SECTION 2

Newton's First Law of Motion: Life and Death before and after Seat Belts

Section Overview

Using a model consisting of a cart and a driver made of clay, students investigate what happens to the driver, with and without a seat belt, during collisions with various impact speeds. They also investigate the effect of different types of seat belts on the driver during a collision. Newton's first law is then discussed using student observations as evidence. Students read about three main collisions involving vehicles: the collision between a vehicle and another object, the collision between a person in a vehicle and an object in the vehicle that brings the person to rest, and the collision between organs inside the body and the body walls that bring the organs to rest. Connections are made between students' observations of different types of seat belts and the concept of pressure (force per unit area). Students apply this concept to solve various problems and engage in a discussion of how Newton's first law and the concept of pressure affect the design of safety features.

Background Information

Scientists see events that occur as interactions between two or more objects. To analyze and explain interactions, scientists use two main approaches: force and/or energy considerations. Force considerations involve vector quantities, and energy considerations involve scalar quantities. In this section, students use one-dimensional force considerations and focus on Newton's first law.

Newton's first law is helpful in describing and explaining why there are so many subsequent collisions that occur during a collision involving a vehicle and a passenger and why safety is so important. Collisions between a person and the object that stops him or her within a vehicle, as well as collisions between internal organs and the walls of the body, can cause severe injuries—including brain damage, aneurysms, broken bones, and damaged organs—or death.

Newton's first law is often called the law of inertia. It states that the motion of an object (whether moving or at rest) will not change unless there is a net external force exerted on the object.

Students are also introduced to the concept of pressure. Pressure, or force per unit area, is an important factor during a collision. When a force is spread out over a greater area (lower pressure), the overall force on any part is less. For example, think about someone standing on snow with snowshoes versus someone standing on snow in stilts. For equal masses, the stilts will sink through the snow whereas the snowshoes will stay on top because they decrease the force per unit area of pressure exerted on the snow.

Crucial Physics

- Newton's first law—an object remains at rest or in motion with constant velocity unless a net external force acts on it.
- The inertia of an object is proportional to its mass.
- Pressure is the amount of force acting perpendicular to a surface on an object divided by the cross-sectional area that it acts on.

Learning Outcomes	Location in the Section	Evidence of Understanding
Explain Newton's first law of motion.	***Physics Talk*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1-4	Students discuss Newton's first law and describe the three parts of it. Students use Newton's first law to explain their observations in the *Investigate* and why a passenger keeps moving when a vehicle suddenly stops.
Describe the role of seat belts.	***Investigate*** Part B Step 3.b) ***Physics Talk*** ***Reflecting on the Section and the Challenge***	Students observe how seat belts affect the outcome of a clay passenger during a collision. Using their observations, students describe the role of seat belts during collisions.
Identify the three collisions in every accident.	***Physics Talk*** ***Physics to Go*** Questions 4, 8	Students identify and describe the three types of collisions that occur during an accident, and identify possible consequences of these collisions.
Compare the effectiveness of various wide and narrow seat belts.	***Investigate*** Part B: Step 3 ***Reflecting on the Section and the Challenge*** ***Physics to Go*** Question 5	Students observe and describe how the effectiveness of seat belts varies with the width of the seat belt. Students' observations are later used to support the concept of pressure.
Express the relationship between pressure, force, and area.	***Physics Talk*** ***What Do You Think Now?*** ***Physics to Go*** Questions 5, 9	Students describe the relationship between pressure, force, and area and provide supporting examples based on their observations. Students apply the relationship between force, area, and pressure to solve problems.

Section 2 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Multimedia DVD/CD Set		1 per class
Ribbon, 12 in. (length), varying widths	3 per group	
Wire, #22, bare copper, ft	1 per group	
Dynamics cart	2 per group	
Clay, modeling, lb	2 per group	
Inclined plane for lab cart	1 per group	
Large ring stand	1 per group	
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as cross arm)	1 per group	
Holder, right angle, cast iron	1 per group	
Scissors	1 per group	
File folders	3 per group	
Tape, masking		6 per group
Concrete block or similar barrier (wall)*		1 per class

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Multimedia DVD/CD Set		1 per class
Ribbon, 12 in. (length), varying widths	3 per group	
Wire, #22, bare copper, ft	1 per group	
Dynamics cart	1 per group	
Clay, modeling, lb	2 per group	
Inclined plane for lab cart	1 per group	
Large ring stand	1 per group	
Holder, right angle, cast iron	1 per group	
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as cross arm)	1 per group	
Scissors	1 per group	
File folders	3 per group	
Tape, masking		6 per group
Concrete block or similar barrier (wall)*		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 Requirement

This *Investigate* should take at least one class period (40–50 min). Allow extra time for variations of the seat belts on the molded clay figures.

Teacher Preparation

- This investigation requires students to crash a loaded cart into a wall, or other suitable barrier. Test out different barriers (walls, desks, bricks, homemade structures) prior to laboratory day.
- If the students will be making measurements on the floor, inform the students the day prior to the investigation so they may wear appropriate clothing.
- Students may either perform this investigation on large lab tables or on the floor. Doing the investigation on the floor is preferable to prevent the dynamics carts from rolling off the tables. In addition, walls may be used as stopping devices for the dynamics carts.
- When the dynamics carts leave the ramp and travel onto the horizontal surface, a transition surface such as a manila file folder taped to the ramp and the floor or table will smooth the transition.

Safety Requirements

- Plastic dynamics carts may be damaged during the collision and are not recommended for this investigation.
- During the collisions, students should wear goggles, particularly if plastic dynamics carts are used.
- If the investigation is done on lab tables, special care should be taken so that the heavy barrier does not fall off the table.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Describing the effects of a collision on a passenger	***Investigate*** Part A: Steps 2-3 ***Investigate*** Part B: Step 3	**Augmentation** • Students will probably enjoy crashing their automobiles and passengers into the wall, but they may struggle to describe the effects of these collisions. Giving two minutes, ask students to individually write a list of possible descriptors for injuries sustained in a collision. Then ask students to share their ideas with the whole group and create a comprehensive list of descriptors. **Accommodation** • Students who struggle with spelling often do not write down their thoughts for fear of appearing ignorant. Provide these students with a typed list of descriptors that they can use to complete this section.
Determining significant injury	***Investigate*** Part B: Step 2	**Augmentation** • Some students are very literal learners and may not be able to decide what a "significant injury" means. After the class compiles the list in the above augmentation, ask students to decide which injuries are severe. Mark those injuries with a star or another symbol of your choice.
Reading comprehension Understanding essential concepts	***Physics Talk***	**Augmentation** • After this section of reading, students need to understand Newton's first law, the three collisions in an accident, and force per unit area. Students may struggle to extract all of this information from reading the *Physics Talk* section. • Provide direct instruction to teach these concepts. • Use the jigsaw strategy to allow students to teach these concepts to the class. Divide the class into three expert groups (A, B, and C). Give these groups a time limit (such as 20 minutes) to read the section on their topic and gather supplemental information from other provided resources (textbooks, the Internet, etc.). Then students should form triads or be assigned to triads (A, B, and C) to teach their classmates the information that they became experts on. Students could teach the class using notes, examples, a poster, and so on. **Accommodation** • Provide guided notes for students to complete using the *Physics Talk* section.
Vocabulary comprehension	***Physics Talk*** Three Collisions in One Accident!	The word "conveyance" is used often among people who work with modes of transportation. In addition to seeing it used here, your students are likely to run into it in their research later on. Be sure they know that it means "a machine that moves people or objects from one place to another," and in context here it means "automobile." Some students may have encountered the similar term "conveyor" (also spelled "conveyer") as a belt used to move bales of hay on a farm, or as a moving sidewalk in an airport.
Vocabulary comprehension	***Reflecting on the Section and the Challenge***	Students know from their experiments in Part B of the *Investigate* that a seat belt can alter the shape of their clay passenger. Therefore, they may be able to deduce the meaning of the word "distortion" in context. Be sure they understand that distortion means the way in which an object has been deformed from its original shape.
Vocabulary comprehension	***Inquiring Further*** Step 2	Be sure students begin their investigations of hydraulic brake systems by looking up the meaning of the word "hydraulic." They should know that it means operated by a fluid, usually water, under pressure.

Strategies for Students with Limited English-Language Proficiency

ELL students benefit greatly from writing practice. Have students describe in writing the three collisions involved in any automobile accident. Then ask pairs of students to exchange papers and comment on each other's sentences and descriptions.

Comparing and contrasting is an important science skill that can be difficult for students. Breaking down the work into simpler steps helps students master this skill. Ask students to compare (say what is similar about) and contrast (say what is different about) driver safety without a seat belt and driver safety with two kinds of seat belts by filling in a chart like the one below. A few boxes have been filled in to get them started. Direct students to think over all the information they have learned during this section and then have them use the circumstances from their experiments during the *Investigate* to complete the chart. Finally, ask students to use the chart to write a paragraph comparing and contrasting driver safety with seat belts and driver safety without seat belts. The paragraph should have a topic sentence, a body with supporting sentences, and a concluding sentence.

Evaluation of Seat Belt Choices

	Prevented or Lessened Collision 1 (✓ = yes, × = no)	Prevented or Lessened Collision 2 (✓ = yes, × = no)	Prevented or Lessened Collision 3 (✓ = yes, × = no)	Caused Visible Injury (1 = severe, 2 = moderate 3 = little to none)	Likely Caused Internal Injury (1 = severe, 2 = moderate, 3 = little to none)
No Seat Belt	×			1	
Wire Seat Belt					
Wide Seat Belt		✓			

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SECTION 2

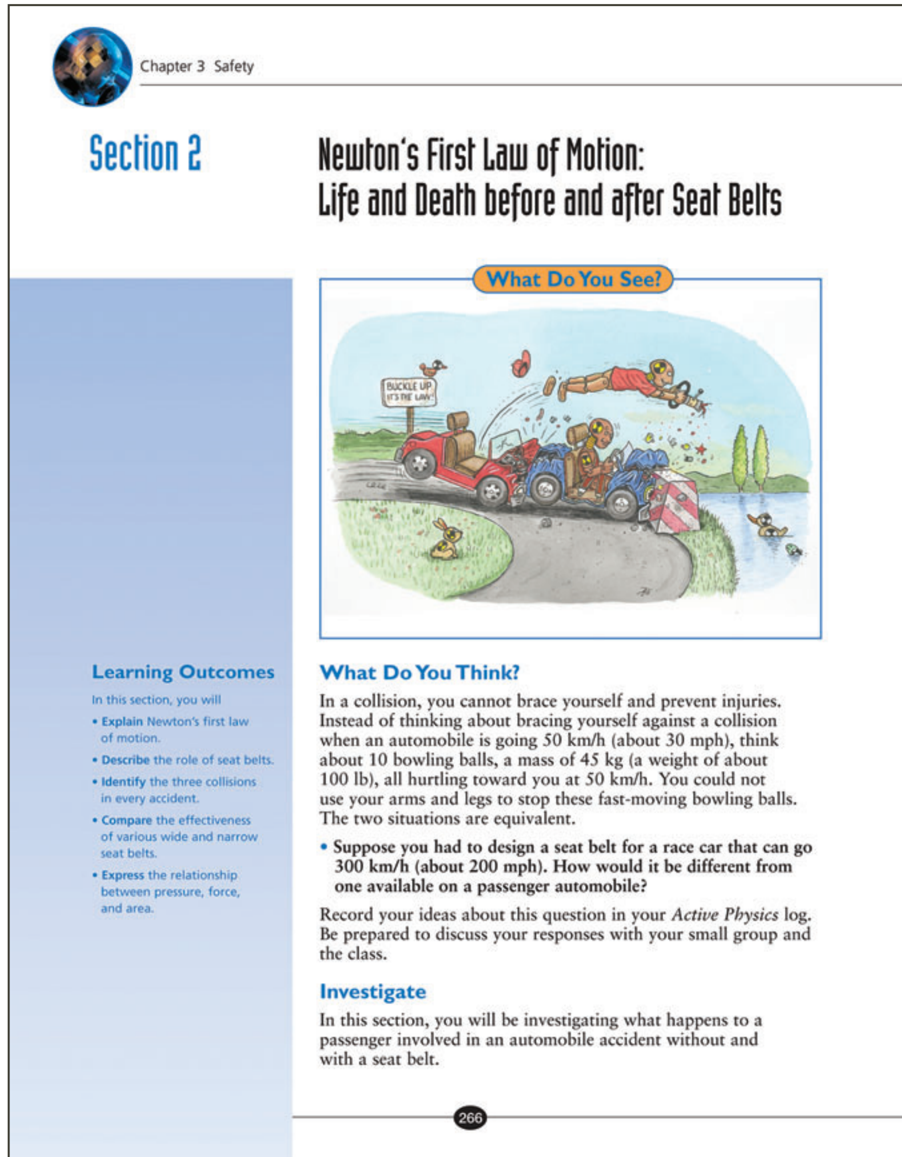
Teaching Suggestions and Sample Answers

What Do You See?

Have a class discussion on students' descriptions of the illustration. Consider using an overhead of the illustration as a focal point for the discussion. Elicit students' initial impressions of what they see in the illustration. Ask students questions such as: What dangerous features of a collision are portrayed? What safety features are shown? Why are these significant in the context of this section?

What Do You Think?

Discuss the description of a collision as compared to being struck by bowling balls and ask students to use the illustration and their own experiences to



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Section 2

Newton's First Law of Motion: Life and Death before and after Seat Belts

What Do You See?

Learning Outcomes

In this section, you will

- **Explain** Newton's first law of motion.
- **Describe** the role of seat belts.
- **Identify** the three collisions in every accident.
- **Compare** the effectiveness of various wide and narrow seat belts.
- **Express** the relationship between pressure, force, and area.

What Do You Think?

In a collision, you cannot brace yourself and prevent injuries. Instead of thinking about bracing yourself against a collision when an automobile is going 50 km/h (about 30 mph), think about 10 bowling balls, a mass of 45 kg (a weight of about 100 lb), all hurtling toward you at 50 km/h. You could not use your arms and legs to stop these fast-moving bowling balls. The two situations are equivalent.

- **Suppose you had to design a seat belt for a race car that can go 300 km/h (about 200 mph). How would it be different from one available on a passenger automobile?**

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 this section, you will be investigating what happens to a passenger involved in an automobile accident without and with a seat belt.

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Students' Prior Conceptions

Identifying types of collisions and the role of safety restraints offer students the opportunity to apply Newton's laws to real-world situations, emphasizing the essential question, "Why should you care?"

1. **A force is needed to keep an object moving with a constant speed.** During the investigations in *Chapters 1* and *2*, students measure distance and time to see what happens when unbalanced forces act on objects either at rest or in motion. This leads students to believe that an object in motion will remain in constant motion in the absence of an unbalanced force. Coupled with this understanding, students recognize how forces affect changes in velocity and cause acceleration. As your class begins *Chapter 3*, consider asking questions during discussions, particularly when students are offering explanations, to ensure that students' language reflects accepted principles. This will enable you to mediate and guide student cognition when their perception of reality differs from the physics of motion.

2. **Students confound inertia with friction believing that objects resist acceleration from a state of rest due to friction.** Friction is a concept that students view as something that always impedes motion. They need to experience the difficulty of changing the state of motion of a heavy mass and a lighter mass that have similar shapes and the same coefficient of friction on the surface upon which the mass moves in order to mentally alter their prior knowledge.

help them answer the question. Remind students to record their ideas in their log. Have a class discussion, eliciting and recording students' responses to the question. Encourage students to ask questions of each other during the discussion. Ask what the main difference is between collisions that involve an average driver and those involving a race-car driver, and how this might affect the design of a seat belt. Remind students that they will revisit this question at the end of the section. Record misconceptions and address them at appropriate times during the section. Focus on the responses that provide an opportunity for you to get the students engaged in the physics concepts. Consider emphasizing that there are no "right" answers and that all answers are acceptable. These questions elicit students' prior knowledge. Let students know they should refer to their answers while they are being introduced to new physics concepts. Point out that when they are aware of what they think, they will be better able to add to what they know.

What Do You Think?

A Physicist's Response

When designing a seat belt for a race-car driver, it is important to keep in mind the higher speeds at which race cars travel. The faster a car is going, the more energy it has. Considering the work-energy theorem, the greater the energy and the greater the force needed or the greater the distance needed to stop the motion. Because the distance between a driver and the dashboard is small, it is important for the seat belt to supply an ample force to stop the driver in this short distance. However, based on observations made in the previous *Investigate*, it is important to spread this force out over as great an area as possible to avoid injuries. Therefore, a seat belt designed to restrain a race-car driver should cover a greater amount of the driver's body, be cushioned to allow it to act over a greater distance, and be easy to get out of in case the vehicle catches fire during a collision.

Investigate

Let students know that they will be making observations of various crashes with and without seat belts. Emphasize that students should record their observations clearly in their *Active Physics* logs. Discuss and demonstrate the equipment they will be using. Show them how to increase the speed of the cart by increasing the height of the ramp, and how to attach the seat belts (tape is sufficient). Emphasize to students that the seat belts have to fit snugly around the driver.

3. **Students often think that a force is needed to sustain motion.** Students' experiences and observations involve friction acting on moving objects, and therefore, they may not realize that a net force is not needed to keep an object in motion. The concept is illustrated through the "second collision" in which the driver's body continues to move after the automobile stops. Consider demonstrating how objects continue their motion as friction is minimized. Then have them imagine what would happen if there were no friction.
4. **Most students cannot differentiate force from pressure.** To illustrate the difference between force and pressure, have students stand on two feet, on one foot, and then on their toes. Then ask them to correlate the pressure in each of the three cases based on the area of contact. Point out that pressure exerted by a force increases with decreasing area. This simple experiment empowers students to restructure their prior conception.

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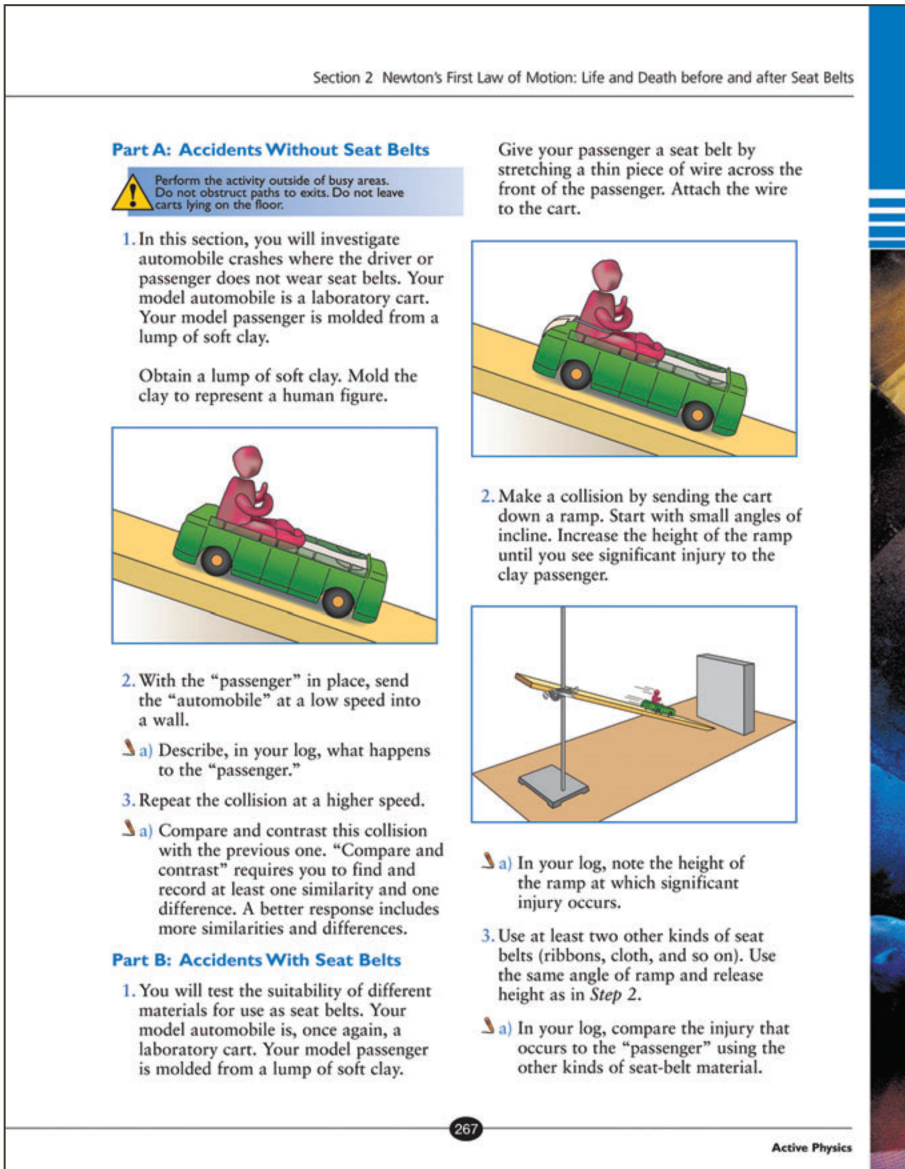


Part A: Accidents Without Seat Belts

Perform the activity outside of busy areas. Do not obstruct paths to exits. Do not leave carts lying on the floor.

1. In this section, you will investigate automobile crashes where the driver or passenger does not wear seat belts. Your model automobile is a laboratory cart. Your model passenger is molded from a lump of soft clay.

   Obtain a lump of soft clay. Mold the clay to represent a human figure.

2. With the "passenger" in place, send the "automobile" at a low speed into a wall.
   a) Describe, in your log, what happens to the "passenger."
3. Repeat the collision at a higher speed.
   a) Compare and contrast this collision with the previous one. "Compare and contrast" requires you to find and record at least one similarity and one difference. A better response includes more similarities and differences.

Part B: Accidents With Seat Belts

1. You will test the suitability of different materials for use as seat belts. Your model automobile is, once again, a laboratory cart. Your model passenger is molded from a lump of soft clay.

   Give your passenger a seat belt by stretching a thin piece of wire across the front of the passenger. Attach the wire to the cart.

2. Make a collision by sending the cart down a ramp. Start with small angles of incline. Increase the height of the ramp until you see significant injury to the clay passenger.
   a) In your log, note the height of the ramp at which significant injury occurs.
3. Use at least two other kinds of seat belts (ribbons, cloth, and so on). Use the same angle of ramp and release height as in *Step 2*.
   a) In your log, compare the injury that occurs to the "passenger" using the other kinds of seat-belt material.

Part A: Accidents Without Seat Belts

Teaching Tip

Using non-toxic, flour-based modeling compound or a similar material may be preferable to using modeling clay, which is oil based to prevent drying. Students with younger siblings often have non-toxic, flour-based modeling compound at home and are willing to bring it to class.

Teaching Tip

If you are using plastic laboratory carts, you may want to attach a piece of wood or some other fairly rigid material to the front of the cart where it will strike the wall to protect the surface. Students' enthusiasm for this investigation occasionally overcomes their sense of judgment, and equipment may get damaged.

1.

Students mold the clay to represent a human figure.

2.a)

Make sure students realize that the higher the ramp, the faster the speed of the cart down the ramp, and the faster and harder the figure will crash into the wall. Students should observe that for both cases the passengers continued in motion when the cart stopped (similarity) but the degree of damage to the passenger and how far the passenger moves depends upon the cart's speed (difference).

3.a)

Students should list similarities and differences between the two collisions. Some similarities might include both cars were moving and came to a stop very quickly; the "passenger" went flying off the cart in both scenarios; and the clay passenger was dented in both cases, indicating some damage occurred. Differences might include the cart in the second trial was moving much faster; the passenger in the second trial flew farther off the cart; and the passenger's "injuries" were worse in the second case.

Part B: Accidents With Seat Belts

Teaching Tip

When attaching the "seat belts" to the carts with tape, it is often wise to double the belt back over the tape, and then tape again to ensure the belt does not slide under the tape.

CHAPTER 3

1.

Have students prepare their materials if needed. Students should attach the seat belt to the cart. Tape is often sufficient, and the seat belt should be snug against the clay passenger.

Teaching Tip

Tape a manila folder near the bottom of the ramp and also to the surface when sending carts down the ramp. This will allow the cart to make a smooth transition from the ramp to the tabletop, so it will maintain its speed.

2.a)

Students should record the starting height where the seat belt seems to cut into the clay driver.

3.a)

Students should note that when a wider seat belt is used (such as one made of ribbon), it is unlikely that a cut will be observed in the clay driver.

3.b)

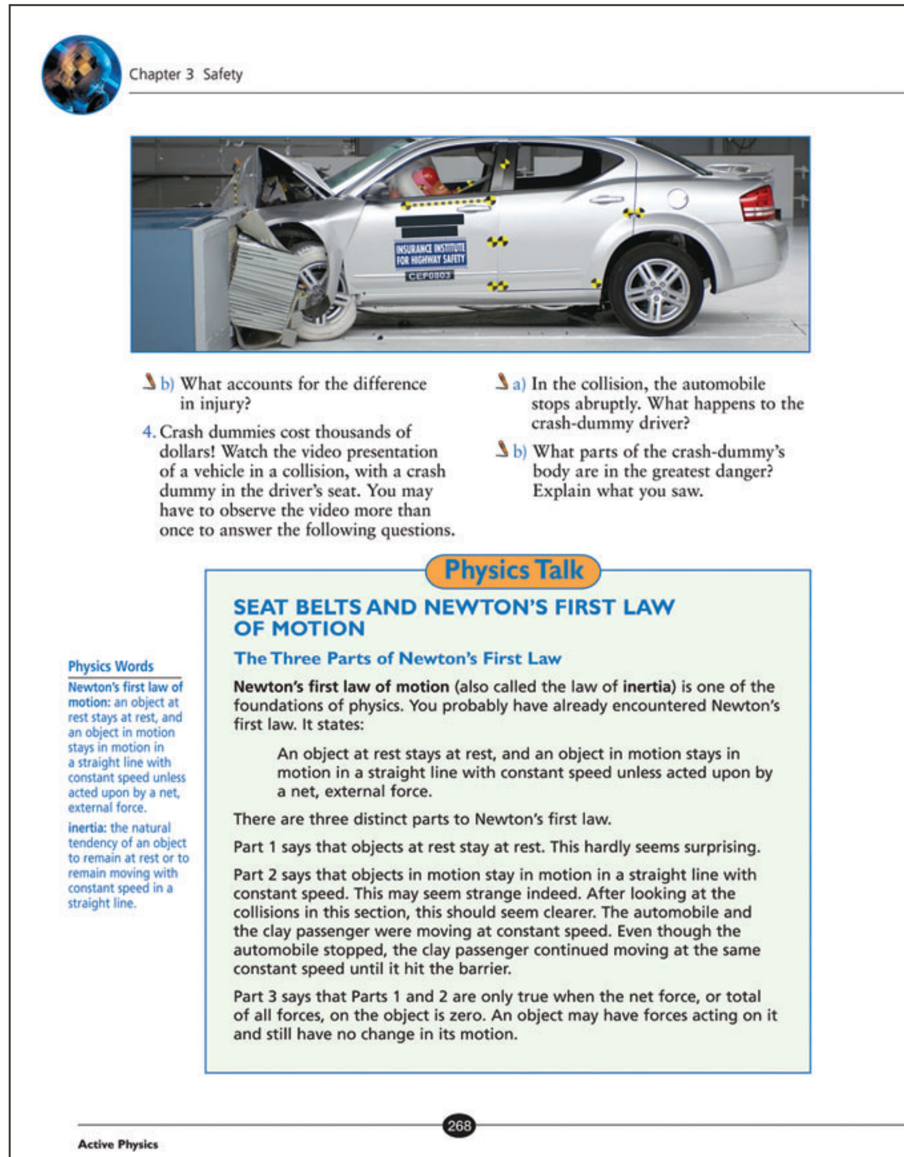
Have students support their response with their reasoning. As will be discussed in the *Physics Talk*, the wider seat belt distributes the force required over a larger area, making it less likely to cut into the clay driver.

4.a)

Students should observe that just as in a "real-world" collision, the crash dummy moves forward when the car stops until it is brought to rest by something, such as an air bag, a steering wheel, or the windshield.

4.b)

Check that students support their response with their observations.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b) What accounts for the difference in injury?

4. Crash dummies cost thousands of dollars! Watch the video presentation of a vehicle in a collision, with a crash dummy in the driver's seat. You may have to observe the video more than once to answer the following questions.

a) In the collision, the automobile stops abruptly. What happens to the crash-dummy driver?

b) What parts of the crash-dummy's body are in the greatest danger? Explain what you saw.

Physics Talk

SEAT BELTS AND NEWTON'S FIRST LAW OF MOTION

The Three Parts of Newton's First Law

Newton's first law of motion (also called the law of **inertia**) is one of the foundations of physics. You probably have already encountered Newton's first law. It states:

An object at rest stays at rest, and an object in motion stays in motion in a straight line with constant speed unless acted upon by a net, external force.

There are three distinct parts to Newton's first law.

Part 1 says that objects at rest stay at rest. This hardly seems surprising.

Part 2 says that objects in motion stay in motion in a straight line with constant speed. This may seem strange indeed. After looking at the collisions in this section, this should seem clearer. The automobile and the clay passenger were moving at constant speed. Even though the automobile stopped, the clay passenger continued moving at the same constant speed until it hit the barrier.

Part 3 says that Parts 1 and 2 are only true when the net force, or total of all forces, on the object is zero. An object may have forces acting on it and still have no change in its motion.

Physics Words

Newton's first law of motion: an object at rest stays at rest, and an object in motion stays in motion in a straight line with constant speed unless acted upon by a net, external force.

inertia: the natural tendency of an object to remain at rest or to remain moving with constant speed in a straight line.

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Active Physics

The head and torso of the crash dummy are in the most danger, because the lower portions of the body are more likely to be constrained by the lap portion of the seat belt.

Consider having a class discussion on students' observations.

Physics Talk

This *Physics Talk* describes Newton's first law and how it applies to the simulated automobile accident students observed in the *Investigate*. It introduces three types of collisions experienced by people involved in collisions. Students are also introduced to the concept of pressure (force per unit area) and this concept is used to explain their observations of different seat belts.

Begin a class discussion by asking students what they know about Newton's first law.

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For example, a book at rest on an outstretched arm has two forces acting on it: gravity pulling the book down and the force of the arm on the book, pushing it up. Because these two forces on the book are equal and opposite in direction, the forces are balanced. They cancel each other out. The net force is zero, and the book remains at rest.

In your simulated automobile accident, the cart stopped and the clay figure kept moving until it hit the wall. This action can be explained using Newton's first law. An object at rest stays at rest. An object in motion stays in motion unless acted upon by an unbalanced force. The cart and the clay figure were moving at a constant speed. The wall stopped the cart, but the clay figure continued moving at constant speed until the wall stopped the clay figure.

Human beings have much more complicated anatomies than clay figures. This leads to more complicated actions during a collision.

Three Collisions in One Accident!

Arthur C. Damask analyzes automobile accidents for insurance companies and police reports. This is how Professor Damask describes an accident:

> "Consider the occupants of a conveyance moving at some speed. If the conveyance strikes an object, it will rapidly decelerate to some lower speed or stop entirely; this is called the first collision. But the occupants have been moving at the same speed, and will continue to do so until they are stopped by striking the interior parts of the automobile (if not ejected); this is the second collision. The brain and body organs have also been moving at the same speed and will continue to do so until they are stopped by colliding with the shell of the body, for example, the interior of the skull, the thoracic cavity, and the abdominal wall. This is called the third collision."

Students should support their ideas. If students have completed *Physics in Action*, have them support their ideas with their observations from that chapter. Discuss the three parts of Newton's first law using the information in the student text.

Encourage students to make connections to each part with the observations they made during the *Investigate*. Consider asking students what they observed as they increased the speed before the collision and how this fits in with Newton's first law.

Continue the discussion, focusing on what occurs to humans (and animals) during a collision using the description by Arthur C. Damask in the student text. Emphasize that a person in a vehicular collision continues to move, even after the vehicle has stopped. The person moves until he or she collides with an object (dashboard, seat belt, and windshield) that stops him or her. Describe how the organs inside the person's body continue moving until they are stopped by the person's body walls. Consider eliciting students' ideas about why all three collisions are of concern. Discuss the concerns using the information in the student text.

Transition the discussion by asking students how seat belts helped their clay figure and what observations they made. Make connections between their observations and the width or area of the belt they used. Describe how the force each seat belt exerted to stop the passenger was the same, but the results were very different. Then introduce the concept of pressure (force per area where the force is perpendicular to the surface). Describe that when the force is distributed over a larger area it is not as great at any given point. Provide examples for students, such as what happens when they try to push a book through a piece of cardboard, or a nail through a piece of cardboard with the same force. Ask students to provide examples.

Discuss the SI units used for pressure, the pascal (Pa). $1\ \text{Pa} = 1\ \text{N/m}^2$. Consider demonstrating the example at the end of the *Physics Talk* by pulling a clay figure with the same force using just a spring scale, and a spring scale attached to a wide belt.

CHAPTER 3

Checking Up

1.

An object does not change its motion (at rest or moving with constant speed in a straight line) unless an unbalanced external force acts on it. Ask students to provide examples of Newton's first law.

2.

The driver in a collision continues his or her motion until a net force acts on him or her, following Newton's first law. Students should realize that just before the collision, the driver and automobile are moving with the same speed. They may mention that what stops the person from moving is the second of the three collisions described in the student text.

3.

Students should describe the third collision using Newton's first law. A person's organs continue to move, undisturbed, until a net external force acts on them. The net force that stops the internal organs is the force applied to the organs from the inner walls of the body as the organs collide into it. Students may not realize that although organs are connected to parts of the body, they are not rigidly attached to any part of the body, so they have the ability to move slightly within the body cavity.

4.

Inertia is the tendency of an object to remain at rest or in motion and is dependent on the object's mass. Consider asking students for examples.

Newton's first law of motion can explain these three collisions when an automobile strikes a pole:

- First collision—The automobile strikes the pole. The pole exerts the force that brings the automobile to rest.
- Second collision—When the automobile stops, the body keeps moving. The structure of the automobile exerts the force that brings the body to rest.
- Third collision—The body stops, but the heart, the brain, and other organs keep moving. The body wall exerts the force that brings the organs to rest.

Even with all the safety features in automobiles, some deaths due to accidents cannot be prevented. In one recorded accident, only a single automobile was involved, with only the driver inside. The automobile failed to follow the road around a turn, and it struck a telephone pole. The seat belt and the air bag prevented any serious injuries apart from a few bruises, but the driver died. An autopsy showed that the driver's aorta (a large blood vessel) had burst, at the point where it leaves the heart. The man's organs were damaged during the "third" collision, when the heart collided with the skeleton.

Force per Unit Area: Designing a Safer Seat Belt

In *Part B* of the *Investigate*, you used a seat belt to stop the clay passenger. Newton's first law states that an object at rest will remain at rest and an object in motion will remain in motion unless acted upon by an unbalanced **force**. The cart stopped, but the passenger continued to move forward until a force acted upon it. In this part, the force stopping the passenger was the force exerted by the seat belt.

Some of the seat belts you used did not work as well as others. Each time you repeated the investigation, the stopping force that the belt exerted on the clay was the same. The force was the same because you released the cart from the same height each time. Yet different materials had different effects on the clay passenger. For example, the wire cut far more deeply into the clay than a broader material did.

The stopping force that each of the seat belts exerted on the clay was approximately the same. When a thin wire was used, all the force was concentrated onto a small area. By replacing the wire with a broader strip of material, you spread the force out over a much larger area of contact.

Force that is spread out over a given area is called **pressure**.

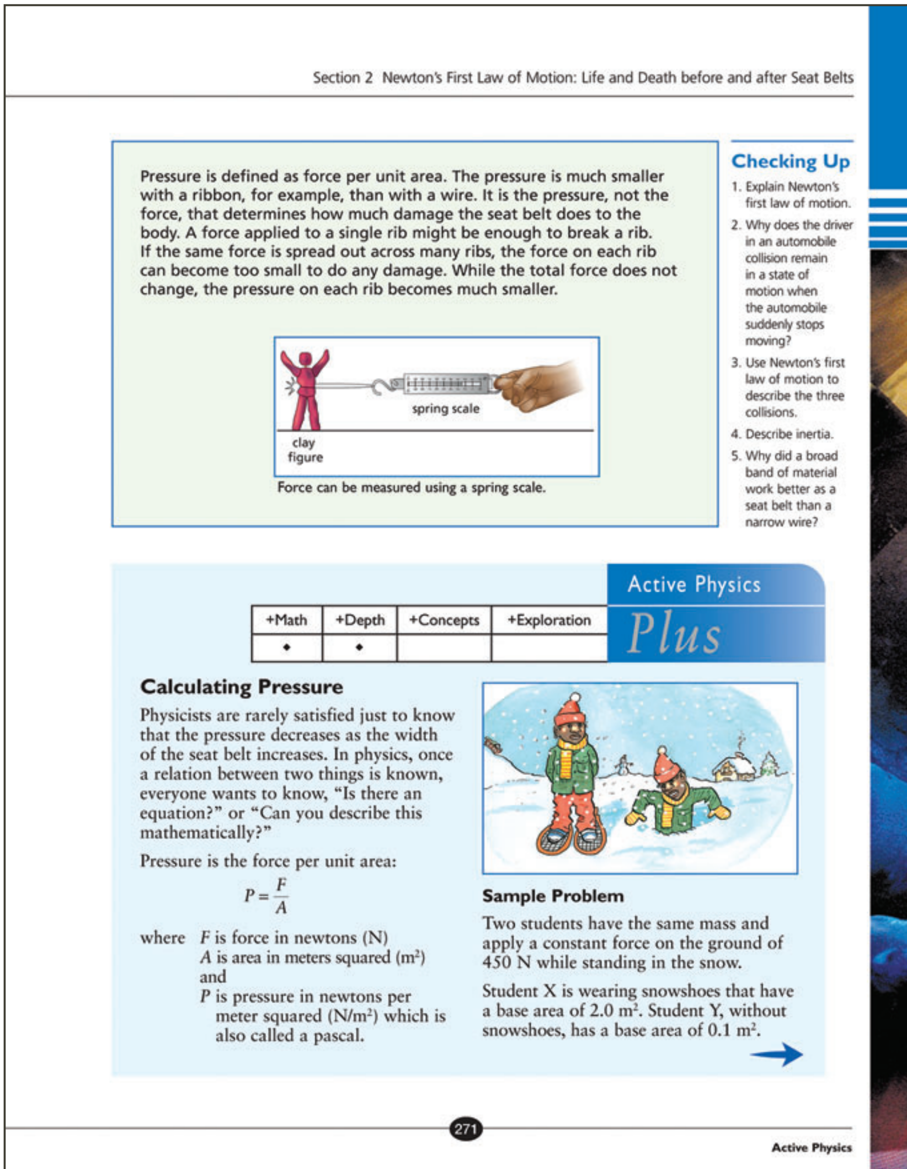
Physics Words

force: an interaction between two objects that can result in an acceleration of either or both objects.

pressure: force per area where the force is normal (perpendicular) to the surface; measured in N/m^2 (newtons per meter squared) or Pa (pascals).

5.

Descriptions should include pressure being force per area and how when the force is spread out over a greater area, it prevents injury and helps to stop a greater area of the person's motion. Consider asking students what they think happens to a person's head during a collision. This will be discussed in *Section 4*.



Section 2 Newton's First Law of Motion: Life and Death before and after Seat Belts

Pressure is defined as force per unit area. The pressure is much smaller with a ribbon, for example, than with a wire. It is the pressure, not the force, that determines how much damage the seat belt does to the body. A force applied to a single rib might be enough to break a rib. If the same force is spread out across many ribs, the force on each rib can become too small to do any damage. While the total force does not change, the pressure on each rib becomes much smaller.

spring scale

clay figure

Force can be measured using a spring scale.

Checking Up

1. Explain Newton's first law of motion.
2. Why does the driver in an automobile collision remain in a state of motion when the automobile suddenly stops moving?
3. Use Newton's first law of motion to describe the three collisions.
4. Describe inertia.
5. Why did a broad band of material work better as a seat belt than a narrow wire?

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
•	•		

Calculating Pressure

Physicists are rarely satisfied just to know that the pressure decreases as the width of the seat belt increases. In physics, once a relation between two things is known, everyone wants to know, "Is there an equation?" or "Can you describe this mathematically?"

Pressure is the force per unit area:

$$P = \frac{F}{A}$$

where F is force in newtons (N)
A is area in meters squared (m^2)
and
P is pressure in newtons per meter squared (N/m^2) which is also called a pascal.

Sample Problem

Two students have the same mass and apply a constant force on the ground of 450 N while standing in the snow.

Student X is wearing snowshoes that have a base area of 2.0 m^2. Student Y, without snowshoes, has a base area of 0.1 m^2.

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Active Physics

Active Physics Plus

This *Active Physics Plus* provides an opportunity for students to increase the depth of their understanding of pressure, and describe Newton's first law and the concept of pressure using an algebraic representation. Introduce the mathematical representation to the class and discuss the sample problems provided in the student text. As a class, discuss students' responses to the questions.

CHAPTER 3

1.a)

$$P = (10\ \text{N})/(1.0\ \text{m}^2) = 10\ \text{N/m}^2$$

1.b)

$$P = (10\ \text{N})/(0.2\ \text{m}^2) = 50\ \text{N/m}^2$$

1.c)

$$P = (10\ \text{N})/(15\ \text{m}^2) = 0.7\ \text{N/m}^2$$

1.d)

$$P = (10\ \text{N})/(0.04\ \text{m}^2) = 250\ \text{N/m}^2$$

2.a)

$$P = (700\ \text{N})/(0.04\ \text{m}^2) =$$

$17{,}500\ \text{N/m}^2$

2.b)

$$P = (700\ \text{N})/(0.02\ \text{m}^2) =$$

$35{,}000\ \text{N/m}^2$ (the pressure is twice as much since the area is half as much)

What Do You Think Now?

Have students review their previous answers to the question. Conduct a survey on how many students would change their answer, and ask how they would answer this question now. Point out that scientists often change their ideas as they gather more information. Consider discussing the information in *A Physicist's Response.*

Why does the student without snowshoes sink into the snow?

Strategy: This problem involves the pressure that is exerted on the snow surface by each student. You can use the equation that relates force and area to compare the pressure exerted by each student.

Given:

$F = 450\ \text{N}$

$A_x = 2.0\ \text{m}^2$

$A_y = 0.1\ \text{m}^2$

Solution:

Student Y	Student X
$P = \frac{F}{A}$	$P = \frac{F}{A}$
$= \frac{450\ \text{N}}{0.1\ \text{m}^2}$	$= \frac{450\ \text{N}}{2.0\ \text{m}^2}$
$= 4500\ \text{N/m}^2$	$= 225\ \text{N/m}^2$

Student Y sinks into the snow because the pressure that Student Y exerts on the snow is much greater than the pressure exerted by Student X.

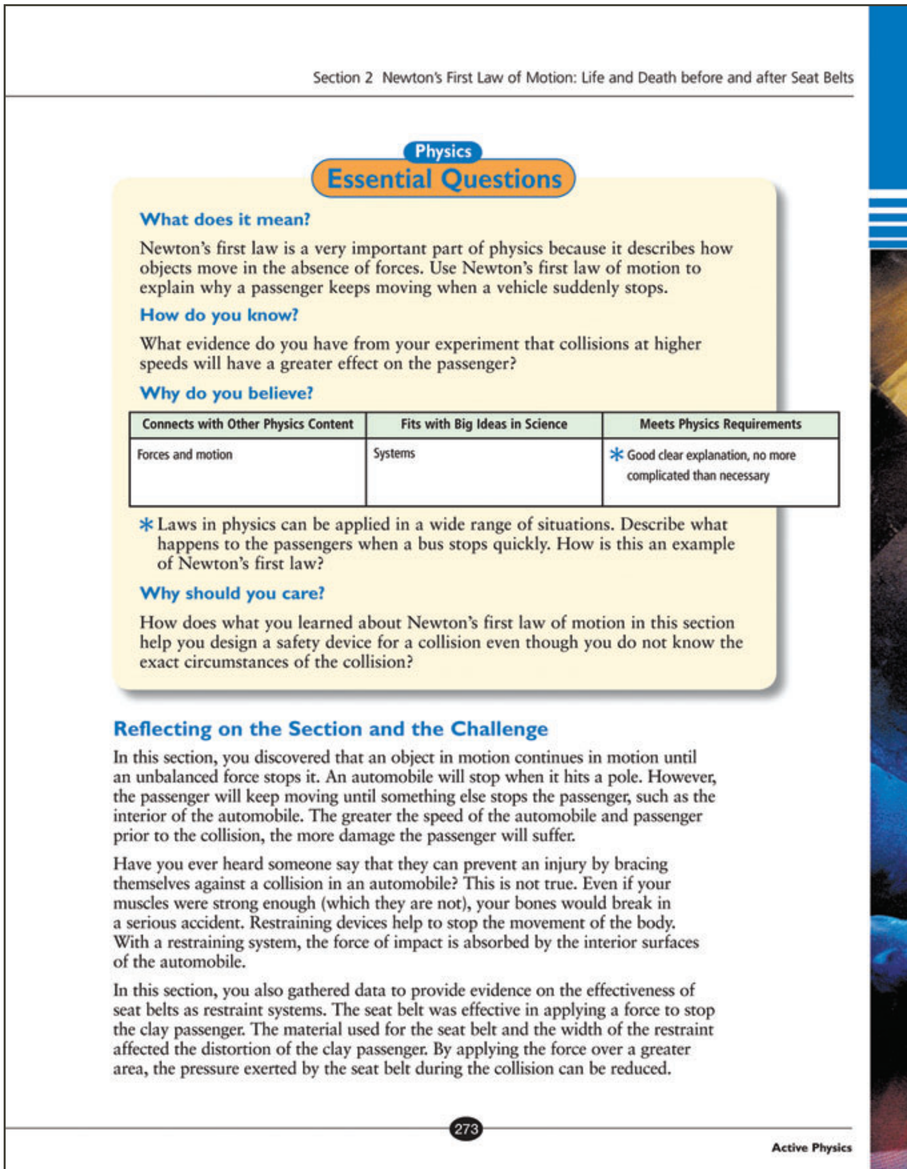
1. What is the pressure exerted when a force of 10 N is applied to an object with each of the following areas?
   a) $1.0\ \text{m}^2$
   b) $0.2\ \text{m}^2$
   c) $15\ \text{m}^2$
   d) $400\ \text{cm}^2$
2. A person who weighs 155 lb exerts approximately 700 N of force on the ground while standing. If the person's shoes cover a total area of $400\ \text{cm}^2$ ($0.04\ \text{m}^2$), calculate the following:
   a) the average pressure the person's shoes exert on the ground
   b) the pressure the person would exert by standing on one foot

What Do You Think Now?

At the beginning of this section, you were asked the following:

- **Suppose you had to design a seat belt for a race car that can go 300 km/h (about 200 mph). How would it be different from one available on a passenger automobile?**

Using Newton's first law of motion, explain why a seat belt is an important safety feature in a vehicle. Now that you have also investigated the relationship between force and area, what would you need to consider when designing a seat belt for a race car? How do your ideas now compare to the ideas you previously recorded in your log?



Physics
Essential Questions

What does it mean?

Newton's first law is a very important part of physics because it describes how objects move in the absence of forces. Use Newton's first law of motion to explain why a passenger keeps moving when a vehicle suddenly stops.

How do you know?

What evidence do you have from your experiment that collisions at higher speeds will have a greater effect on the passenger?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	Systems	* Good clear explanation, no more complicated than necessary

* Laws in physics can be applied in a wide range of situations. Describe what happens to the passengers when a bus stops quickly. How is this an example of Newton's first law?

Why should you care?

How does what you learned about Newton's first law of motion in this section help you design a safety device for a collision even though you do not know the exact circumstances of the collision?

Reflecting on the Section and the Challenge

In this section, you discovered that an object in motion continues in motion until an unbalanced force stops it. An automobile will stop when it hits a pole. However, the passenger will keep moving until something else stops the passenger, such as the interior of the automobile. The greater the speed of the automobile and passenger prior to the collision, the more damage the passenger will suffer.

Have you ever heard someone say that they can prevent an injury by bracing themselves against a collision in an automobile? This is not true. Even if your muscles were strong enough (which they are not), your bones would break in a serious accident. Restraining devices help to stop the movement of the body. With a restraining system, the force of impact is absorbed by the interior surfaces of the automobile.

In this section, you also gathered data to provide evidence on the effectiveness of seat belts as restraint systems. The seat belt was effective in applying a force to stop the clay passenger. The material used for the seat belt and the width of the restraint affected the distortion of the clay passenger. By applying the force over a greater area, the pressure exerted by the seat belt during the collision can be reduced.

Reflecting on the Section and the Challenge

Using the information in the student text, review Newton's first law and how it applies to the three types of collisions that occur during an accident, and how pressure is an important concept to keep in mind when designing safety features such as seat belts. Emphasize that these concepts are important for the *Chapter Challenge* and that students should consider these concepts as they design their prototype and form their explanations.

Physics Essential Questions

What does it mean?

Newton's first law states that an object in motion stays in motion. When the vehicle stops, the passenger keeps moving until something stops him or her.

How do you know?

At higher speeds, the clay figure was more damaged during the crash.

Why do you believe?

When the bus stops, the passengers lean or fall forward. The passengers were moving and continue to move even though the bus has stopped.

Why should you care?

You know that the passenger will move forward if the vehicle is suddenly stopped. Therefore, you have to protect the passenger while he or she continues to move forward.

It is important to note that not every safety restraint system will be a seat belt or harness, but that all restraints attempt to reduce the pressure exerted on an object by increasing the area over which a force is applied.

Physics to Go

1. Describe how Newton's first law applies to the following situations:
   a) You step on the brakes to bring your vehicle to a safe stop.
   (Sample answer: You and the vehicle are moving forward. The brakes apply a force and the vehicle stops. Newton's first law states that an object in motion will remain in motion unless an unbalanced force acts upon it. In this case, the force stops the vehicle from moving forward. You stop moving because the interior of the automobile–seat, seat belts, dashboard, floor—apply a force to stop you.)
   b) You step on the accelerator to get going.
   c) You step on the brakes, and an object in the back of the automobile comes flying forward.
   d) A vehicle is involved in a collision and a passenger is wearing a seat belt.
2. Give two more examples of how Newton's first law applies to vehicles or people in motion.
3. The skateboard, shown in the diagram at the right, strikes the curb. Draw a diagram indicating the direction in which the person on the skateboard moves after the impact. Use Newton's first law to explain the direction of movement.

4. Explain, in your own words, the three collisions during a single automobile accident as described by Professor Damask in the *Physics Talk*.
5. Describe why a wire seat belt would not be effective even though the force exerted on you by the wire seat belt is identical to that of a cloth seat belt.
6. Do you think laws making seat belts mandatory are fair? In answering this question, consider how using seat belts affect the society as a whole.
7. Suppose one of your friends wanted a ride in your automobile, but refused to wear a seat belt.
   a) Give two arguments that he or she might make against wearing a seat belt.
   b) How can you challenge these arguments using what you have learned about Newton's first law of motion?

Physics to Go

1.a)

Students' responses should contain the following:

You and the automobile are moving forward. The brakes apply a force and the automobile stops. Newton's first law states that an object in motion will remain in motion unless a force acts upon it. In this case, the force stops the car from moving forward. You stop moving because the interior of the automobile—seat, seat belts, dashboard, and floor—apply a force to stop you.

1.b)

You and the car are stopped. The engine provides a force that causes the car to move forward. Following Newton's first law, inertia will keep you at rest until a force acts upon you. The force that pushes you forward is exerted on you by the seat-back, which pushes you forward at the same rate as the car. To provide this force, the back of the seat must compress like a spring, and when sufficiently compressed, applies a forward force to accelerate you at the same rate as the car. The passenger is likely to attribute this compression to being "pushed back" in the seat, but actually the seat is pushing him or her forward.

1.c)

The object was moving with the same velocity as the automobile. The force, which caused the automobile to stop, was not acting on the object, only a small amount of friction from the surface of the object was resting on what was acting on the object. The inertia of the object kept it moving in a straight path (until it collided with something in the automobile to change its motion, for example, the driver or the windshield).

1.d)

During a collision, the seat belt helps provide the force necessary to stop the passenger when the vehicle stops. The seat belt typically does this over a larger area than other parts of the vehicle, such as the steering wheel or windshield, so there is less injury to the driver and passengers.

2.

Students' are to give two examples that should describe clearly how Newton's first law applies. Some students might include the sensation of being pushed forward or backward when accelerated, for example, being slammed into the seat of a bus, as it accelerates from the stop. This occurs because the passenger continues his or her motion until something in the vehicle acts on the passenger to change his or her motion.

3.

A force from the curb has stopped the skateboard, however, according to Newton's first law, the person on the skateboard will continue to move in the same direction as before the collision, because there is nothing to stop him from changing that motion. This is why there is the need for a helmet, knee pads, and gloves!

4.

Students' responses should include the following: The first collision is the vehicle hitting a tree. The second collision is the driver or passenger hitting something in the vehicle. The third collision occurs when the internal organs in the driver or passenger hit the internal walls of the body, or the brain hits the internal surface of the skull.

5.

Students' responses should indicate an understanding that if the restraining belt causes an acting pressure on the passenger that that is too high, it will injure the passenger. A wire seat belt would be ineffective (and dangerous) because the force it exerts on the body to stop it during a collision occurs over too small of an area. In a severe collision, the pressure could be sufficient to cut deeply into the wearer's body, possibly causing more injury than not using a seat belt.

6.

Students should support their response. For example, people who don't use seat belts may end up having greater injuries, thereby increasing the cost of health care, or may lose control of their vehicle more easily, thereby causing more damage to their own vehicle or others. Have students explore the concept of social responsibility. What constitutes the need for any law? How does the use or lack of use of safety restraints affect us as a society? How do economics affect the passing of legislation in this area? Forty-nine states and the District of Columbia have mandatory seat-belt laws. In some states, seat-belt laws date back to 1985.

7.a)

Two of the more common reasons for not wanting to wear seat belts are the myths that if a vehicle catches fire, or if it goes into water, you will be able to exit more easily if you are not wearing a seat belt. Other reasons suggested may be that the seat belt is too constraining or uncomfortable, or that the passenger will brace him or herself in time for the collision.

7.b)

The force required to make a person stop in time to prevent injury is too big to be provided by bracing. The people who wear seat belts during a collision are far more likely to be conscious and not badly hurt, making it easier to exit a vehicle that catches fire or goes into the water. If the seat belt locks, a device can be stored in the vehicle to cut through the seat belt.

8.

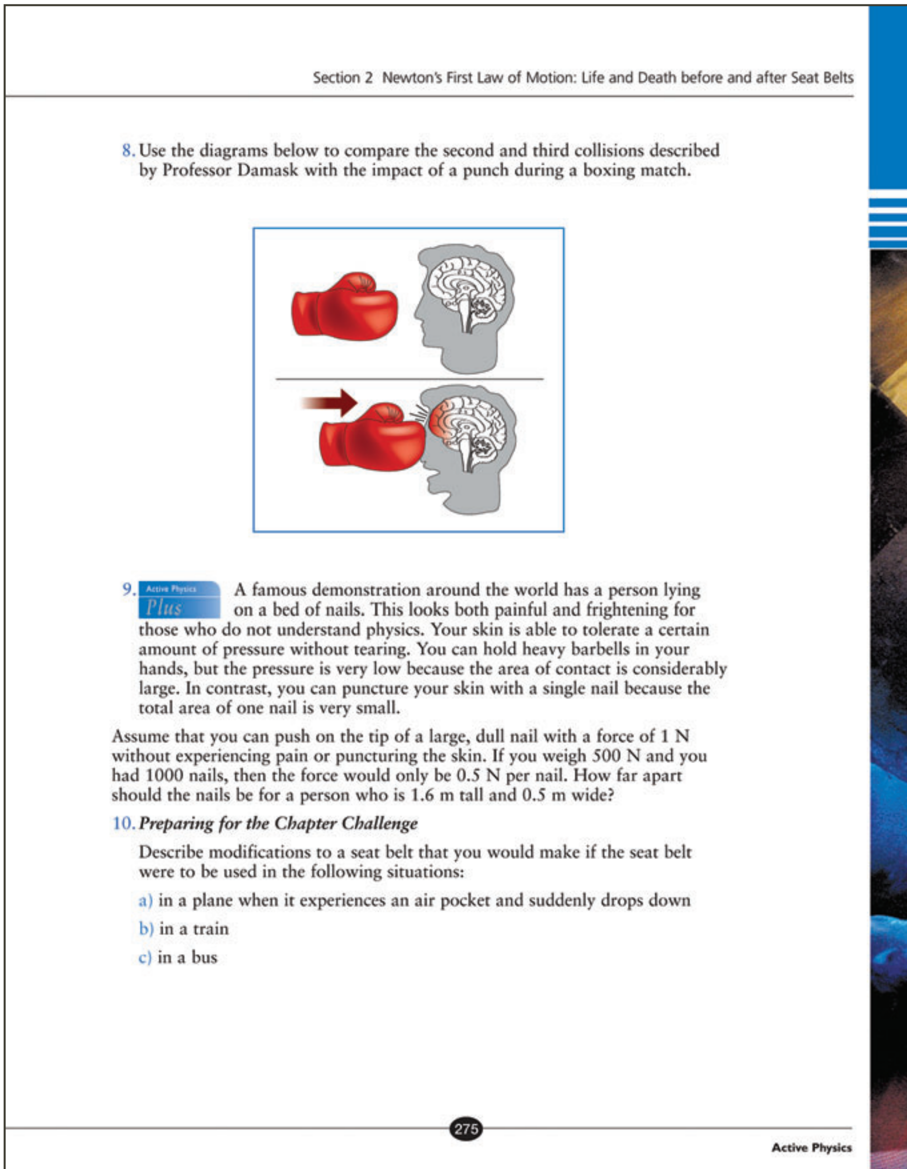
The boxing glove hitting a boxer's head corresponds to the "second collision" in the Damask model. This is when the body first makes contact with an external object. The "third collision" occurs when the internal parts of the body collide. In this case, the skull moves backward, and the brain collides with the interior of the skull.

9. Active Physics *Plus*

Students should show reasoning with their response. Five hundred N divided by 1000 nails would only be 0.5 N per nail, which is not sufficient to puncture the skin. For a rough estimate of spacing, assume the 1.6-m-tall person is 0.5 m wide on average. This would give an area of $A = l \times w = 0.8\ \text{m}^2$, or 8000 cm^2. Dividing by 1000 nails means each nail should occupy 8 cm^2. If the area is a square, then each side should be the square root of 8 cm^2, or about 2.8 cm on a side. The nails in a square array should be approximately 2.8 cm from one another. Some students might note that the difficult task is getting on and off the bed of nails rather than lying on the bed of nails. The easiest way to do so would be to have the person lying flat, lowered onto and then lifted off of the bed of nails.

CHAPTER 3

NOTES



8. Use the diagrams below to compare the second and third collisions described by Professor Damask with the impact of a punch during a boxing match.

9. Active Physics *Plus* A famous demonstration around the world has a person lying on a bed of nails. This looks both painful and frightening for those who do not understand physics. Your skin is able to tolerate a certain amount of pressure without tearing. You can hold heavy barbells in your hands, but the pressure is very low because the area of contact is considerably large. In contrast, you can puncture your skin with a single nail because the total area of one nail is very small.

Assume that you can push on the tip of a large, dull nail with a force of 1 N without experiencing pain or puncturing the skin. If you weigh 500 N and you had 1000 nails, then the force would only be 0.5 N per nail. How far apart should the nails be for a person who is 1.6 m tall and 0.5 m wide?

10. *Preparing for the Chapter Challenge*

Describe modifications to a seat belt that you would make if the seat belt were to be used in the following situations:

a) in a plane when it experiences an air pocket and suddenly drops down

b) in a train

c) in a bus

10.

Preparing for the Chapter Challenge

Students should describe why they have suggested the modifications using the concepts of pressure and Newton's first law. Suggestions are provided for the scenarios listed in the student text.

10.a)

When a plane suddenly drops down, the passenger lifts out of the seat due to Newton's first law. A possible seat belt for this situation would be one that goes over one or both shoulders such as a three-point buckling system as found on infant seats, or a cushioned bar as found on roller coasters.

10.b)

A seat belt similar to an automobile's would suffice for a train.

10.c)

A seat belt similar to an automobile's would suffice for a bus. School buses could take into account the smaller passenger size, allowing for adjustable shoulder straps.

CHAPTER 3

Inquiring Further

1. Opinions about wearing seat belts

Students should have a minimum of five surveys for each age group: Group A = 15 to 24 years, Group B = 25 to 59 years, and Group C = 60 years and older. Check that students have the same number of surveys in each group. Students should compile, analyze, and synthesize their data. Consider having students present their data to the class.

2. Brakes in an automobile

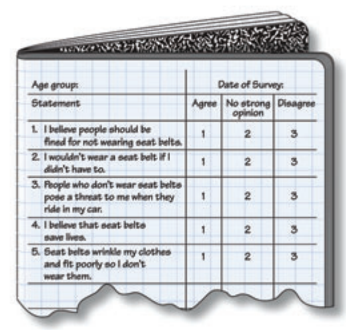
Students should research brake systems of cars and hydraulic systems. They should relate their findings to pressure. Information on hydraulic brakes and how they work can be obtained by doing an Internet search on "hydraulic brakes." Some information your students should include for common braking systems follows. When you push against a brake, it actually pushes against a plunger in what is called the master cylinder. This forces a fluid (brake fluid) through the braking unit at each wheel. The fluid does not compress by any significant amount, so as it goes through the system it maintains the same pressure. No air is in the system because that would compress and not be as effective. The fluid usually presses on a piston that pushes the brake pads against a disk that is attached to a wheel, or the fluid is forced into a cylinder, which then pushes brake shoes out until they push against a drum attached to the wheel. In both cases, friction is used to slow the wheel.

Inquiring Further

1. **Opinions about wearing seat belts**

Determine what opinions people in your community hold about wearing seat belts. Survey at least five people in each of theses age groups: Group A = 15 to 24 years, Group B = 25 to 59 years, and Group C = 60 years and older. Survey the same number of individuals in each age group. Ask each individual to fill out a questionnaire. Compare the opinions of the different groups.

A sample questionnaire is provided below. Eliminate any question that you feel is not relevant. Develop questions of your own that help you understand what attitudes people in your community hold about wearing seat belts. The answers have been divided into three categories: 1 = agree; 2 = will accept, but do not hold a strong opinion; and 3 = disagree. Try to keep your survey to between five and ten questions.



Age group:	Date of Survey:		
Statement	Agree	No strong opinion	Disagree
1. I believe people should be fined for not wearing seat belts.	1	2	3
2. I wouldn't wear a seat belt if I didn't have to.	1	2	3
3. People who don't wear seat belts pose a threat to me when they ride in my car.	1	2	3
4. I believe that seat belts save lives.	1	2	3
5. Seat belts wrinkle my clothes and fit poorly so I don't wear them.	1	2	3

2. **Brakes in an automobile**

How is your foot able to stop an automobile? How can the small force of your foot on the brake create a large enough force on the brakes of the automobile to stop the automobile? Investigate how the hydraulic systems in automobile brakes work and relate this to your study of pressure in this section.

Students could also discuss how a machine such as brakes can change the input force and direction.

SECTION 2 QUIZ

3-2a **Blackline Master**

1. Which person has the greatest inertia?

   a) A 110-kg wrestler resting on a mat.
   b) A 90-kg man walking at 2 m/s.
   c) A 70-kg man running at 5 m/s.
   d) A 50-kg girl sprinting at 8 m/s.

2. Two equal-mass safety dummies are being used to test seat belts. Dummy A has a wide seat belt and Dummy B has a narrow seat belt. Both dummies are crashed into a barrier while in the same car. Which statement below best describes the forces needed to stop each dummy?

   a) Dummy A's force is bigger than Dummy B's.
   b) Dummy B's force is bigger than Dummy A's.
   c) The forces on the two dummies are equal.
   d) The forces cannot be determined unless you know the size of the seat belts.

3. In the collision in *Question 2*, which statement below correctly describes the pressure exerted by the seat belt on the dummies during the stopping process?

   a) Dummy A's pressure is greater than Dummy B's.
   b) Dummy B's pressure is greater than Dummy A's.
   c) The pressures of the two seat belts are equal because the dummies have equal mass.
   d) The pressures of the two seat belts are equal because both dummies stop in the same time.

4. When a rapidly descending elevator is quickly stopped, blood tends to drain away from the head of a rider in the elevator. The principle that best describes this phenomenon is

   a) objects at rest tend to remain at rest.
   b) pressure varies with area and the applied force.
   c) for every action there is an equal and opposite reaction.
   d) objects in motion tend to continue in motion with constant speed.

5. A 50-kg mass is moving at a constant speed of 10 m/s in a straight line. When the mass begins to slow down, which of the following must be occurring?

   a) The object must be losing some of its inertia.

   b) The object must be losing some of its mass.

   c) A net force must be acting opposite the object's motion.

   d) No force is needed because objects slow down naturally.

SECTION 2 QUIZ ANSWERS

1. a) A 110-kg wrestler resting on a mat.

2. c) The forces on the two dummies are equal.

3. b) Dummy B's pressure is greater than Dummy A's.

4. d) objects in motion tend to continue in motion with constant speed.

5. c) A net force must be acting opposite the object's motion.

NOTES