note the longer arrow):

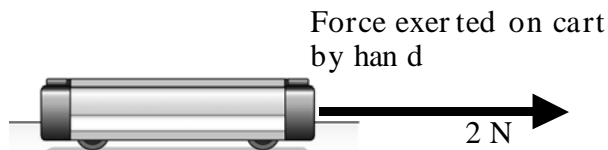


Notice that the force diagram shows only one of the objects involved in the interaction (the cart), and that the other object involved (the hand) is only mentioned in the labeling of the arrow representing the force it is exerting. In this sense these force diagrams are very like the Input/Output (I/O) energy diagrams you drew at the end of Chapter 1.

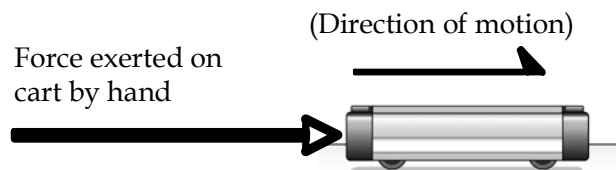
The strength of a force is measured in units of newtons (N), named in honor of Sir Isaac Newton, a famous English scientist you will learn more about later on. Sometimes it may be necessary to add information on the strength of a force to a force diagram. For example, if a hand pulls on a cart with a force of 2 N, that would be represented by the following diagram<sup>2</sup>:

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<sup>2</sup> As you saw in Chapter 1, a push and a pull of the same strength have exactly the same effect on the motion of an object. Thus we could equally well represent this pull to the right using exactly the same force arrow as we would use for a push to the right. Since the effect is the same, distinguishing between pushes and pulls is simply a matter of choice. In this course, we will always draw force arrows on the side of the object from which the force is applied. Hence, a push will always be represented by a force arrow pointing toward the object, and a pull will always be represented by an arrow pointing away from the object.



Finally, if the object we are concerned with is in motion at the moment in time for which we are drawing the force diagram, it is sometimes important to know in which direction the object is moving. We can show this by drawing a speed arrow above the object (just like the speed arrow in the *I&M Simulator*). (We use a half-arrow so as not to confuse it with the force-arrows, since it represents the speed of the cart, **not** a force acting on the cart.) The length of the speed arrow represents the relative speed of the object. For example, when you gave the moving cart a push in the same direction as its motion, the force diagram for a moment in time during your push would look like this:



Note that the speed arrow only tells about the speed of the object at the particular moment in time for which the force diagram is being drawn. It does not tell anything about whether the object's speed is in the process of changing, or whether it is remaining constant.

You may have noticed that all the situations discussed above show only one force acting on the cart. It is certainly possible for more than one force to act on an object at the same time, but it is important to understand the effect of a single force before considering situations involving multiple forces. Thus, in the first few activities in this chapter, you will study the effect that a single force has on an object.

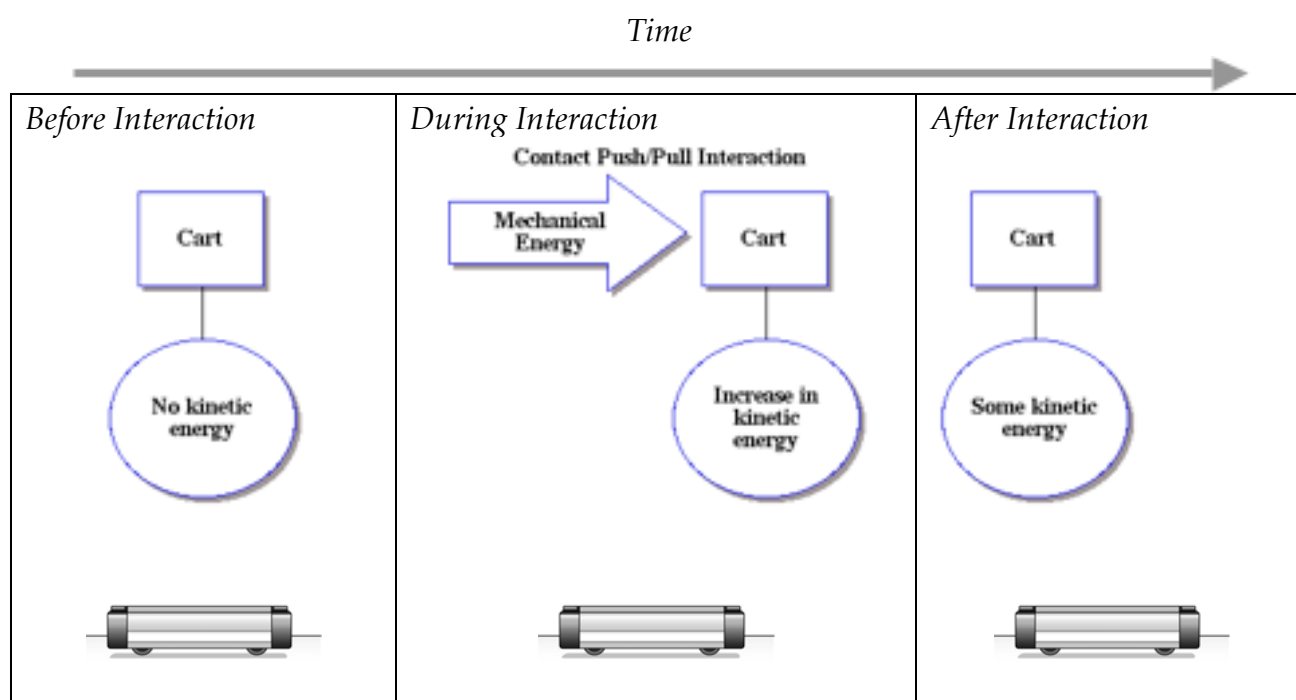
## Comparing Force and Energy Diagrams

To help you start thinking about how force and energy ideas of describing contact push/pull interactions relate to each other, consider the situation of a stationary cart that is given a quick shove with a hand to start it moving. Shown below is a timeline of I/O energy diagrams showing how the energy

transfer to the cart and changes in its kinetic energy are related to the interaction.



Below the energy diagrams are three pictures of the cart. Use these pictures to draw force diagrams, representing the force (due to the contact push/pull interaction between the hand and the cart) acting on the cart at the same three points in time as the energy diagrams. (Be sure to include force and speed arrows as you think appropriate. However, if you think there is no force acting at a particular time, then do not draw a force arrow.)




## Summarizing Questions

- S1:** If a cart is at rest and a single force acts on it, what happens? If the same force continues to act on the cart what happens to the cart's speed?
- S2:** In general, during the time a single force with a **constant strength** acts on a moving object, in the **same direction as its motion**, what is the object's motion like? (Does it move at a constant speed, does its speed continuously increase, or does the speed only increase at first and then

become constant after a short time?) What evidence from this activity supports your thinking?

- S3:** When you were using your finger to try to push the cart with a constant strength force, you probably noticed the cart was 'getting away' from you. (If not, try it again.) Why do you think the cart behaved in this way?
- S4:** Suppose that, while the cart was being pushed along the track by the fan unit, a wire suddenly broke so that the fan unit stopped pushing on the cart. What do you think would happen to the speed of the cart? Explain your reasoning.
- S5:** When you gave the cart a quick shove, at what moment do you think the force of the hand stopped acting on the cart? What evidence from this activity supports your idea?
- S6:** During a contact push/pull interaction, what do you think is transferred from the source to the receiver: energy, force, both, or neither? Explain your reasoning.

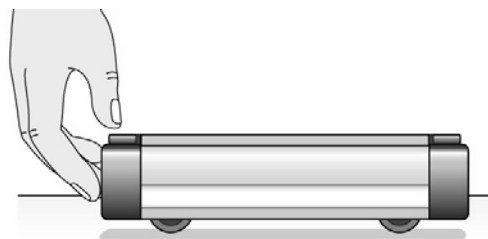
-  Participate in a whole class discussion to go over your answers to the Summarizing Questions and force diagrams.

## Writing Scientific Explanations using Force Ideas

As previously stated, the contact push/pull interactions you are examining in this chapter are the same as those you were introduced to in Chapter 1. However, whereas in Chapter 1 you described these interactions in terms of ideas about energy transfers and changes, in this chapter you are developing ideas about forces and their effects that allow you to think about these same interactions in a different way.

The process of writing scientific explanations of phenomena using force ideas is very similar to the process you used in Chapter 1 when using energy ideas. However, instead of drawing an energy diagram, you should draw a **force diagram**. Also, instead of writing a narrative that describes the behavior of an object in terms of energy transfers and changes, you should do so in terms of the **forces** acting on the object and the effect they have on its motion (if any). When writing your scientific explanations (or evaluating those of others) you should keep in mind the criteria of *accuracy, completeness, logical reasoning* and *clarity* introduced in Chapter 1.

To illustrate the similarities between energy-based and force-based explanations, consider the following two parallel explanations of why a stationary cart begins to move when it is given a quick push by someone's hand.

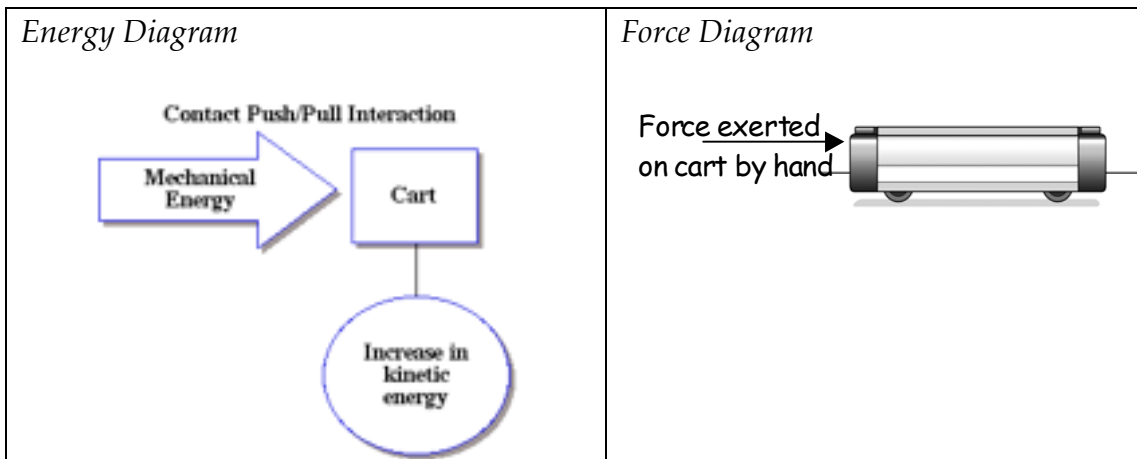


*Note: These explanations do not mention friction since we have not yet considered its effects in developing our ideas about forces. However, since we are dealing with a low-friction cart it can be assumed that the effects of friction are negligible.*



**Explanation: Why does a stationary cart begin to move when it is pushed?**

*Describe the situation using a diagram:*



*Write the narrative:*

<p>During the contact push/pull interaction between the hand and the cart, there is a transfer of mechanical energy to the cart. According to the idea of Conservation of Energy, since there is no energy output, this input of energy must be accounted for completely by an increase in the kinetic energy of the cart. Since the cart is initially at rest, this increase in kinetic energy means that the cart starts moving.</p>	<p>The only force acting on the cart is that exerted by the hand. When a single force acts on an object at rest, the object starts to move in the direction of the force, so the cart starts to move in the direction of the force exerted by the hand.</p>
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So one explanation says that the cart starts to move because Conservation of Energy suggests that the mechanical energy input to the cart results in an increase in its kinetic energy, while the other says it moves because the hand exerts a force on it during the interaction between them. Which explanation is better? They are **both** good – they are just two different ways of looking at the **same interaction**, one based on the ideas of energy, the other on the ideas of forces. Further, as you are seeing in this activity, though these two sets of ideas are different, they are closely related.

The previous explanation was meant to show you how both energy and force ideas can be used to explain the same phenomenon. For the remaining

explanations in this Chapter you should consider, and use, **only** force ideas. In this activity you saw that a cart with a fan unit attached started to move when the fan was turned on, and continued to speed up as it moved along the track. You should now use a general idea you developed about force and motion in this activity to write a scientific explanation for why this happened in this particular case.

**Explanation: Why did the cart with a fan-unit attached continue to speed up as it moved along the track?**

*Describe the situation using a diagram:* (Draw a force diagram for the cart while it is moving along the track and being pushed by the fan unit.)



*Write the narrative:* (Use the general idea you developed in this activity about what happens to the speed of a moving object when a continuous force acts on it in the same direction as its motion.)



Participate in a class discussion about this scientific explanation.