SECTION 6

Newton's Third Law: Run and Jump

Section Overview

In this section, students analyze the forces involved in running, stopping, and jumping. To illustrate this concept, a student on a skateboard pushes against a wall and slowly accelerates to roll across the floor with constant speed. To explain movement away from the wall, students identify the force causing the acceleration. Then they perform a thought experiment about the forces involved when running or walking on a horizontal surface, using words and sketches to answer questions on the forces. To assist in identifying the acting forces, students learn about free-body diagrams. Finally, to understand the concept of the normal force that is supplied by an inanimate object, students do an experiment with a meter stick and weights of different masses to see what happens each time a weight is placed on the meter stick. The bending of the meter stick under the force of the weights demonstrates the spring-like nature of surfaces, and helps explain how a normal force is exerted.

Background Information

Before proceeding with this section, it is recommended that you read *Physics Talk: Newton's Third Law of Motion* in the student text. The explanation of forces involved in walking given in the teacher's *Background Information* for *Section 7* will serve to explain the forces involved with walking and running brought up in this section. The pairs of equal and opposite forces identified during earlier sections to explain friction and walking are examples of Newton's third law of motion, often stated as: "For every action there is an equal and opposite reaction." Another equal and opposite pair of forces arises during this *Investigate* when a student standing on a skateboard sets himself into motion by using a leg and foot to push off from the wall.

Inevitably, forces exist in equal and opposite pairs, and often the force that you identify as the force responsible for motion is not the correct one. For example, a person who says, "I pushed down on the trampoline with a mighty force, and my force launched me upward in a high jump," is mistaken; it was the equal and opposite reaction force provided by the trampoline that launched the person upward.

One of the key concepts associated with Newton's third law but often misunderstood is that although action-reaction forces come in pairs, they never act on the same body. This restriction means that these forces never cancel one another out because they are not acting on the same object. In the *Investigate*, the student pushing off the wall while on the skateboard is exerting a force on the wall by trying to make the wall move. The reaction force exerted by the wall on the student is pushing the student in the opposite direction. It is this force that moves the student, not the student's foot. To convince the students, simply have the skateboarder stand on the skateboard when away from the wall and try to push. To further the argument, have some vertical meter sticks brought into position so the student can push off on them. The meter stick's obvious bending should convince the students that the bendable nature of the meter sticks provides the forward force.

Crucial Physics

- Forces come from interactions between objects. This means that forces come in pairs, with each of the forces acting on each of the interacting objects.
- For each pair of forces due to an interaction, the forces are equal but point in opposite directions.

Learning Outcomes	Location in the Section	Evidence of Understanding
Provide evidence that forces come in pairs, with each force acting on a different object.	***Investigate*** Part A: Steps 1-4	Students state reaction force of wall on skateboarder is responsible for the acceleration.
Use Newton's third law to analyze physical situations.	***Investigate*** Part B: Steps 2-4	Students demonstrate knowledge of the normal force to explain the bending of a meter stick when masses are added.
Describe how Newton's third law explains much of the motion in your everyday life.	***Investigate*** Part A: Steps 3-4 Part B: Steps 3-4 ***Physics Talk***	Students correctly identify the action–reaction force pairs in cases such as a student walking across the floor.

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CHAPTER 2

Section 6 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Ruler, metric, 30 cm	1 per group	
Meter stick, wood	1 per class	
Washer, 3/4 in. (outside diameter) x 5/16 in. (inside diameter)	2 per group	
Weight, slotted, 100 g	10 per group	
Scale, spring, 0-20 N	2 per group	
Board, roller, Reaction Force (skateboard)		2 per class
Chair (with wheels)*		1 per class
Safety helmet*		1 per class
Pads, knee*		1 per class
Pads, elbow*		1 per class
Stack of books*		1 per class

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Ruler, metric, 30 cm	1 per group	
Meter stick, wood	1 per class	
Washer, 3/4 in. (outside diameter) x 5/16 in. (inside diameter)	2 per group	
Weight, slotted, 100 g	10 per group	
Scale, spring, 0-20 N	2 per group	
Board, roller, Reaction Force (skateboard)		2 per class
Chair (with wheels)*		1 per class
Safety helmet*		1 per class
Pads, knee*		1 per class
Pads, elbow*		1 per class
Stack of books*		1 per class

*Additional items needed not supplied

Note: Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

Time Requirements

This *Investigate* will take approximately one class period.

Teacher Preparation

- If you do not have access to skateboards and the associated safety equipment, ask for student volunteers to bring theirs to class the day of the *Investigate*. The first part of this *Investigate* should be done as a class demonstration with one or two students pushing off the wall while on skateboards. Two skateboard riders or two wheeled chairs will be necessary for the step that requires them to push on each other to observe the action-reaction phenomenon.
- When the student groups are using the spring scales to observe the equal and opposite forces, caution them not to pull so hard as to exceed the maximum reading on the scale. In addition, the students should not twist the scale in their hand while the scale is attached to the second student's hand because this will also twist the second student's hand.
- Have stacks of books or other support material available for the students to use to support the meter sticks for *Part B*.

Safety Requirements

- Using a wheeled chair will most likely be a safer alternative than using the skateboards; however, student interest and engagement is better with the skateboard, with little additional risk. If skateboards are used when the two students push off on each other, choose two students who are not too dissimilar in mass to prevent one student from accelerating too much, and possibly losing balance. All students on the skateboards should wear appropriate safety equipment, including helmets and knee and elbow pads. Make certain that the area the students will use while on the skateboards is clear of all obstructions.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

<table>
<tr><th>Learning Issue</th><th>Reference</th><th>Augmentation and Accommodations</th></tr>
<tr><td>Describing motion</td><td>Investigate
Part A</td><td>Augmentation
• Students with language issues struggle to describe qualitative features in a way that is meaningful. In small groups, ask students to brainstorm a list of words or phrases that describe motion. Compile the list and then ask students to complete Investigate, Part A.
• Encourage students to use diagrams or drawings to support their descriptions of motion.</td></tr>
<tr><td>Vocabulary

Scientific measurements</td><td>Investigate
Part B
Physics to Go
Question 2</td><td>Augmentation
• Students are asked to measure the deflection of the meter stick and record the values for comparison.
• Explain the meaning of deflection using the diagram in Investigate, Part B, Step 4.
• Model an appropriate way to measure the deflection. Put a taut string across the distance between the stack of books to mark the original position of the meter stick before any weights are placed on it. This will give students a consistent reference point to measure from.
• Measuring from the surface of the table or floor to the lowest position of the meter stick may be easier for some students. Then they can calculate the deflection by subtracting the deflected position of the meter stick from its original position.</td></tr>
<tr><td>Reading comprehension

Understanding key concepts</td><td>Physics Talk</td><td>Augmentation
• Students often do not complete longer reading assignments and may miss important information in this section if they do not read the entire section. Break the reading into smaller chunks using some of the following ideas.
• Ask students to draw diagrams or sketches to represent each of the four bulleted examples near the beginning of this section.
• Provide direct instruction on how to draw free-body diagrams. Ask students to write a procedure, in their own words, that could be used to teach new students how to draw free-body diagrams.
• Provide opportunities for guided practice to draw free-body diagrams and identify equal and opposite forces.
• Ask students to summarize Newton's third law and most of the content in Physics Talk in a bulleted format.</td></tr>
</table>

Strategies for Students with Limited English-Language Proficiency

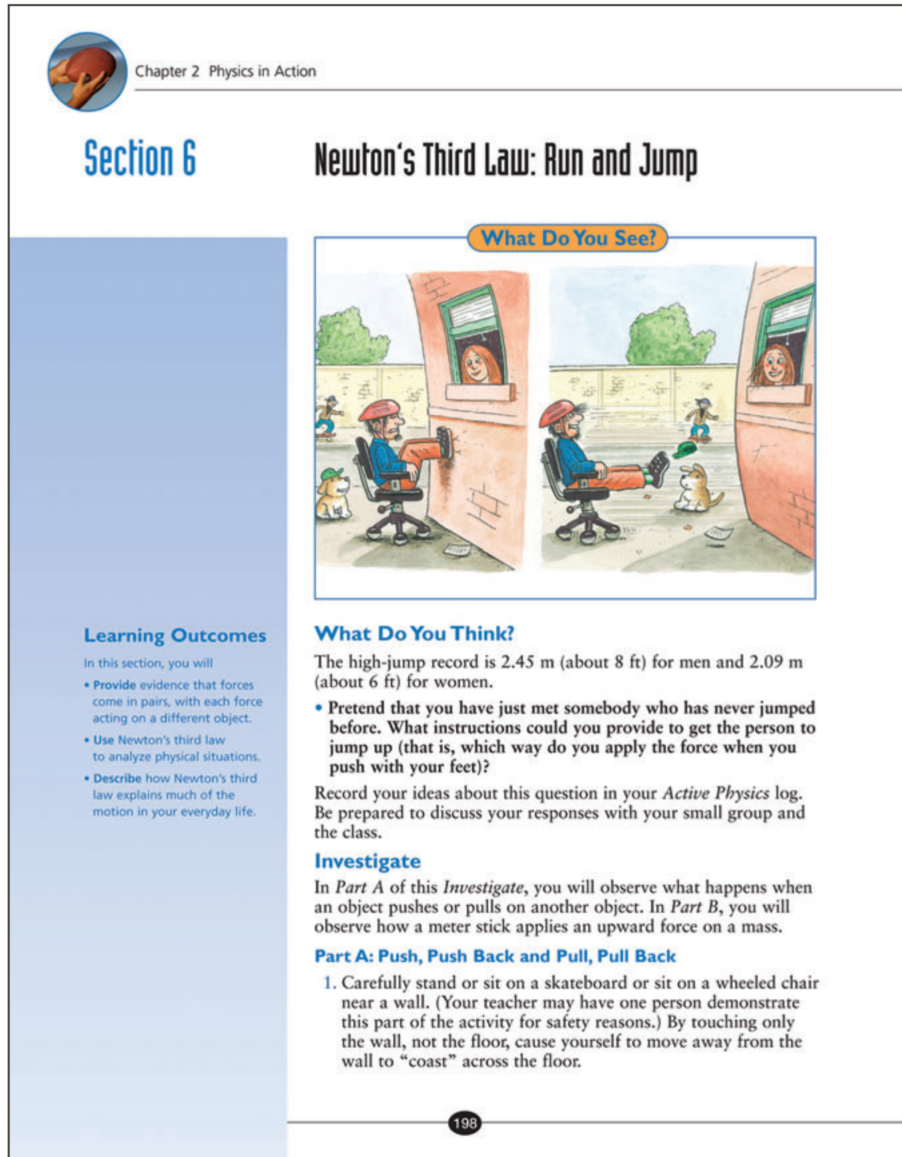
Learning Issue	Reference	Augmentation
Following complex procedures	***Investigate***	Break down the *Investigate* into smaller chunks that allow students to comprehend each portion of the activity before moving on to the next one. This approach will allow students to get comfortable following the procedures outlined within each step, and to internalize new concepts and any new vocabulary that is introduced. Lead a brief class discussion after each step to allow students the opportunity to demonstrate acquired knowledge and understanding of vocabulary, instructions, and concepts.
Comprehension	***Investigate*** Part A Steps 3.a) and 3.b)	Once students have finished answering the questions in their *Active Physics* log, look through their work and discuss it with them to check for accurate representations and understanding of the forces involved in walking or running. Or you may wish to draw and label your own diagrams and project them on the overhead. Hold a class discussion about the diagrams and allow students time to make corrections to the drawings in their logs if necessary.
Vocabulary comprehension	***Investigate*** Part B Steps 1 and 4.a)	ELL students may not be familiar with the word "inanimate." Allow them sufficient time to read the paragraph and infer the meaning from context. Explain that "animate" means "alive" or "full of life." It may help to think of animals, which generally can control their movement, as opposed to plant life, which generally cannot. Have students classify objects in the room as animate or inanimate. Check their understanding before moving on. The word "deflection" will likely be unfamiliar to ELL students. The illustration will help put the term in context. However, before moving on, be sure students know that deflection means the amount an object has moved away from its normal, or resting, position.
Comprehension Cooperative learning	***Active Physics Plus***	Once students have finished drawing their free-body diagrams and answering the questions, have them work in pairs to interpret each other's diagrams. The phrase "force of tension" may be challenging for ELL students. Explain that "tension" comes from a Latin root word that means "to stretch." Have students brainstorm common usages of the words "tense" and "tension," for example tensing up their muscles, or tightening a violin string. Clarify that tension is a force that can vary—the force of tension will increase as more force is applied to the string, up to the point at which the string can stretch no more and breaks.

SECTION 6

Teaching Suggestions and Sample Answers

What Do You See?

This illustration captures the viewer's attention on many levels. Draw students' attention to the changing facial expressions of the two persons in the illustration. Guide their intuitive interest from a general observation to the more specific purpose of the topic by asking questions related to the person pushing on the wall. Why does the boy appear to be so disgruntled in one visual but so cheerful in the other? Why is the girl so disinterested before but so happy later? How did the boy push back? These are some questions among others that should lead to an engaging discussion. You might want to bring in earlier discussions on force and motion.



Chapter 2 Physics in Action

Section 6 Newton's Third Law: Run and Jump

What Do You See?

Learning Outcomes

In this section, you will

- **Provide** evidence that forces come in pairs, with each force acting on a different object.
- **Use** Newton's third law to analyze physical situations.
- **Describe** how Newton's third law explains much of the motion in your everyday life.

What Do You Think?

The high-jump record is 2.45 m (about 8 ft) for men and 2.09 m (about 6 ft) for women.

- **Pretend that you have just met somebody who has never jumped before. What instructions could you provide to get the person to jump up (that is, which way do you apply the force when you push with your feet)?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

In *Part A* of this *Investigate*, you will observe what happens when an object pushes or pulls on another object. In *Part B*, you will observe how a meter stick applies an upward force on a mass.

Part A: Push, Push Back and Pull, Pull Back

1. Carefully stand or sit on a skateboard or sit on a wheeled chair near a wall. (Your teacher may have one person demonstrate this part of the activity for safety reasons.) By touching only the wall, not the floor, cause yourself to move away from the wall to "coast" across the floor.

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Students' Prior Conceptions

This section provides evidence that forces come in pairs and that each force acts on a different object. It introduces Newton's third law, the action-reaction law, leading to student understanding of the motions of everyday life. The stage for the major conservation law, the conservation of momentum, builds.

1. **Students may continue to assign forces to animate objects only.** You could use this section to spiral learning and create ladders built upon previous activities in this chapter. This technique also works when encouraging students to align their thinking about subsequent preconceptions.

2. **Students may believe that a force implies motion. If there is a force there must be motion.** Teachers should emphasize that forces always occur in equal and opposite pairs; these equal and opposite pairs always act on different objects; inanimate objects can push back.

You are likely to get a few humorous responses from your students. This *What Do You See?* illustration prompts students to begin thinking about action reaction forces. Your task is to encourage them and at the same time draw responses that set the stage for Newton's third law. Use those responses to steer students toward the purpose of this section. Encourage them to notice the smaller images and suggest that other images also contribute to the overall effect of the artist's intent. Remind students that they will have a chance to revisit their ideas and recognize how their knowledge has progressed.

What Do You Think?

Students will have a difficult time coming up with good instructions. You may try "acting out" some instructions as a way of demonstrating that the instructions must be very precise. Accept all explanations and encourage students to write down their answers in their *Active Physics* log. Reassure them that at a later stage they will get the time to edit their responses, and that they should treat this activity as a means of improving what they might already know or are about to learn.

What Do You Think?

A Physicist's Response

To jump, I push downward on the floor. When I do, the floor pushes upward on me. My push on the floor bends or deflects it a little bit and this deflection springs back in the form of the upward force. If the floor were too weak to generate the 10-cm jump, then I could not jump that high because the floor would break instead. When I tried to push hard enough to jump the 10 cm, the floor would break if it were that weak.

Investigate

This investigation is best done as a teacher-led demonstration for safety reasons. Students will not easily accept that the wall exerts a force on them. At the right point in the section, you might ask a second student to "be the wall" by allowing the first student to push off his or her hands. The second student should quickly realize that if he or she does not push the first student, the first student does not accelerate.

NOTES

Part A

1.a)

Your motion is accelerated when you push away from the wall. The acceleration lasts for a short distance when you speed up from zero to your top speed, after which you move at a constant velocity, and then slow down. The direction of acceleration is away from the wall.

1.b)

Motion is at a constant speed just after the initial acceleration, when the force is no longer acting on you. If you neglected friction, you would keep moving until another force acted on you to slow you down or stop you. During this part of the section, encourage students to rely on their motion to determine the forces acting on them. This will help to put preconceived notions out of their minds as they think through the situation.

1.c)

The force is supplied by the wall. The force must be acting in the direction of acceleration, away from the wall.

1.d)

You push on the wall, in a direction toward the wall.

Use words and diagrams to record answers to the following questions in your log:

a) When is your motion accelerated? (Recall that acceleration is the change in velocity over time.) For what distance does the accelerated motion last? In what direction do you accelerate?

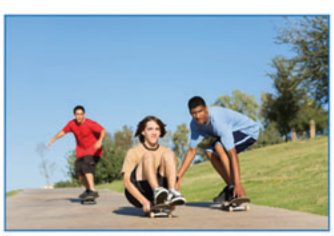
b) When is your motion at constant speed? If you ignore the effects of friction, how far should you travel? (Remember Galileo's principle of inertia and Newton's first law when answering this question.)

c) Newton's second law, $F = ma$, says that a force must be acting when acceleration occurs. What is the source of the force, the push or pull, that causes you to accelerate in this case? Identify the object that pushes on your mass (body plus skateboard) to cause the acceleration. Also identify the direction of the push that causes you to accelerate.

d) Obviously, you do some pushing, too. On what object do you push? In what direction?

e) How do you think, on the basis of both amount and direction, the following two forces compare?

- The force exerted by you on the wall.
- The force exerted by the wall on you.



2. Once again, as a class demonstration, two students can stand on skateboards. With extreme caution, the students should push on each other's palms.

a) Describe the motion of student A.

b) What force caused the motion of student A?

c) Describe the motion of student B.

d) What force caused the motion of student B?

3. Do a "thought experiment" about the forces involved when you are running or walking on a horizontal surface. Use words and sketches to answer the following questions in your log:

a) Since you move forward, not backward, there must be a force in the forward direction that causes you to accelerate. Identify where the forward force comes from, and compare its amount and direction to the backward force exerted by your shoe with each step.

b) Would it be possible to start walking or running on an extremely slippery surface (like an ice-skating rink) when wearing ordinary shoes? Discuss why or why not in terms of forces.

4. You and a member of your group will now see if you can apply unequal forces on each other. Clip two spring scales together. Each of you will pull on one scale. Try to pull so that one of you pulls with twice the force of the other. Do not pull on the scales so hard that they read a measurement above the highest value. You will have applied unequal forces if you can make one scale read twice the value of the other scale.

a) Record your results in your log.

b) In a diagram, draw the force exerted by you on your partner and the force exerted by your partner on you.

Teaching Tip

If two large spring scales or bathroom scales are available, two students can push on the bathroom scales back-to-back so the reading on each can be seen by the class. The students will be able to clearly see that the two readings are equal.

1.e)

Although the two forces are equal but opposite in direction, the students may not come to this conclusion at this point.

2.a)

Student A accelerates from student B while the push is taking place.

2.b)

The force of student B on student A made student A accelerate.

2.c)

Student B accelerates away from student A while the push is taking place.

2.d)

The force of student A on student B

3.a)

You push your foot on the ground backward from yourself. How strongly you can push your foot parallel to the surface of the sidewalk depends on how much frictional force exists between the sole of the shoe and the sidewalk's surface. If the shoe does not slip on the surface, then the sidewalk surface reacts with an equal and opposite force that causes your body to accelerate forward.

3.b)

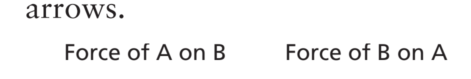
On the slippery ice surface, the force of friction is greatly reduced. You are unable to apply much of a backward force on the ice surface because your shoe will slide on the surface. In turn, the opposite force of the sidewalk will also be minimal with the result that you accelerate by such a small amount that it is not noticeable. There is no significant force to push you forward.

4.a)

The students will find that the readings on the two scales are always equal.

4.b)

Students drawing should appear as below with equal length arrows.



CHAPTER 2

Part B

The weights specified in this section work with a meter stick of a certain stiffness. Be prepared to adjust the weights used by the students in order for them to work well with the meter sticks being used.

1.

Students read about free-body diagrams.

Teaching Tip

If the students are having trouble identifying the forces that act on a body (the free-body diagram), have them draw a circle around the object for which they are trying to identify the forces. Anything that touches the circle is a source of force. The only other forces that can act on the object are forces like gravity that do not need to touch objects to exert a force. This will allow the students to identify more forces more easily.

2.

Students set up the meter stick with a coin or washer in the center.

3.a)

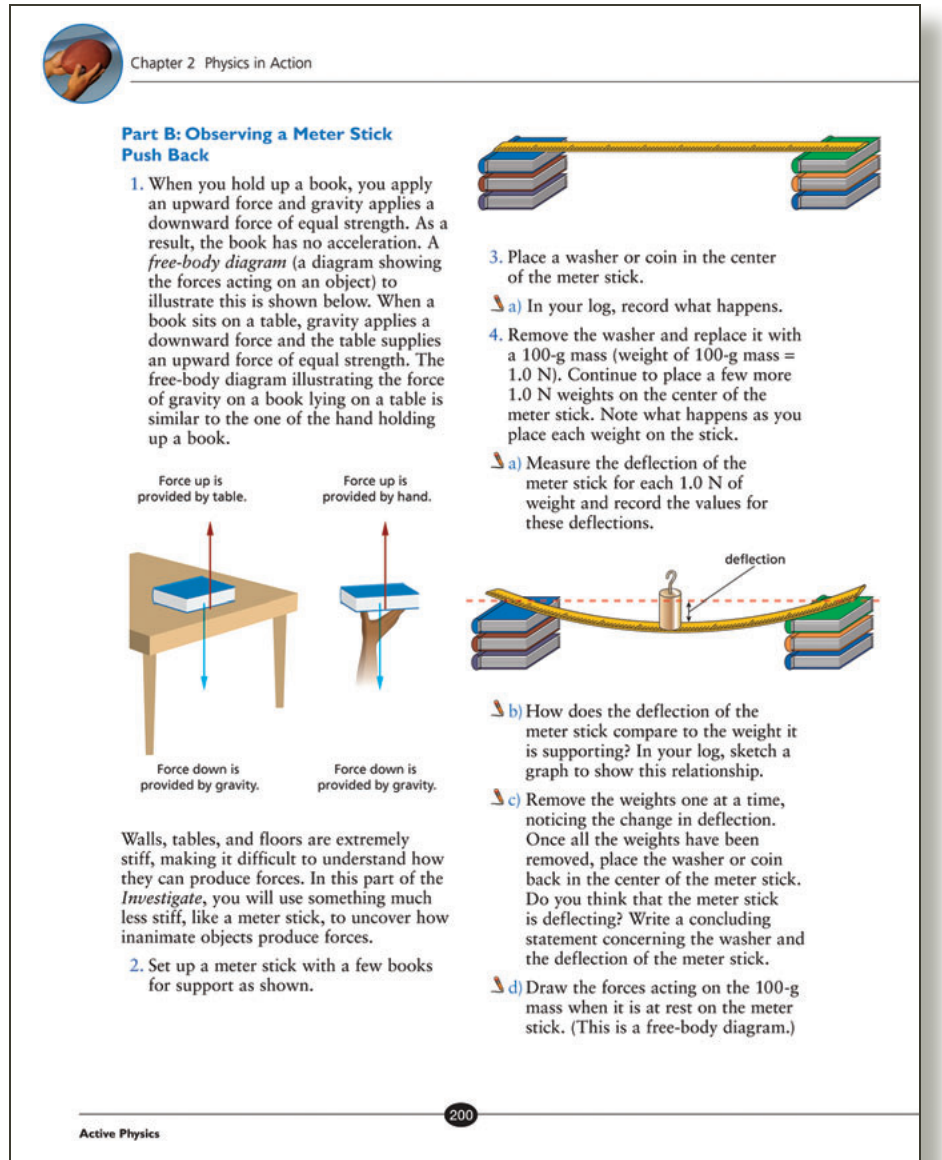
Nothing happens, or else the meter stick bends very slightly to produce a force equal to the weight of the object.

4.a)

The more weight that is added to the meter stick, the greater the deflection of the stick.

4.b)

As the meter stick is deflected, the restoring forces in the wood build up until they exert an upward force equal to the downward force of the weight. A graph



Chapter 2 Physics in Action

Part B: Observing a Meter Stick Push Back

1. When you hold up a book, you apply an upward force and gravity applies a downward force of equal strength. As a result, the book has no acceleration. A *free-body diagram* (a diagram showing the forces acting on an object) to illustrate this is shown below. When a book sits on a table, gravity applies a downward force and the table supplies an upward force of equal strength. The free-body diagram illustrating the force of gravity on a book lying on a table is similar to the one of the hand holding up a book.

Walls, tables, and floors are extremely stiff, making it difficult to understand how they can produce forces. In this part of the *Investigate*, you will use something much less stiff, like a meter stick, to uncover how inanimate objects produce forces.

2. Set up a meter stick with a few books for support as shown.

3. Place a washer or coin in the center of the meter stick.

a) In your log, record what happens.

4. Remove the washer and replace it with a 100-g mass (weight of 100-g mass = 1.0 N). Continue to place a few more 1.0 N weights on the center of the meter stick. Note what happens as you place each weight on the stick.

a) Measure the deflection of the meter stick for each 1.0 N of weight and record the values for these deflections.

b) How does the deflection of the meter stick compare to the weight it is supporting? In your log, sketch a graph to show this relationship.

c) Remove the weights one at a time, noticing the change in deflection. Once all the weights have been removed, place the washer or coin back in the center of the meter stick. Do you think that the meter stick is deflecting? Write a concluding statement concerning the washer and the deflection of the meter stick.

d) Draw the forces acting on the 100-g mass when it is at rest on the meter stick. (This is a free-body diagram.)

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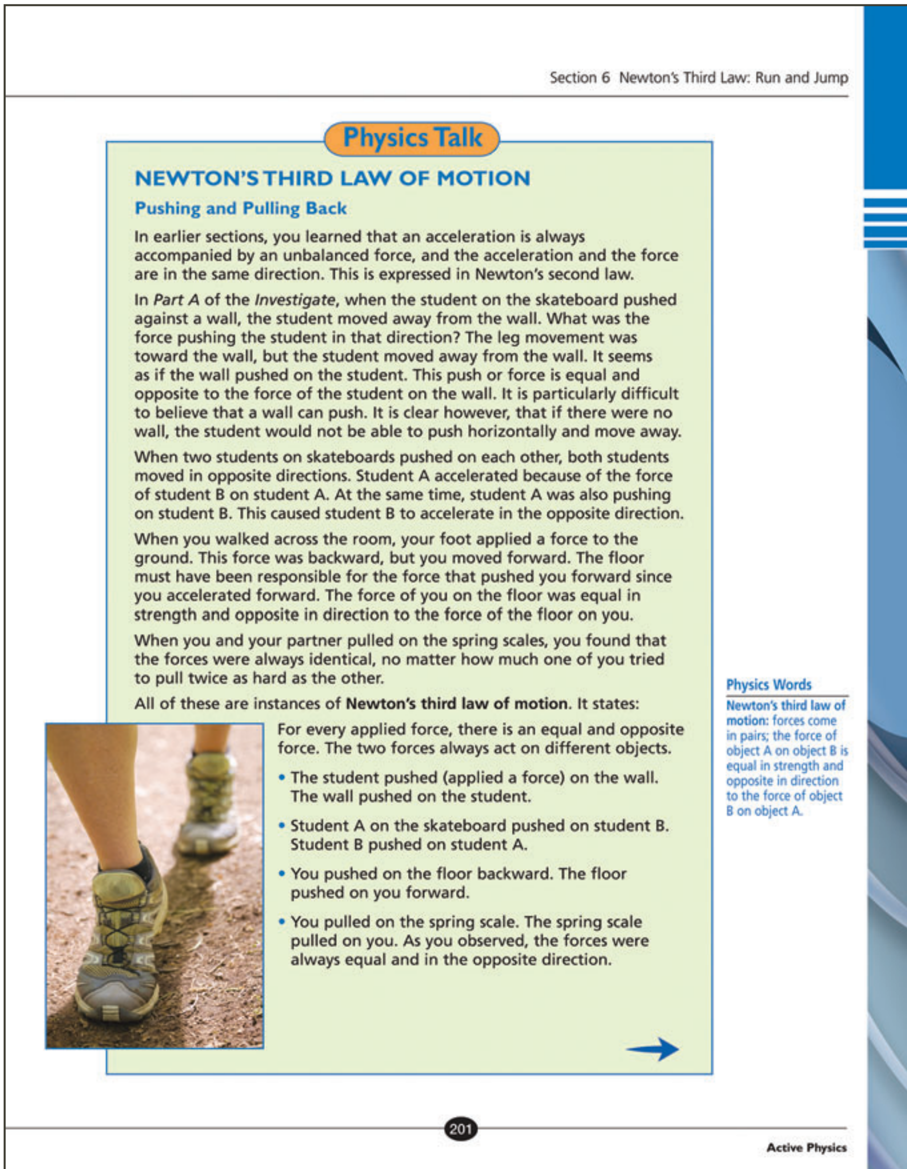
of the deflection vs. the weight added would look something like the one shown on the next page. Ask the students to consider many situations in which an object deflects and produces a force equal and opposite to the one causing the deflection. A chair does this when they sit on it, a floor does this when they are standing, the layer of ice does this when they are skating on a pond, etc. Encourage them to consider slight variations of this, but with the same basic principles. When they hang on a rope, it stretches in order to produce an upward force equal and opposite to their weight. Bungee cords are no different from ropes; they just have to stretch a much larger distance to generate the same force as a rope.


Section 6 Newton's Third Law: Run and Jump

Physics Talk

NEWTON'S THIRD LAW OF MOTION

Pushing and Pulling Back

In earlier sections, you learned that an acceleration is always accompanied by an unbalanced force, and the acceleration and the force are in the same direction. This is expressed in Newton's second law.

In *Part A* of the *Investigate*, when the student on the skateboard pushed against a wall, the student moved away from the wall. What was the force pushing the student in that direction? The leg movement was toward the wall, but the student moved away from the wall. It seems as if the wall pushed on the student. This push or force is equal and opposite to the force of the student on the wall. It is particularly difficult to believe that a wall can push. It is clear however, that if there were no wall, the student would not be able to push horizontally and move away.

When two students on skateboards pushed on each other, both students moved in opposite directions. Student A accelerated because of the force of student B on student A. At the same time, student A was also pushing on student B. This caused student B to accelerate in the opposite direction.

When you walked across the room, your foot applied a force to the ground. This force was backward, but you moved forward. The floor must have been responsible for the force that pushed you forward since you accelerated forward. The force of you on the floor was equal in strength and opposite in direction to the force of the floor on you.

When you and your partner pulled on the spring scales, you found that the forces were always identical, no matter how much one of you tried to pull twice as hard as the other.

All of these are instances of **Newton's third law of motion**. It states:

For every applied force, there is an equal and opposite force. The two forces always act on different objects.

- The student pushed (applied a force) on the wall. The wall pushed on the student.
- Student A on the skateboard pushed on student B. Student B pushed on student A.
- You pushed on the floor backward. The floor pushed on you forward.
- You pulled on the spring scale. The spring scale pulled on you. As you observed, the forces were always equal and in the opposite direction.

Physics Words

Newton's third law of motion: forces come in pairs; the force of object A on object B is equal in strength and opposite in direction to the force of object B on object A.

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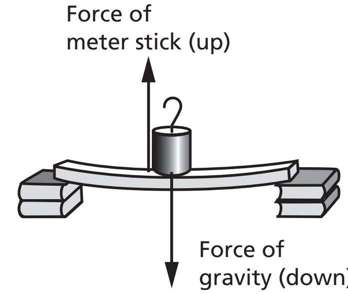

Physics Talk

Ask the students to read the *Physics Talk*, and then write down in their *Active Physics* logs what they have understood so far. Encourage students to draw free-body diagrams that explain Newton's third law. The idea that inanimate objects can push back might be a useful starting point for a discussion. Emphasize that forces always act in pairs, including why a mass cannot exert a force in one direction without being acted upon by an equal force in the opposite direction. Providing different opportunities for students to identify the different forces acting on an object will give them a visual reference, and enhance their understanding. Try to come up with examples of action-reaction pairs that are in different contexts to what is discussed in the *Physics Talk* to see if students revert to their prior conceptions. For example, in contrast to a person being accelerated by the floor while walking across, ask what force accelerates a car forward when the driver steps on the gas. Another possibility is to ask a student how the forces compare when a bug strikes the windshield of a car.

At this stage, you can ask students to explain each aspect of

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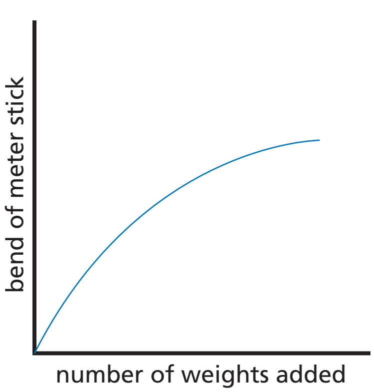


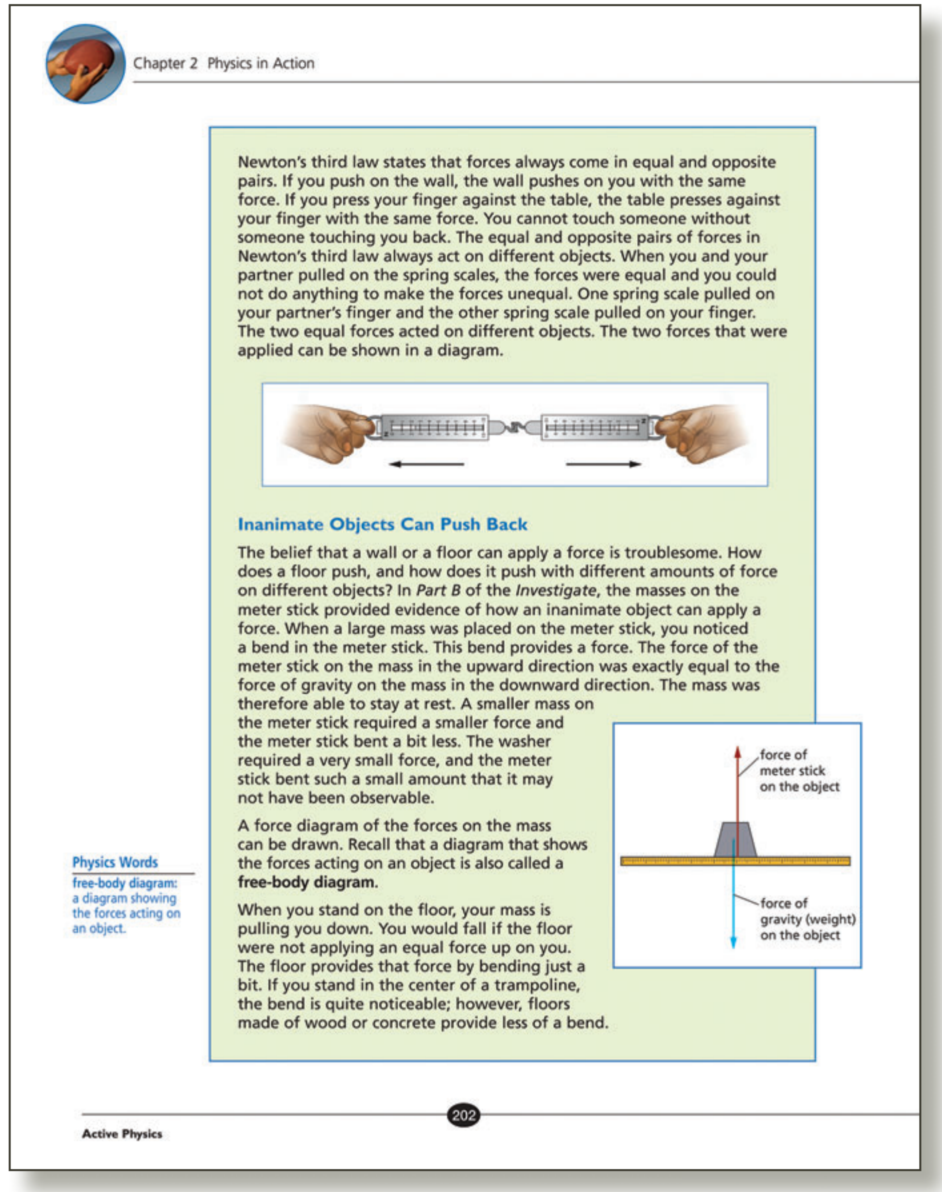
4.c)

The students should conclude that the meter stick deflects with the coin on it, but the deflection is too small to measure.

4.d)

The forces are its weight (0.98 N directed downward) and the force of the meter stick on the mass (also equal to 0.98 N) directed upward. The total or net force on the mass is zero.

Newton's third law and compare it with the previous two laws of motion. Have them illustrate their explanation through diagrams. Students may need some practice drawing free-body diagrams. Ask students to point out the steps of the *Investigate* that demonstrate Newton's third law. An important question to ponder would be why a bend in an inanimate object is produced when a force is applied to it. Review the concept of the normal force being provided by a surface. Point out that the normal force is always a reaction force, that it does not appear by itself, but only in response to another force being applied. Students should also understand the significance of the **center of mass**. As you bring your discussion of the *Physics Talk* to an end, discuss the term "reaction" from Newton's third law and its usage in the context of the law.



Newton's third law states that forces always come in equal and opposite pairs. If you push on the wall, the wall pushes on you with the same force. If you press your finger against the table, the table presses against your finger with the same force. You cannot touch someone without someone touching you back. The equal and opposite pairs of forces in Newton's third law always act on different objects. When you and your partner pulled on the spring scales, the forces were equal and you could not do anything to make the forces unequal. One spring scale pulled on your partner's finger and the other spring scale pulled on your finger. The two equal forces acted on different objects. The two forces that were applied can be shown in a diagram.

Inanimate Objects Can Push Back

The belief that a wall or a floor can apply a force is troublesome. How does a floor push, and how does it push with different amounts of force on different objects? In *Part B* of the *Investigate*, the masses on the meter stick provided evidence of how an inanimate object can apply a force. When a large mass was placed on the meter stick, you noticed a bend in the meter stick. This bend provides a force. The force of the meter stick on the mass in the upward direction was exactly equal to the force of gravity on the mass in the downward direction. The mass was therefore able to stay at rest. A smaller mass on the meter stick required a smaller force and the meter stick bent a bit less. The washer required a very small force, and the meter stick bent such a small amount that it may not have been observable.

A force diagram of the forces on the mass can be drawn. Recall that a diagram that shows the forces acting on an object is also called a **free-body diagram**.

When you stand on the floor, your mass is pulling you down. You would fall if the floor were not applying an equal force up on you. The floor provides that force by bending just a bit. If you stand in the center of a trampoline, the bend is quite noticeable; however, floors made of wood or concrete provide less of a bend.

Physics Words
free-body diagram: a diagram showing the forces acting on an object.

Section 6 Newton's Third Law: Run and Jump

How to Draw a Free-Body Diagram

A free-body diagram is a diagram used to show the relative strength and the direction of all the forces acting on an object in a given situation. In a free-body diagram, each force is represented by an arrow. The direction of the arrow is the direction of the force. The size of the arrow is the strength of the force. Each arrow is labeled to show the type of force acting. Often, the actual object is drawn as a box. The weight of the object can be represented by an arrow emerging from the **center of mass**. This is the point at which all the mass of an object is considered to be concentrated. The other forces can be represented by arrows emerging from the contact point (such as the table on the book).

Physics Words

center of mass: the point at which all the mass of an object is considered to be concentrated.

Identifying the Opposite and Equal Forces of Newton's Third Law

Do not confuse *Part A* with *Part B* of the *Investigate*. In *Part A*, you found evidence for Newton's third law, which states that forces always come in pairs. These forces always act on different objects. You pushed on the wall and the wall pushed on you. Your weight applied a force to the floor and the floor pushed up on you. You pulled your partner's finger with the spring scale and your partner pulled your finger with the spring scale.

In *Part B*, you found evidence that an inanimate object can apply a force by bending. When the 100-g mass did not move as it rested on the meter stick, you drew two forces acting on the mass. The force of gravity pulled down on the mass. The meter stick pushed up with an equal force on the mass. These two forces are not the equal and opposite forces of Newton's third law. They are two forces on the same object, not equal and opposite forces acting on different objects.

You can combine your knowledge from *Parts A* and *B* of the *Investigate* to get the full picture. When the mass sits on the meter stick, there are two pairs of forces.

First pair of forces of Newton's third law: The meter stick pushes up on the mass and the mass pushes down on the meter stick. (Do not worry about the force on the meter stick here.)

Second pair of forces of Newton's third law: Earth pulls down on the mass with a force of gravity and the mass pulls up on Earth with an equal force of gravity. (Do not worry about the force on Earth here.)

In this situation, the focus is only on the mass. The two forces on the mass are the force of gravity pulling downward, and the force of the meter stick pushing upward. Each of these has an equal and opposite force on a different object and that is not a concern because attention is restricted only to the mass.

CHAPTER 2

Drawing Free-Body Diagrams

When you drew the force diagram (free-body diagram) of the forces on the mass, you only showed the forces on the mass and you did not show the force on the meter stick or the force on Earth.

When you drew the forces on the 100-g mass resting on the meter stick, you drew them from a point located in the center of the 100-g mass. The force of gravity acts on every little part that makes up the 100-g mass, and if you add all these forces on different parts together, it equals the weight of the 100-g mass (Weight = mg = (100 g)(10 m/s^2) = 1.0 N). So instead of many forces on different parts of the 100-g mass, you can consider a single force equal to the weight acting on the 100-g mass. But on what part of the 100-g mass should this single force act? The proper point is called the center of mass of the 100-g mass.

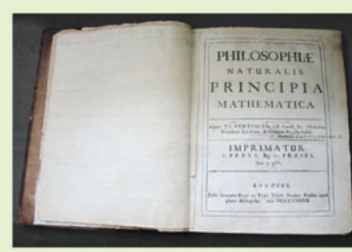
How Newton Described the Third Law of Motion

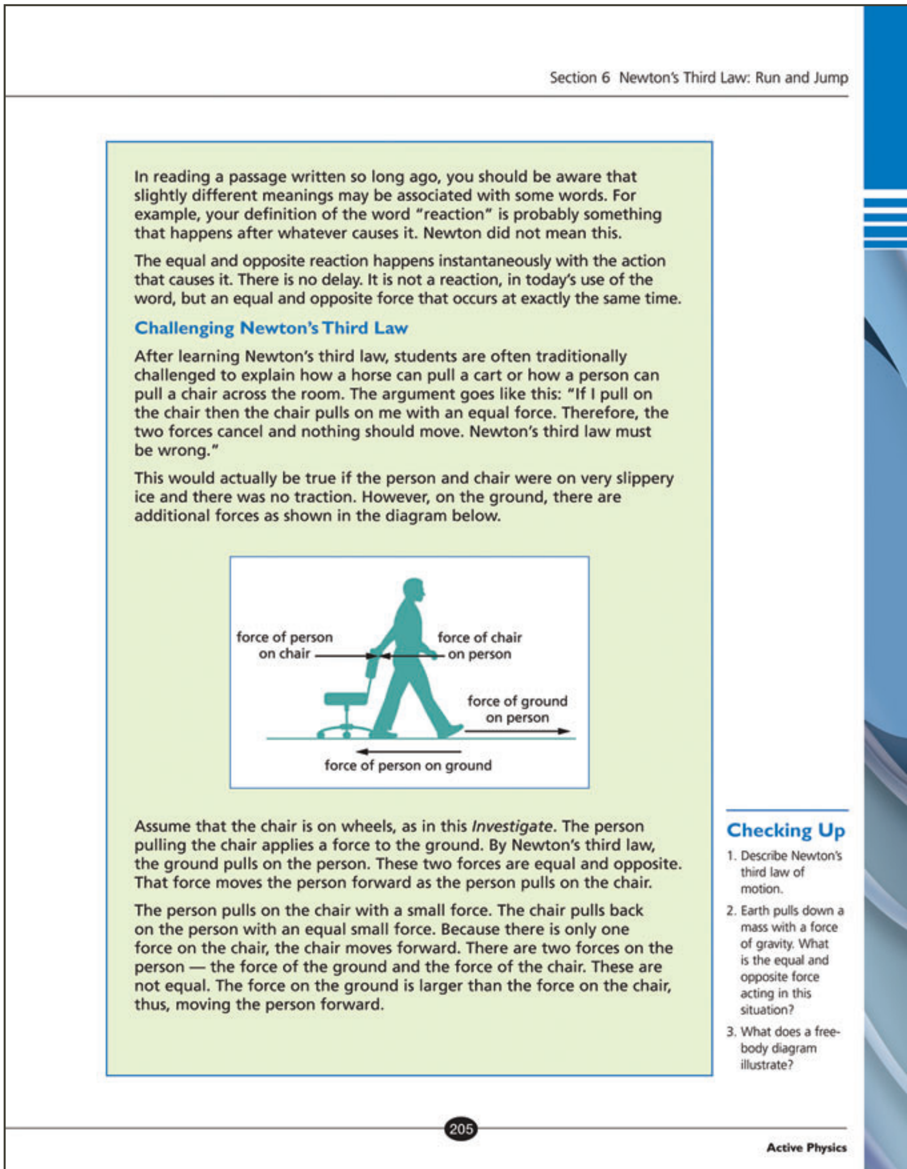
Newton's third law of motion can be stated in three equivalent ways:

- For every force applied to object A by another object B, there is an equal and opposite force applied to object B by object A.
- If you push or pull on something, that something pushes or pulls back on you with an equal amount of force in the opposite direction. This is an inescapable fact — it happens every time.
- Forces always come in pairs.

In one of the most important science books of all time, *Principia*, Isaac Newton wrote his third law of motion. It is interesting both historically and in terms of understanding physics to read Newton's third law in his own words:

"To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."





In reading a passage written so long ago, you should be aware that slightly different meanings may be associated with some words. For example, your definition of the word "reaction" is probably something that happens after whatever causes it. Newton did not mean this.

The equal and opposite reaction happens instantaneously with the action that causes it. There is no delay. It is not a reaction, in today's use of the word, but an equal and opposite force that occurs at exactly the same time.

Challenging Newton's Third Law

After learning Newton's third law, students are often traditionally challenged to explain how a horse can pull a cart or how a person can pull a chair across the room. The argument goes like this: "If I pull on the chair then the chair pulls on me with an equal force. Therefore, the two forces cancel and nothing should move. Newton's third law must be wrong."

This would actually be true if the person and chair were on very slippery ice and there was no traction. However, on the ground, there are additional forces as shown in the diagram below.

Assume that the chair is on wheels, as in this *Investigate*. The person pulling the chair applies a force to the ground. By Newton's third law, the ground pulls on the person. These two forces are equal and opposite. That force moves the person forward as the person pulls on the chair.

The person pulls on the chair with a small force. The chair pulls back on the person with an equal small force. Because there is only one force on the chair, the chair moves forward. There are two forces on the person — the force of the ground and the force of the chair. These are not equal. The force on the ground is larger than the force on the chair, thus, moving the person forward.

Checking Up

1. Describe Newton's third law of motion.
2. Earth pulls down a mass with a force of gravity. What is the equal and opposite force acting in this situation?
3. What does a free-body diagram illustrate?

Checking Up

1.

Newton's third law of motion says that every action has an equal and opposite reaction. If you push or pull on something you will experience the same push or pull in the opposite direction.

2.

The mass pulls up on Earth with a force that equals the gravitational pull.

3.

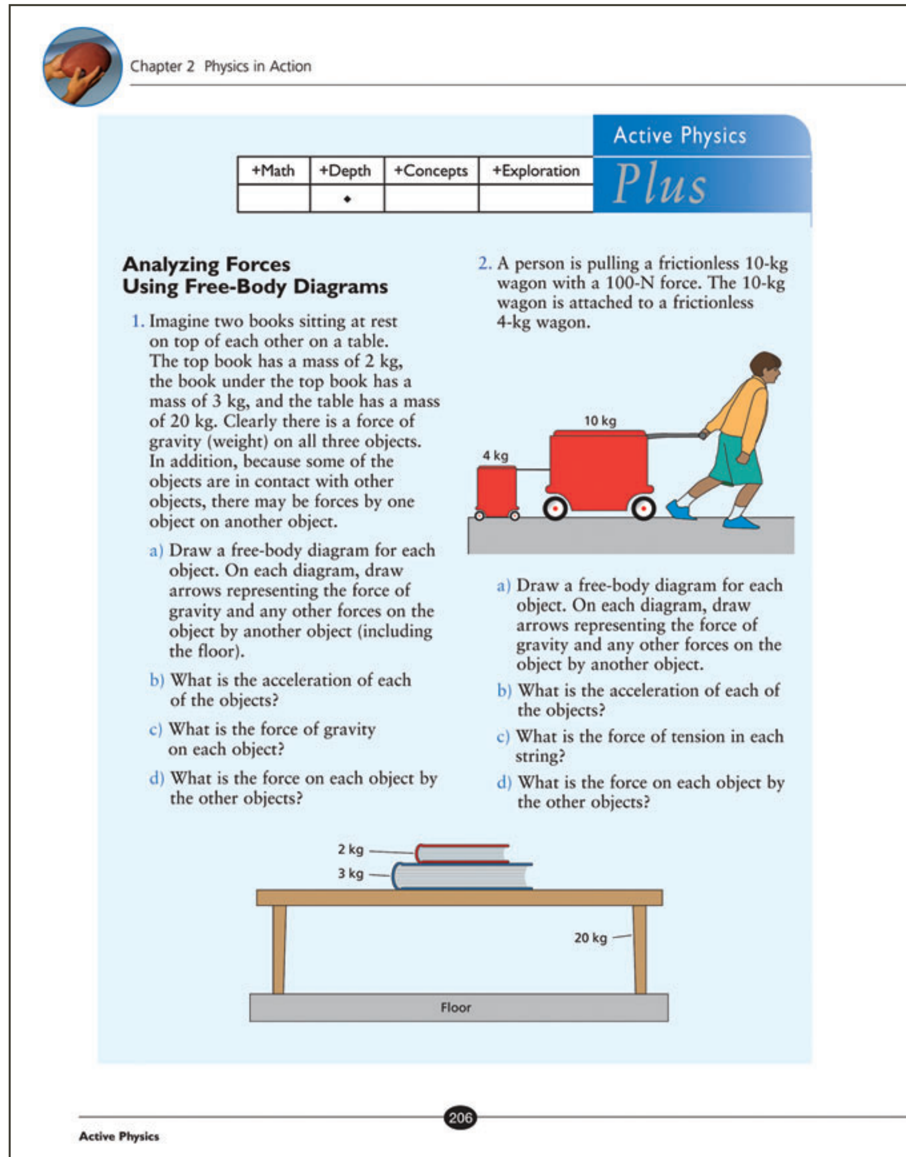
A free-body diagram illustrates the direction of all the forces acting on an object in a given situation.

2-6a **Blackline Master**

CHAPTER 2

Active Physics Plus

This section gives students the chance to explore Newton's third law in more depth, and also provides an opportunity for the teacher to have students explain problems by drawing diagrams. Developing the *Active Physics Plus* as an interactive tool by having students work in groups will help the entire class to understand how forces work.



Chapter 2 Physics in Action

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
	•		

Analyzing Forces Using Free-Body Diagrams

1. Imagine two books sitting at rest on top of each other on a table. The top book has a mass of 2 kg, the book under the top book has a mass of 3 kg, and the table has a mass of 20 kg. Clearly there is a force of gravity (weight) on all three objects. In addition, because some of the objects are in contact with other objects, there may be forces by one object on another object.
   a) Draw a free-body diagram for each object. On each diagram, draw arrows representing the force of gravity and any other forces on the object by another object (including the floor).
   b) What is the acceleration of each of the objects?
   c) What is the force of gravity on each object?
   d) What is the force on each object by the other objects?

2. A person is pulling a frictionless 10-kg wagon with a 100-N force. The 10-kg wagon is attached to a frictionless 4-kg wagon.

   a) Draw a free-body diagram for each object. On each diagram, draw arrows representing the force of gravity and any other forces on the object by another object.
   b) What is the acceleration of each of the objects?
   c) What is the force of tension in each string?
   d) What is the force on each object by the other objects?

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Active Physics

1.a)

The 2-kg book has two forces on it: its weight downward and the force from the 3-kg book upward. The 3-kg book has three forces on it: its weight downward, the force from the 2-kg book downward, and the force from the 20-kg table upward. The table has three forces on it: its weight downward, the force from the 3-kg book downward, and the force from the floor upward.

1.b)

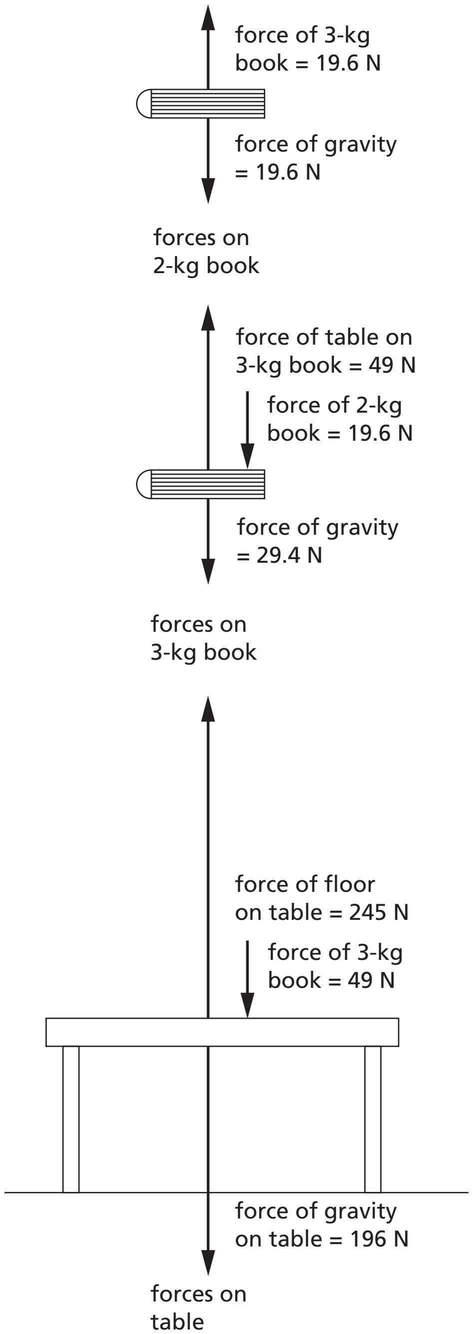
All three objects are stationary, so the acceleration of each is zero.

1.c)

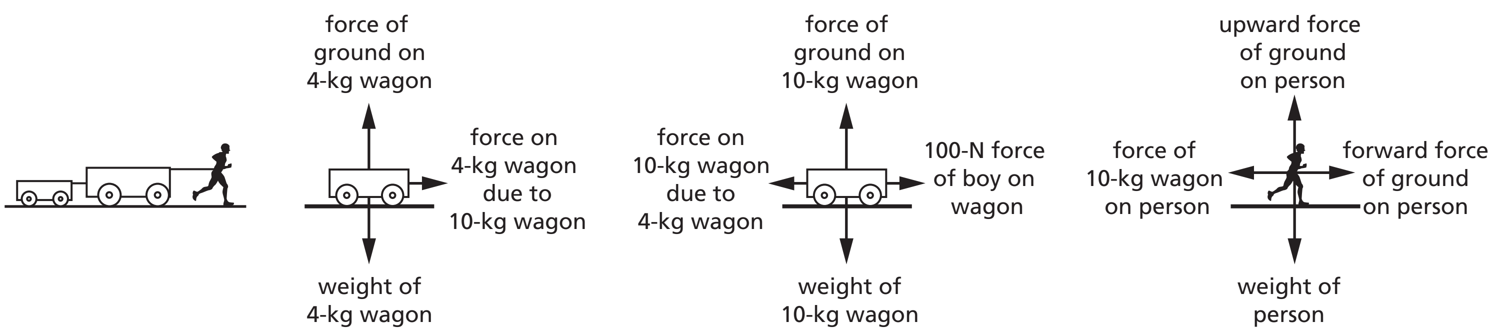
The force of gravity on the 2-kg book is 19.6 N, on the 3-kg book is 29.4 N, and on the 20-kg table is 196 N.

1.d)

Because the total or net force on each object is zero (since its acceleration is zero), the force from the 3-kg book on the 2-kg mass must be 19.6 N upward. By Newton's third law, the 2-kg book must exert an equal and opposite force on the 3-kg book. Therefore the combination of its weight and the downward force from the 2-kg book is 29.4 N plus 19.6 N, or 49.0 N. Since the total or net force on the 3-kg book is zero, the upward force from the table on the 3-kg book must be 49.0 N. Again, the third law indicates that the 3-kg book exerts a downward force on the table of 49 N. This combined with its weight of 196 N means the floor must exert an upward force on the table of 49 N plus 196 N, or 245 N. Notice that it is easy to check this last answer. The total weight of the table and books is 25 kg multiplied by 9.8 m/s^2, or 245 N.



2.a)



2.b)

Using Newton's second law,

$\Sigma F = ma$

$100 \text{ N} = (14 \text{ kg})a$

$a = 7.1 \text{ m/s}^2$

All the objects will accelerate together at the same rate.

2.c)

To find the force on the 4-kg wagon, let the tension in the string pulling the 4-kg wagon be T_1.

$\Sigma F = ma$

$T_1 = (4 \text{ kg})(7.1 \text{ m/s}^2) = 28.4 \text{ N}$

The tension in the string pulling the 10-kg wagon is 100 N.

2.d)

The force on the 4-kg cart by the 10-kg cart is 28.4 N, and the force on the 10-kg cart by the 4-kg cart is also 28.4 N (equal and opposite forces). The force on the 10-kg cart by the person pulling is 100 N, and the 10-kg cart pulls back on the person with a force of 100 N, making the net force on the 10-kg cart 71.6 N (so it may accelerate at 7.1 m/s^2). The force on the person by the ground will depend upon the person's mass, but will be greater than 100 N (so the person can also accelerate at 7.1 m/s^2).

CHAPTER 2

NOTES

What Do You Think Now?

At the beginning of this section, you were asked the question

- **Pretend that you have just met somebody who has never jumped before. What instructions could you provide to get the person to jump up (that is, which way do you apply the force when you push with your feet)?**

When you jump, in what direction do you push on the floor? When you push on the floor, what direction does the floor push on you? What happens to the floor that results in an upward force on you? Use your investigations of Newton's third law to justify your answers.

Physics

Essential Questions

What does it mean?

In a video clip, a player catches a football. In another video clip, a soccer ball is caught by the goalie. Newton's third law states that there are equal and opposite forces in each video. Identify the forces of Newton's third law for each of these situations.

How do you know?

Two children pull on spring scales and neither child moves. What evidence do you have that the forces of the students are equal and opposite?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Force and motion	Models	* Experimental evidence is consistent with models and theories

* In relying on observation to come up with explanations, physics often includes ideas that do not seem plausible to someone who has not thought about it. Why do you believe that a table bends when you put a plate on it?

Why should you care?

In sports, forces are exerted by both animate and inanimate objects. In your sports voice-over, you will need to comment on one or both of these situations. Give an example from the sport you have selected in which a force is exerted by an inanimate object.

What Do You Think Now?

Now that students have investigated Newton's third law, they should be able come up with useful instructions. You might want to point out the role of acceleration and mass in determining the strength of a person's force and the direction in which it will act. Sharing the answer provided in *A Physicist's Response* would give you an opportunity to discuss the *What Do You Think Now?* question in more detail.

CHAPTER 2

Physics Essential Questions

What does it mean?

There is a force of the player on the football and a force of the football on the player. There is a force of the goalie on the soccer ball and a force of the soccer ball on the goalie.

How do you know?

The spring scales read the same value regardless of how each is pulled.

Why do you believe?

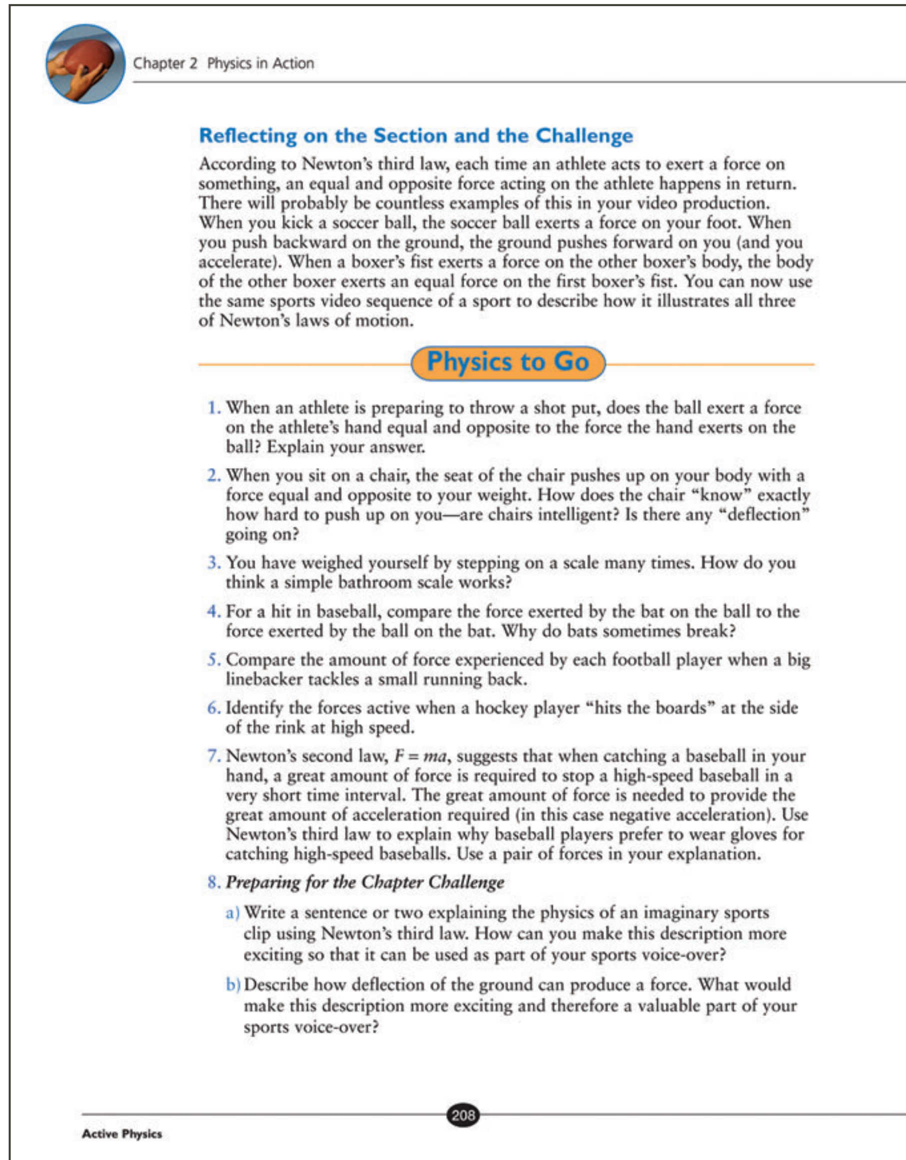
Because the gravitational force is pulling on the plate, there must be a force pushing upward on the plate. The table is the only thing in contact with the plate. The assumption is that the table bent a small amount to provide that force.

Why should you care?

When a basketball is dribbled, the ball hits the floor and bounces up. The floor must be providing a force to change the direction of the ball.

Reflecting on the Section and the Challenge

Reflecting on Newton's third law will challenge students to think of how they can connect their understanding of equal and opposite forces to the *Chapter Challenge*. You could point out to them how this section, in gradual steps, should have given them more confidence in describing a player's technique on a sports field. Have them read the examples in the *Reflection on the Section and Challenge* and draw a visual of one of these examples so they can review what they have learned, and think of the different ways they encounter Newton's third law.



Chapter 2 Physics in Action

Reflecting on the Section and the Challenge

According to Newton's third law, each time an athlete acts to exert a force on something, an equal and opposite force acting on the athlete happens in return. There will probably be countless examples of this in your video production. When you kick a soccer ball, the soccer ball exerts a force on your foot. When you push backward on the ground, the ground pushes forward on you (and you accelerate). When a boxer's fist exerts a force on the other boxer's body, the body of the other boxer exerts an equal force on the first boxer's fist. You can now use the same sports video sequence of a sport to describe how it illustrates all three of Newton's laws of motion.

Physics to Go

1. When an athlete is preparing to throw a shot put, does the ball exert a force on the athlete's hand equal and opposite to the force the hand exerts on the ball? Explain your answer.
2. When you sit on a chair, the seat of the chair pushes up on your body with a force equal and opposite to your weight. How does the chair "know" exactly how hard to push up on you—are chairs intelligent? Is there any "deflection" going on?
3. You have weighed yourself by stepping on a scale many times. How do you think a simple bathroom scale works?
4. For a hit in baseball, compare the force exerted by the bat on the ball to the force exerted by the ball on the bat. Why do bats sometimes break?
5. Compare the amount of force experienced by each football player when a big linebacker tackles a small running back.
6. Identify the forces active when a hockey player "hits the boards" at the side of the rink at high speed.
7. Newton's second law, $F = ma$, suggests that when catching a baseball in your hand, a great amount of force is required to stop a high-speed baseball in a very short time interval. The great amount of force is needed to provide the great amount of acceleration required (in this case negative acceleration). Use Newton's third law to explain why baseball players prefer to wear gloves for catching high-speed baseballs. Use a pair of forces in your explanation.
8. ***Preparing for the Chapter Challenge***
   a) Write a sentence or two explaining the physics of an imaginary sports clip using Newton's third law. How can you make this description more exciting so that it can be used as part of your sports voice-over?
   b) Describe how deflection of the ground can produce a force. What would make this description more exciting and therefore a valuable part of your sports voice-over?

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Active Physics

Physics to Go

1.

Yes, the forces are equal and opposite. The force of the shot put on the hand keeps the hand from accelerating much faster under the applied force.

2.

The restoring forces within the material making up the chair build up until the upward force exerted by the chair equals the downward force caused by your weight. If someone sits in your lap, the chair "bends" (or is otherwise deformed) more, resulting in a higher reaction force, equal and opposite to the combined weight. No intelligence is required by the chair, only the people who designed it.

3.

A spring system in the scale bends to produce the opposite force. A needle or a sensor is attached to that spring to indicate the amount of force needed to oppose the weight.

4.

The forces on the ball and the bat are equal and opposite; sometimes the force exerted by the ball on the bat is enough to break the wood of the bat.

5.

The forces on the players are equal and opposite, but the smaller player experiences a greater acceleration, which can have more harmful effects on the human body than a lesser acceleration.

6.

The forces are equal and opposite; the hockey player is more likely than the boards to complain about the pain involved.

7.

Gloves having padding which compresses and/or webbing which deforms when the ball hits the glove. The "softness" of a glove reduces the force which the glove exerts on the ball. This force is lower than the force that a stationary hand would need to exert to stop the ball. The lesser force causes the ball to decelerate at a lower rate, also reducing the force which the ball exerts on the glove during stopping. A sure way to reduce the forces during a collision is to increase the amount of time that the objects exert forces on each other during the collision; that is one reason why air bags reduce injuries in automobile collisions.

Preparing for the Chapter Challenge

8.a)

Student answers will vary, but each one should indicate that the force exerted on one object is equal and opposite to the force exerted on the other. In addition, the students should point out that although the forces are equal and opposite, they never act on the same body, and thus do not "cancel" each other.

8.b)

Student answers again will vary, but each should indicate that the deflection of the ground is similar to a compressing spring, which is how the force is provided.

NOTES

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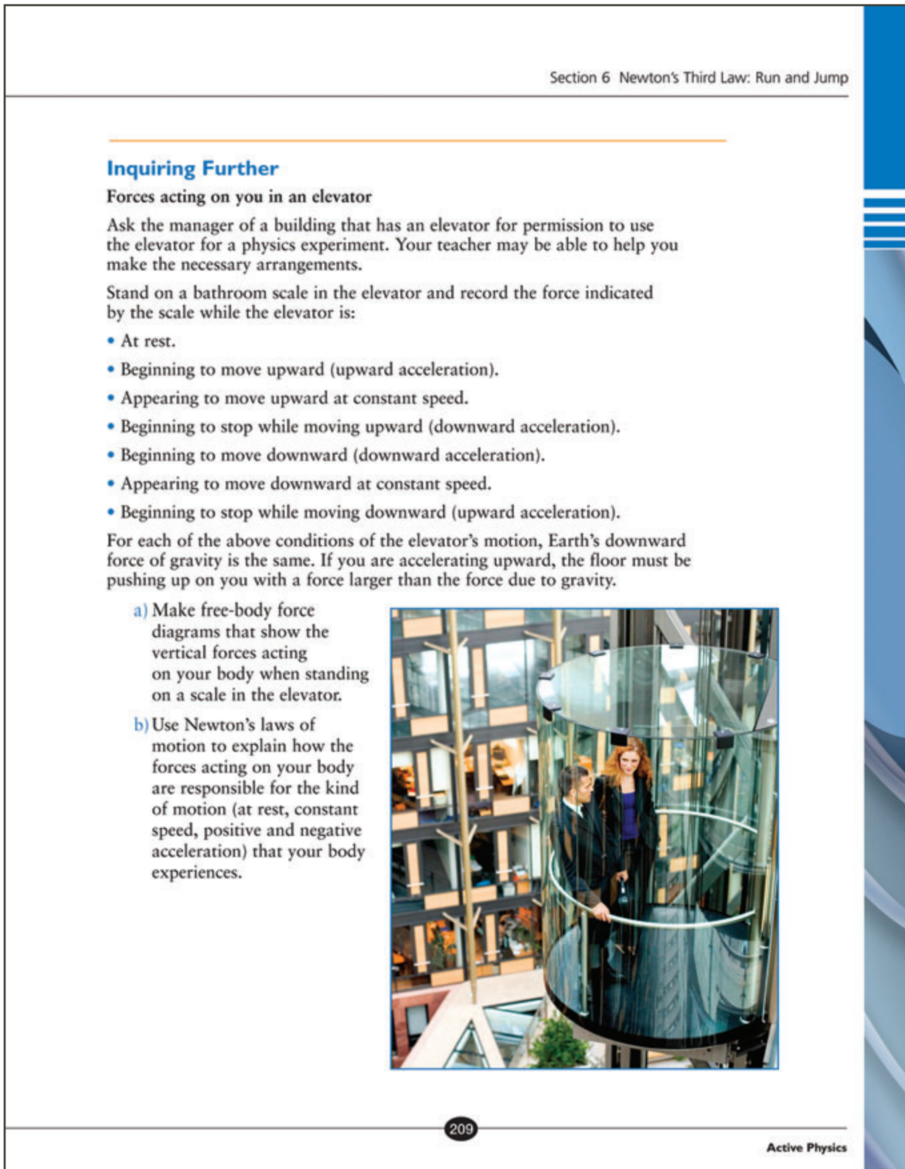

Section 6 Newton's Third Law: Run and Jump

Inquiring Further

Forces acting on you in an elevator

Ask the manager of a building that has an elevator for permission to use the elevator for a physics experiment. Your teacher may be able to help you make the necessary arrangements.

Stand on a bathroom scale in the elevator and record the force indicated by the scale while the elevator is:

- At rest.
- Beginning to move upward (upward acceleration).
- Appearing to move upward at constant speed.
- Beginning to stop while moving upward (downward acceleration).
- Beginning to move downward (downward acceleration).
- Appearing to move downward at constant speed.
- Beginning to stop while moving downward (upward acceleration).

For each of the above conditions of the elevator's motion, Earth's downward force of gravity is the same. If you are accelerating upward, the floor must be pushing up on you with a force larger than the force due to gravity.

a) Make free-body force diagrams that show the vertical forces acting on your body when standing on a scale in the elevator.

b) Use Newton's laws of motion to explain how the forces acting on your body are responsible for the kind of motion (at rest, constant speed, positive and negative acceleration) that your body experiences.

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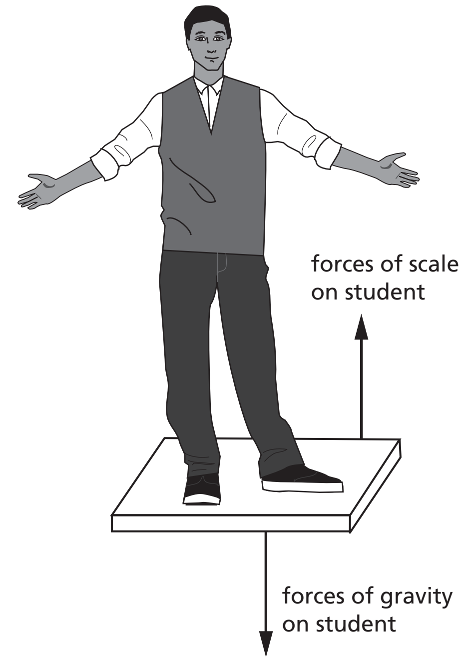
Active Physics



When the force of the scale on the student is equal to the force of gravity on the student (the student's weight), the forces are equal and opposite, and according to Newton's first law the student may either be at rest or traveling with constant velocity (either up or down).

When the force of the scale is greater than the student's weight, the student will be accelerating upward, either by having an increasing upward velocity or a decreasing downward velocity.

When the force of gravity is less than the student's weight, the student will be accelerating downward, either by increasing the downward velocity or decreasing the upward velocity.

Inquiring Further

The force reading on the scale is equal to the student's weight.

- The force is greater than the student's weight.
- The force is equal to the student's weight.
- The force is less than the student's weight.
- The force reading is less than the student's weight.
- The force is equal to the student's weight.
- The reading is more than the student's weight.

SECTION 6 QUIZ

2-6b **Blackline Master**

1. Which statement explains why a book resting on a table is in equilibrium?

   a) There is a net force acting downward on the book.

   b) The weight of the book equals the weight of the table.

   c) The acceleration due to gravity is 9.8 m/s^2 for both the book and the table.

   d) The weight of the book and the table's upward force on the book are equal in magnitude, but opposite in direction.

2. A book that is resting on a shelf 1.5 m above the floor has a weight of 12 N. The force the shelf exerts upon the book must be

   a) 8 N

   b) 12 N

   c) 18 N

   d) 24 N

3. While closing a door of mass 10 kg, a student pushes on it with a force of 25 N. As the door is accelerating to close, what force does the door exert on the student?

   a) 5 N

   b) 25 N

   c) 250 N

   d) 35 N

4. A man is attempting to push a chair across the floor with constant speed by exerting a force of 50 N. When will the chair exert a force of 50 N on the man?

   a) only if the man and the chair are at rest

   b) only if the man and the chair are accelerating

   c) only if the man and the chair are moving with constant velocity

   d) in all of the above cases

5. A man standing on a chair weighs 800 N. In order for the chair to support the man, the chair must exert an upward force of

   a) less than 800 N.

   b) 800 N.

   c) more than 800 N.

SECTION 6 QUIZ ANSWERS

1. d) The book is in equilibrium so there must be no net force acting on the book. The downward force of the book on the table due to its weight must be counterbalanced by the upward force of the table to result in zero net force on the book.

2. b) By Newton's third law, the force of the book on the shelf must be equal and opposite to the shelf's force on the book.

3. b) By Newton's third law, the forces must be equal and opposite. The fact that the door is accelerating only means that the force the person is exerting on the door will be difficult to maintain as the door moves away.

4. d) Newton's third law holds in all cases, regardless of motion or other factors.

5. b) The force must be exactly equal and opposite to the man's weight. If the force were greater than 800 N, the man would experience a net upward force and would accelerate upward.

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