Understanding Car Crashes
When Physics Meets Biology

Teacher's guide for grades 9-12

This teaching guide will help you to:
Effectively present the video in your classroom
Teach inquiry-based "Crash Science" lessons
Integrate life science and physical science concepts
Address National Science Education Standards
Stimulate students' interest in modern crashworthiness

1005 N. Glebe Road, Arlington, VA 22201

INSURANCE INSTITUTE
FOR HIGHWAY SAFETY
www.iihs.org

How to use this guide

The lessons in this guide introduce students to the science of car crashes with high-interest, grade-level appropriate activities designed to meet National Science Education Standards. Students will learn why a crash is a potentially devastating event. They will gain new perspective on how crash forces are measured and evaluated using crash test dummies, and they will see how these forces affect human anatomy and physiology.

Teacher lesson plans and accompanying student activity sheets are provided. The lessons are intended to supplement a high school life science or integrated science curriculum with inquiry-based activities that demonstrate basic science principles and relate them to car crash injuries.

Using the Video Concept Organizer
The Video Concept Organizer serves as an advanced organizer of the content provided in the video. Students complete the low-order questions as they watch the video. Teachers may find it beneficial to stop the video periodically for students to collaborate on the answers. Once completed, the Video Concept Organizer may be used as a study guide and review sheet for the key concepts introduced in the video.

Using the Post-Video Questions
The Post-Video Questions are higher-order questions intended to stimulate discussion among students. Individual questions may be assigned to small groups for discussion, with each group responsible for presenting answers to the class for discussion.

Using the Lesson Plans
Two **teacher lesson plans** and accompanying **student activity sheets** are provided. The lessons are intended to supplement a high school life science or integrated science curriculum with inquiry-based activities that demonstrate how the basic principles of physics are integrated with biology and applied in real-world events.

Lesson format
Each lesson is organized using the same standard format and includes the following components:

Key questions - States the primary focus of the activity in a question that is relevant to the students' experiences. The key questions may be used to initiate or conclude the activity.

Grade level - Suggests appropriate grade levels.

Time required to complete lesson - Estimates the range of time needed to complete the main procedure of the lesson with a class size of 28-32 students. Additional time is necessary to complete Extensions.

Objectives - Identifies desired student outcomes in the form of observable behaviors.

National Science Education Standards - Activities correlated to Content Standards: Grades 9-12 of the National Science Education Standards, National Academy of Sciences, Washington D.C., 1996.

Background information - Contains relevant background information on the science concepts explored in the activity. Key concepts and vocabulary are in bold face type.

Crash course definitions - Lists and defines key science vocabulary used in the lesson.

Materials needed - Lists all supplies needed for students working in small groups to complete the activity.

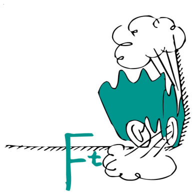
Advance preparation and safety considerations - Describes steps the teacher should take to prepare for the activity including safety precautions.

Procedure - Includes step-by-step instructions for completion of the lesson. The procedure follows the three-stage learning cycle of exploration, concept development, and application. Answers to the student activity sheet questions are provided.

Extensions - Suggests extension activities that continue to make the science concepts relevant to students and introduce related concepts.

Using the website

The Insurance Institute for Highway Safety's website (www.iihs.org) is easy to use and can provide students and teachers with a wide variety of information on the factors involved in motor vehicle crashes and how to reduce injuries.



Name ______________________________ Period ______ Date __________

Student Organizer Questions

Understanding Car Crashes
When Physics Meets Biology

Video Concept Organizer

Part I: Pre-video inquiry
Directions: Before viewing the video, record your ideas about questions #1 and #2 below. Be prepared to discuss your responses with your partner(s) and the class.

1. Why is it that some spectacular race car crashes produce only minor injuries?

____

____

2. How can three collisions occur in one crash between a car and a wall?

____

____

Running time 24 minutes

Part II: During the video
Directions: To help you remember the key science concepts discussed during the video, fill in the blanks or circle the correct answers.

01:36

What is the first scientific discipline that comes to mind when you think of car crashes? It's probably physics because ____________________________________ govern what happens to a vehicle in a crash.

But if we want to understand the effects of a crash on a human body, we need look at what occurs when physical ______________ are applied to organs, tissues and cells, and this happens when physics meets biology in the field of ______________________________.

History of crash research

04:04

___________________________________, a medical doctor and biophysicist in the United States Air Force, used himself as the test subject in his investigations of human tolerance to high *g* environments.

04:20

In one of his many tests, Dr. Stapp reached a speed of _____ miles per hour before one of the most powerful braking systems of all time stopped him in ____ seconds, subjecting him to more than 40 times the pull of gravity, or ____ *g*s.

05:12

Crash test dummy lab

These dummies behind me are a perfect example of combining **science**, **technology**, **engineering**, and **mathematics** to produce new **tools** that extend scientific understanding.

06:00

Family of dummies	Height (feet)	[meters]	Weight (lbs)	[mass in kg]
95th percentile male	6' 2"	[1.88 m]	223 lbs	[101 kg]
5th percentile female	5'	[1.52 m]	107 lbs	[48.5 kg]
50th percentile male	5' 9"	[1.75]	172 lbs	[78.0kg]
CRABI - 6 month old	26.3"	[0.67 m]	17.3 lbs	[7.85 kg]

06:24

Side impact dummy: The accelerometers give us the __________________ of the mass. The load cell measures ___________, and we have the potentiometers that measure the ____________________.

07:44

Biofidelity (circle *more* or *less*): The *more* or *less* biofidelic, the *more* or *less* like a human being it is in representing how it moves, what types of stresses it measures in the crash test, and then the true-to-lifeness of those measurements to the prediction of injury in a real person.

08:30

Crash anatomy

Let's start with some basic anatomy. The human body contains more than ________________ cells. The body is structurally organized into four levels: ________, ____________, ____________, and _____________________.

The body contains four large, fluid-filled spaces called ____________________ that house and protect the major internal organs.

11:30

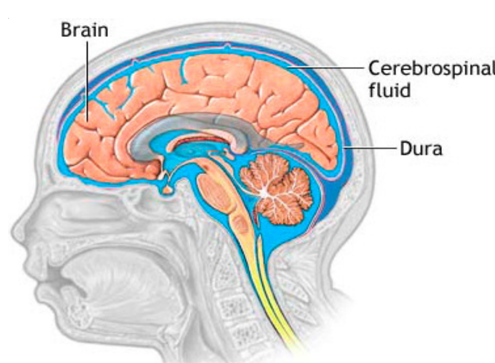
The third collision

The first collision is between the car and the __________. The second is between the driver and the ___________________. And the third is between the driver's _____________________ and the inside walls of his or her ____________________.

What do you think will happen to the brain during impact?
Circle one: Will it *move forward*, *move backward*, or *stay in the same spot*?

The initial movement of the gel or brain is toward the ________ of the skull.

This type of brain injury is called coup-contrecoup, which is a French term meaning ___________________________.



Stretch, twist, and tear

13:00 With the heart and its blood vessels, the ascending aorta and its arch are _______________ while the descending aorta is ___________.

Predict what will happen to the unsupported section of gel during the collision:

14:10 The unsupported section of gel _____________________________ and tears away from the supported gel.

Stress and strain

14:30 ______________ is a measure of the average deforming force exerted over a defined area of tissue. Stress produces ______________. Strain is a measure of how much the tissue ________________ as a result of the stress.

Three basic types of stress are _______________ stress from stretching, ___________________ stress from opposing forces, and ______________________ stress from uniform compression.

_______________ to human tissue is like failure to a structure.

Shockwaves

16:00 Shockwaves change ______________ and/or _________________ as they move through tissues of different densities producing complex wave interactions and stress on your organs.

Cell damage and death

Chemicals leaving the cell (circle three): *potassium, glutamine, phosphate, glucose, calcium*

Chemicals entering the cell (circle one): *glucose, calcium, potassium*

This failed auto-regulation can cause areas of the brain to become **ischemic**, that means inadequate _________________ delivery, and therefore are at risk of malfunction to the point of cellular death.

Building safer race cars

18:00 Crash recorders measure __________________________ in three directions.

Crash recorder data are used to design ___________________________________ that re-enact the crash and help produce design changes.

List three race car safety features brought about by the study of injury biomechanics:

1. ____
2. ____
3. ____

19:15

Crash testing at the Vehicle Research Center (VRC)

You try to design the structure of the car so that it crushes in front so you're bringing the car to a stop ___________________________________.

21:06

Bed of nails

Pressure is equal to the ____________ exerted on a surface divided by the total ____________ over which the force is exerted.

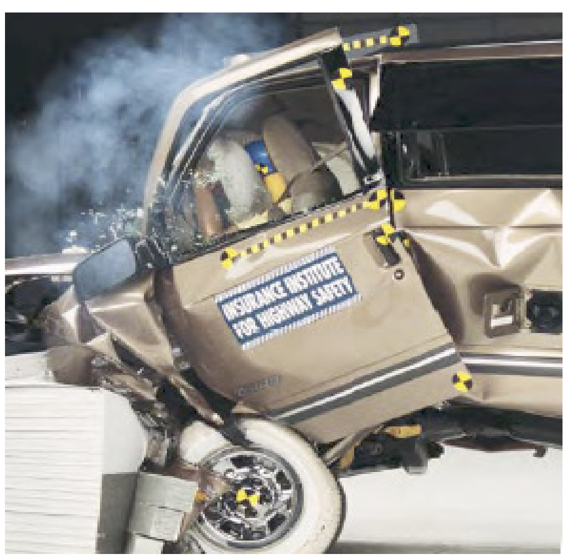
Pressure = _______________

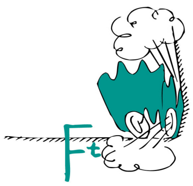
More nails means ____________ pressure.

22:18

Sundown

Keeping people safe in crashes has to do with extending ____________________, keeping the occupant compartment _________________, and _________________ the occupants to the compartment.





Teacher Organizer Answers

Understanding Car Crashes
When Physics Meets Biology

Video Concept Organizer

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1. Why is it that some spectacular race car crashes produce only minor injuries?

____Answers will vary____

____

2. How can three collisions occur in one crash between a car and a wall?

____ Answers will vary____

____

Running time 24 minutes

Part II: During the video
Directions: To help you remember the key science concepts discussed during the video, fill in the blanks or circle the correct answers.

01:36

What is the first scientific discipline that comes to mind when you think of car crashes? It's probably physics because ______Newton's laws of motion______ govern what happens to a vehicle in a crash.

But if we want to understand the effects of a crash on a human body, we need look at what occurs when physical ____forces ____ are applied to organs, tissues and cells, and this happens when physics meets biology in the field of ______injury biomechanics______.

History of crash research

04:04

________Colonel John Stapp________, a medical doctor and biophysicist in the United States Air Force, used himself as the test subject in his investigations of human tolerance to high *g* environments.

04:20

In one of his many tests, Dr. Stapp reached a speed of _632_ miles per hour before one of the most powerful braking systems of all time stopped him in _1.4_ seconds, subjecting him to more than 40 times the pull of gravity, or _40_ *g*s.

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Side impact dummy: The accelerometers give us the ___acceleration___ of the mass. The load cell measures ___force___, and we have the potentiometers that measure the ____displacement____.

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Crash anatomy

08:30

Let's start with some basic anatomy. The human body contains more than ___100 trillion___ cells. The body is structurally organized into four levels: __cells__, ___tissues___, ___organs___, and ____organ systems____.

The body contains four large, fluid-filled spaces called ____body cavities____ that house and protect the major internal organs.

The third collision

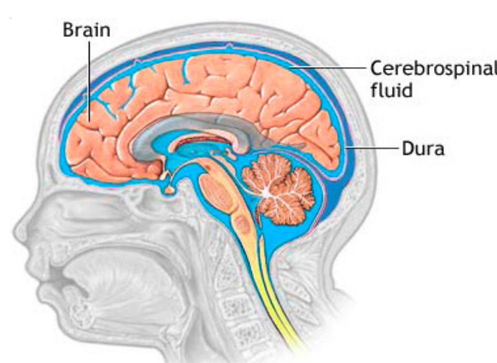
11:30

The first collision is between the car and the ___wall___. The second is between the driver and the ____car's interior____. And the third is between the driver's ____internal organs____ and the inside walls of his or her ____body cavities____.

What do you think will happen to the brain during impact?
Circle one: Will it *move forward*, *move backward*, or *stay in the same spot*?

The initial movement of the gel or brain is toward the __back__ of the skull.

This type of brain injury is called coup-contrecoup, which is a French term meaning ______blow-against-blow______.



13:00

Stretch, twist, and tear

With the heart and its blood vessels, the ascending aorta and its arch are ____mobile____ while the descending aorta is ___fixed___.

Predict what will happen to the unsupported section of gel during the collision:

14:10

The unsupported section of gel _____continues forward_____ and tears away from the supported gel.

14:30

Stress and strain

____Stress____ is a measure of the average deforming force exerted over a defined area of tissue. Stress produces ____strain____. Strain is a measure of how much the tissue _____deforms____ as a result of the stress.

Three basic types of stress are ____tensile____ stress from stretching, _____shearing_____ stress from opposing forces, and _____compressive_____ stress from uniform compression.

____Trauma____ to human tissue is like failure to a structure.

16:00

Shockwaves

Shockwaves change ____speed____ and/or ____direction____ as they move through tissues of different densities producing complex wave interactions and stress on your organs.

Cell damage and death

Chemicals leaving the cell (circle three): *_potassium*, *glutamine*, *phosphate*, *glucose*, *calcium*

Chemicals entering the cell (circle one): *glucose*, *calcium*, *potassium*

This failed auto-regulation can cause areas of the brain to become **ischemic**, that means inadequate _____oxygen_____ delivery, and therefore are at risk of malfunction to the point of cellular death.

18:00

Building safer race cars

Crash recorders measure ______accelerations______ in three directions.

Crash recorder data are used to design ________computer models________ that re-enact the crash and help produce design changes.

List three race car safety features brought about by the study of injury biomechanics:

1. ______six-point safety harnesses______________
2. ______rigid safety cages or “tubs”_______________
3. ______energy absorbing “head surrounds” ______

breakaway parts and energy absorbing walls are also acceptable answers

19:15

Crash testing at the Vehicle Research Center (VRC)
You try to design the structure of the car so that it crushes in front so you're bringing the car to a stop _________slowly over time__________.

21:06

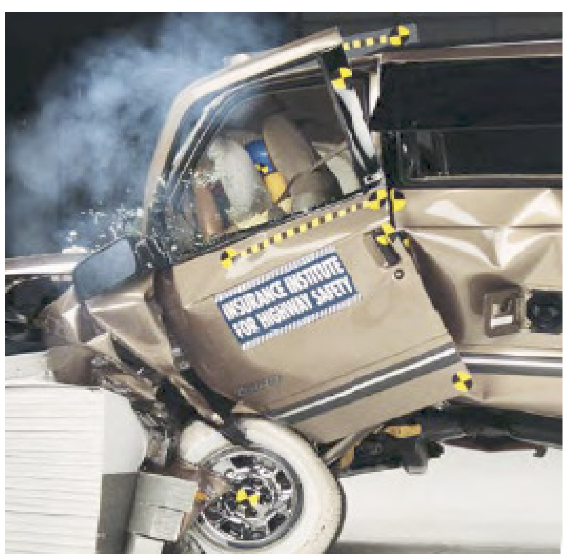
Bed of nails
Pressure is equal to the ____force____ exerted on a surface divided by the total ____area____ over which the force is exerted.

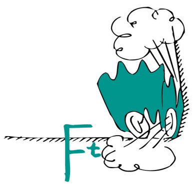
Pressure = ______F/A______

More nails means ____less____ pressure.

22:18

Sundown
Keeping people safe in crashes has to do with extending _____impact time_____, keeping the occupant compartment ______intact______, and ______tying______ the occupants to the compartment.





Name ______________________________ Period ______ Date __________

Student Post-Video Questions

Understanding Car Crashes
When Physics Meets Biology

Post-Video Questions

Directions
After viewing the video, answer the following questions in the space provided. Be prepared to discuss your responses while in small groups or as an entire class.

1. Historically crash research, like many scientific investigations, has required the cooperation and combined knowledge, skills, creativity, and passion of individuals from many different fields. Discuss how Col. John Stapp's research combined several different fields to save human lives.

____

____

____

____

2. Crash test dummies are tough, complicated and expensive, some costing over $130,000.

a) List the three types of measurements most dummies record.

____

____

____

b) Describe how these measurements are used to help predict crash injuries.

____

____

____

3. Explain how the term biofidelity is used to describe the effectiveness of crash test dummies in injury biomechanics research.

____

____

____

4. During a collision someone may experience a blunt force trauma to his/her chest. Summarize how the appropriate body cavity and major bones protect the person's heart and lungs.

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5. Describe the how three collisions can occur during a single crash between a truck and a wall.

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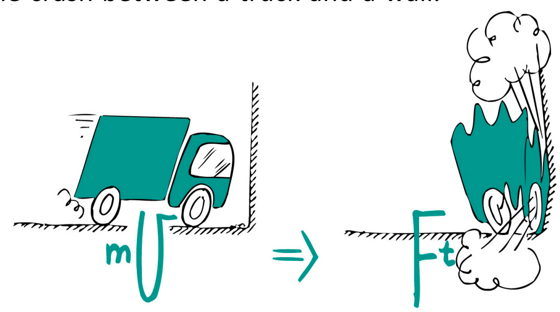
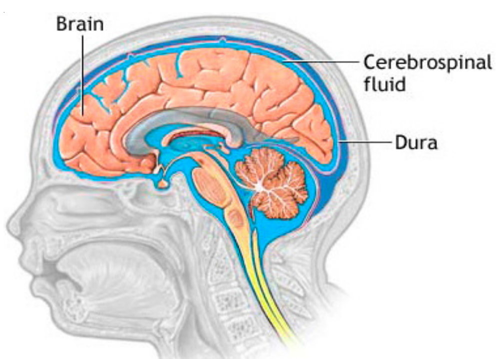


6. a) In the two images below, draw arrows to indicate the direction the brain and the cerebral spinal fluid are moving before and during a frontal collision resulting in a coup-contrecoup brain injury.

b) Write captions for each image that summarizes what is happening to the brain and the cerebral spinal fluid.



Before the collision

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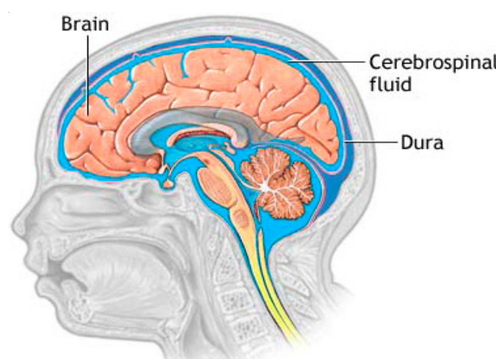


During the collision

____

____

____

7. The strength of any tissue or organ depends on many factors, such as its elasticity or the type of stress it experiences. Distinguish between stress and strain. Explain their effects on human tissue.

____

____

____

8. Describe how shockwaves create stress and strain that injure tissue.

9. Interpret this statement: Trauma to human tissue is like failure to a structure. In your answer, describe how **critical stress limit** relates to tissue trauma and structural failure.

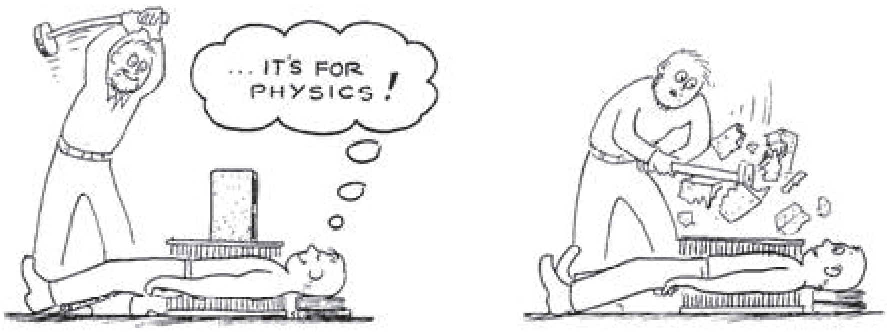
10. Analyze the photos below of Tony Kanaan's race car from the Andretti Green Racing Team. Circle and label three safety features of the car that help reduce forces on drivers thereby preventing injuries during a crash.

Tony Kanaan's race car

Dr. Jones buckling up

11. Describe how new technologies, such as crash recorders, help engineers build safer race cars.

12. In the video, a 223 pound crash test dummy was lowered onto Dr. Jones' chest while he was sandwiched between two beds of nails. Similarly, the diagram below shows a man lying between two beds of nails while having a concrete block shattered on his chest.



a) How are forces from his weight, the block, and the impact reduced to allow him to survive the experience?

____

____

____

b) How are the same physics concepts applied in the bed of nails demonstration utilized to improve a vehicle's crashworthiness?

____

____

____

13. One of the key principles to keeping people safe in crashes is extending impact time. If the change of momentum occurs over a long time, the force of impact is small. Examine the pictures below of the driver's area of a stock car. Circle and label safety features that reduce impact forces by extending the impact time.

Driver's seat inside a stock car

Steering wheel and dashboard of a stock car

Teacher Post-Video Answers

Understanding Car Crashes When Physics Meets Biology

Post-Video Questions

Directions
After viewing the video, answer the following questions in the space provided. Be prepared to discuss your responses while in small groups or as an entire class.

1. Historically crash research, like many scientific investigations, has required the cooperation and combined knowledge, skills, creativity, and passion of individuals from many different fields. Discuss how Col. John Stapp's research combined several different fields to save human lives.

By combining the sciences of biology, physics, human anatomy and physiology with engineering, mathematics and technology, Dr. Stapp's research helped establish the limits of human tolerance to high g environments and saved many lives through development and improvement of protective systems for ejection seats and passenger vehicles.

2. Crash test dummies are tough, complicated and expensive, some costing over $130,000.

a) List the three types of measurements most dummies record.

They measure acceleration, force, and in some cases distortion of the body parts. These measurements can be compared against similar measurements made in experiments on biological tissues, using either animal models or cadaver models, to get an idea of how much stress a body part takes before it breaks.

b) Describe how these measurements are used to help predict crash injuries.

In order to understand whether or not a person would be injured in a crash, you need to know how strong human bones and tissue are and what conditions will cause them to break.

3. Explain how the term biofidelity is used to describe the effectiveness of crash test dummies in injury biomechanics research.

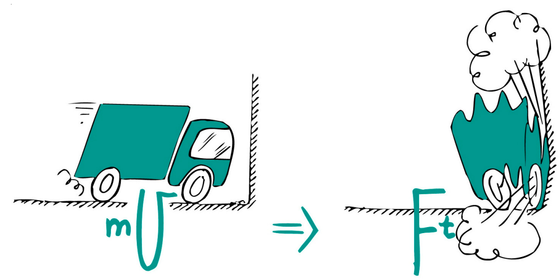
The higher the dummy's biofidelity, the more like a human being the crash test dummy is in representing how it moves, what types of stresses it measures in the crash test, and then the true-to-lifeness of those measurements to the prediction of injury in a real person.

4. During a collision someone may experience a blunt force trauma to his/her chest. Summarize how the appropriate body cavity and major bones protect the person's heart and lungs.

Within the thoracic body cavity the heart and lungs are suspended in fluid that supports their weight and prevents them from being deformed by normal movements. The heart and lungs are additionally protected by the rib cage and sternum.

5. Describe the how three collisions can occur during a single crash between a truck and a wall.

The first collision is between the truck and the wall.
The second is between the driver and the truck's interior.
And the third is between the driver's internal organs and the inside walls of his or her body cavities.



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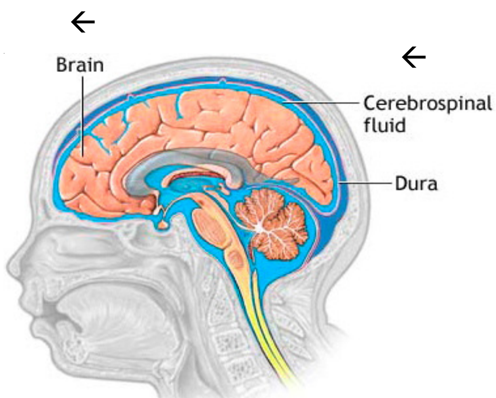
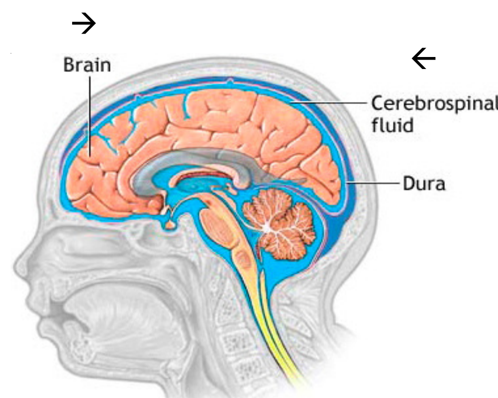
b) Write captions for each image that summarizes what is happening to the brain and the cerebral spinal fluid.



Before the collision

The brain is enclosed in a rigid case, the skull, and it's cushioned and surrounded by the cerebral spinal fluid. All are moving in the same direction.



During the collision

The more dense cerebral spinal fluid moves toward the site of skull impact displacing the brain in the opposite direction

7. The strength of any tissue or organ depends on many factors, such as its elasticity or the type of stress it experiences. Distinguish between stress and strain. Explain their affects on human tissue.

____

____

____

8. Describe how shockwaves create stress and strain that injure tissue.

As shockwaves move through tissue, the shearing and tensile stresses can stretch and tear the tissue. Stretching the tissue can create severe damage by disrupting normal cellular functions, such as active transport across the cellular membrane.

9. Interpret this statement: Trauma to human tissue is like failure to a structure. In your answer, describe how **critical stress limit** relates to tissue trauma and structural failure.

Every material, whether it's concrete or different types of human tissue, has a critical stress limit. Stay below the limit there is no damage or failure. Go beyond the stress limit and there is failure.

10. Analyze the photos below of Tony Kanaan's race car from the Andretti Green Racing Team. Circle and label three safety features of the car that help reduce forces on drivers thereby preventing injuries during a crash.

Tony Kanaan's race car

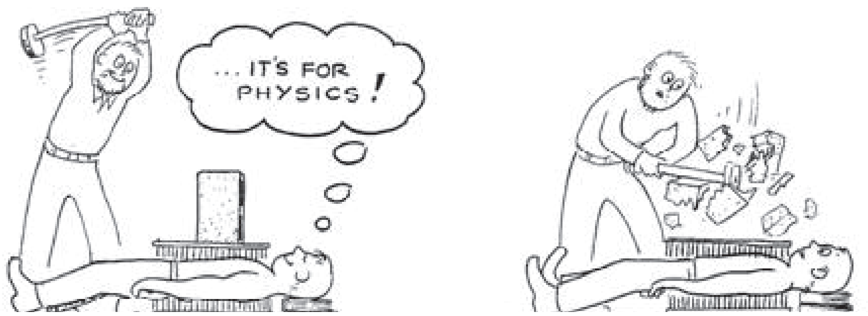
Dr. Jones buckling up

Safety features like six-point harnesses, rigid safety cages or "tubs", energy absorbing "head surrounds", and break away parts, have contributed to reducing forces on drivers and preventing injuries.

11. Describe how new technologies, such as crash recorders, help engineers build safer race cars.

Crash recorders allow scientists and engineers to measure accelerations in three directions. This data is used to make more accurate computer models to re-enact the crash and determine where and how injuries occur. Safety design changes are made based on this data.

12. In the video, a 223 pound crash test dummy was lowered onto Dr. Jones' chest while he was sandwiched between two beds of nails. Similarly, the diagram below shows a man lying between two beds of nails while having a concrete block shattered on his chest.



a) How are forces from his weight, the block, and the impact reduced to allow him to survive the experience?

Much of the force from his weight and the weight of the block is distributed over the large number of nails that make contact with his body. This reduces the pressure on any one nail. The inertia of the block and that it breaks apart contribute to reducing the force applied to his skin.

b) How are the same physics concepts applied in the bed of nails demonstration utilized to improve a vehicle's crashworthiness?

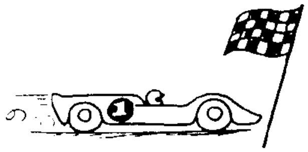
Widening seat belts and rounding edges on objects that may come in contact with occupants during a collision reduce pressure by distributing the impact forces over a greater area. Break-away parts in race cars help dissipate the kinetic energy during a collision.

13. One of the key principles to keeping people safe in crashes is extending impact time. If the change of momentum occurs over a long time, the force of impact is small. Examine the pictures below of the driver's area of a stock car. Circle and label safety features that reduce impact forces by extending the impact time.

Driver's seat inside a stock car

Steering wheel and dashboard of a stock car

Padded head surround, padded steering column, padded steering wheel, padding around support rods. By hitting the padded areas instead of hard surfaces, you extend the contact time – the time during which your momentum is reduced to zero. A longer contact time reduces the impact force. For example, if the time is extended 10 times, the force of impact is reduced 10 times. The exact relationship is impulse equals the change in momentum or $F\Delta t = \Delta(mv)$.



TEACHER LESSON 1

"Crash Course" Activity

Think Fast, Act Fast!

Crash course definitions

speed: distance covered divided by unit of time (ex. meters per second or mph)

***"g"*:** the symbol for the acceleration due to gravity, equal to 9.81 m/s^2 at the earth's surface

Key questions

- Is your reaction time fast enough to help you avoid a car collision?
- How far can a car travel during your reaction time?

Grade levels: 9 - 12

Time required: 30 - 40 minutes

Objectives

Students will be able to:

- Calculate their reaction time using a measured distance.
- Calculate the distance a car travels during their reaction time.

National Science Education Standards

- Standard A: Science as Inquiry
  - Identify questions and concepts that guide scientific investigations
- Standard B: Physical Science
  - Motion and forces
- Standard C: Life Science
  - The behavior of organisms
- Standard F: Science in Personal and Social Perspectives
  - Natural and human-induced hazards

Background information

Experimental psychologist, physiologists, and even batting coaches have used reaction time tests to gauge human mental and physical performance. In general, reaction time is defined as the elapsed time between the presentation of a sensory stimulus and the following behavioral response. There are three basic types of reaction time experiments: 1) simple reaction time with one stimulus and one response (i.e., pressing a button at the sound of a buzzer); 2) recognition reaction time with recognized stimuli mixed with unrecognized detractors (i.e., pressing a button when a familiar voice is heard); and 3) choice reaction time experiments where the participant provides a response that corresponds to the stimulus (i.e., pressing the matching keyboard key of the letter appearing on the screen).

Many studies have indicated that reaction to sound stimuli is faster than reaction to light. Due to physiological differences there is no single accepted value for simple reaction times. Typical mean reaction times for college-age individuals are between 140-160 milliseconds (0.14 -0.16 seconds) to detect sound stimuli and between 180 to 200 milliseconds (0.18-0.20 seconds) to detect visual stimuli.

Various factors can affect someone's response time (i.e., visual or auditory distractions, too much sugar or caffeine in the diet, stress, lack of sleep, alcohol, personality type, physical fitness, better hand-eye coordination, age, brain injury, etc.). Most teenagers have a very good response time but distractions while driving (i.e., eating, listening to loud music, or talking on the phone) may slow their response time.

Distractions of any type are a common factor in crashes of newly licensed 16-year-old drivers. Some research shows teenage drivers tend to use cellphones and other emerging technologies more than adult drivers. States increasingly have graduated licensing laws that place restrictions on newly licensed drivers (e.g., limiting nighttime driving and the number of passengers a novice driver can carry). Cellphone bans are being added to those restrictions.

Materials needed

For each group:

- dollar bill or paper strips of equivalent size (1)
- metric ruler or meter stick (1)
- calculator with square root function (1)
- student activity sheets (2)
- pencils (2)

Advance preparation and safety considerations

If dollar bills are not available or advisable, cut strips of paper to the equivalent size. Assemble the materials for each group. ***There are no significant safety concerns. Discourage "ruler twirling" on pencils.***

Procedure

1. Request two student volunteers to come to the front of the classroom. Ask them who has the fastest reaction time. Tell them you have a test that decides who has the fastest reaction time.

2. Pull a dollar bill from your pocket and announce if they catch it they can keep it (or they can get extra credit).

    a. The student trying to catch the dollar should rest their arm on the edge of a table or desk with their thumb and forefinger 3.0 cm apart.
    b. The person dropping the dollar bill should hold it so George Washington's face is even with the catcher-student's fingers (see Figure 1).

Figure 1

c. Try to avoid giving the student-catcher an unintended hint of the bill's release. Also, make sure the dollar bill is completely vertical to allow it to drop straight down.
d. Drop the dollar bill. It is very difficult for someone to catch a dollar bill with only one-half the dollar bill starting above his or her fingers. Allow each volunteer several tries to catch the bill.
e. Ask the class how they could change the experiment to improve the volunteers' chances of catching the bill. Have one of the volunteers list the responses on the board (i.e., decrease the 3.0 cm space between their forefinger and thumb, give the catcher a warning when you intend to drop the bill, drop the bill from a greater height to allow more of the bill to drop through their fingers, give the catcher some caffeine, or lengthen the dollar bill).
f. Try the drop again but this time substitute a metric ruler or meter stick for the dollar bill.

3. Inform students that reaction time is the elapsed time between the presentation of a sensory stimulus and the desired behavioral response (i.e., catching the bill, pressing a button, moving a foot from a car's accelerator to the brake).

4. Ask students to predict what fraction of a second it took for the volunteers to catch the ruler (i.e., tenth, hundredth, thousandth). Reaction times are usually measured in 1/1000 of a second (1 millisecond = 0.001 second or 1000 milliseconds = 1 second). Inform students they will use the ruler to help them calculate their reaction times.

5. Distribute the materials and review the procedures for dropping the dollar bill or paper strips (Step 2 a-d). Students may practice with a dollar bill or paper strips. When they are ready to begin their measurements have them drop and catch metric rulers or meter sticks. For dropping the ruler make sure the students:

   a. Position the zero centimeter mark (0.0 cm) of the ruler level with the top of the catcher's open fingers.
   b. As with the dollar bill drop, the catcher should rest their arm on the edge of a table or desk with their thumb and forefinger 3.0 cm apart.
   c. Try not to give the catcher any advance notice of the drop.
   d. Have students record the distance from the bottom of the ruler to the bottom of their fingers to the nearest millimeter. Record 10 trials in the data table record.
   e. Each partner should complete 10 trials and record only their own trials on their data table.

6. To calculate reactions, use the measured distance (d) and the formula:

$$d = \frac{1}{2} g t^2$$

t = is the time it takes the dollar bill to fall through the students' fingers before it is caught (a.k.a., their reaction time)

g = is the symbol for the acceleration due to gravity (at the earth's surface, 9.81 m/s^2)

   a. Depending on their mathematical skills, you my ask students to show how to solve the formula, $d = \frac{1}{2} g t^{2,}$ for time or you may guide them through the following steps:

$$d = \frac{1}{2} g t^2$$
$$2d = g t^2$$
$$2d/g = t^2$$
$$t = \sqrt{2d/g}$$

b. Since the distance, d, was measured in centimeters the acceleration of gravity value, g, must be converted from 9.81 m/s^2 to 981 cm/s^2.

On the student activity sheet the formula has been simplified further by calculating $\sqrt{2/981}$ for the students. To give:

$$\mathbf{t = 0.0452\sqrt{d}}$$

Example: student catches the ruler at the 12.2 cm mark (d = 12.2 cm)

$$t = 0.0452\sqrt{12.2\text{cm}} = 0.158 \text{ s}$$

7. Have students calculate their average reaction time.

Answers to Analysis questions

1. Did your reaction times vary throughout the trials? Explain.

As the number of trials increase the students' reaction time tends to decrease. Due to physiological differences there is no single accepted value for reaction time. Typical reaction times are between 0.13 - 0.50 seconds. The students can develop a range for reaction times based on lab data.

2. a) Describe factors that could affect someone's response time.

Answers will vary. Visual or auditory distractions, too much sugar or caffeine in the diet, stress, lack of sleep, better hand-eye coordination, etc.

b) What conditions or distractions might slow your reaction time while driving?

Talking or texting on the cellphone, socializing with passengers, operating stereo, etc.

Answers to Crash questions

3. Analyze Figure 2 illustrating an overview of information processing by nervous systems. In general, your nervous system's response to stimuli occurs in three stages: 1) sensory input, 2) integration, and 3) motor output. Imagine while driving you must react quickly and step on the brake pedal. Explain the order information is processed by your central nervous system (CNS) and peripheral nervous system (PNS), and the role your CNS and PNS, along with your senses and muscles, play in reacting to the visual stimuli to hit your vehicle's brakes.

Sensory neurons transmit information from the eyes through the peripheral nervous system to the central nervous system. The sensory information is then analyzed and interpreted producing a motor output. The motor output travels back through the PNS to the muscle cells in the leg.

4. You are driving 72 km/hr (45 mph) and an incident forces you to quickly hit your brakes. Calculate how far your car travels during your average reaction time?

Report your answer in meters and feet (72 km/hr = 20 m/s or 45 mph = 66 ft/s).

Assuming the car's velocity does not change significantly during the reaction time of moving the foot from the accelerator to the brake, the distance is equal to the velocity multiplied by the reaction time, d = velocity × time.

The distance your car will travel is found using **d = velocity × time**

> *d = velocity × time*
> *d = 20 m/s × 0.158s = 3.2 meters   or   d = 66 ft/s × 0.158s = 10 feet*

5. How does the distance calculated in question #4 factor in to the total braking distance required to bring your car to a stop?

The distance the car travels during the reaction time must be added to the optimum braking distance required to bring the car to a stop.

Extensions

1. Cellphone bans for young drivers are becoming commonplace amid concerns about the role distractions play in teenagers' elevated crash risk. First, have students read and summarize the research on cellphones and driving from the Insurance Institute for Highway Safety website (http://www.iihs.org/research/qanda/cellphones.html). Second, ask students to design an argument supporting or fighting a graduated licensing law banning cellphone use by novice drivers.

2. Have students explore the following websites on reaction time:

- A Literature Review on Reaction Time by Robert J. Kosinski, Clemson University, Sept. 2008
  http://biae.clemson.edu/bpc/bp/Lab/110/reaction.htm

- Fastball Reaction Time with the Exploratorium
  http://www.exploratorium.edu/baseball/reactiontime.html

- A Different Reaction Time Test from National Research Council Canada
  http://www.nrc-cnrc.gc.ca/eng/education/teachers/space/reaction.html

Name ________________________ Period ____ Date ______

"Crash Course" Activity

Think Fast, Act Fast!

Crash course questions

- How fast is your reaction time?
- How far can a car travel during your reaction time?

Purpose

- To calculate reaction time using a measured distance.
- To calculate the distance a car travels during your reaction time.

Materials needed

For each group:

- dollar bill or paper strips of equivalent size (1)
- metric ruler or meter stick (1)
- calculator with square root function (1)
- student activity sheets (2)
- pencils or pens (2)

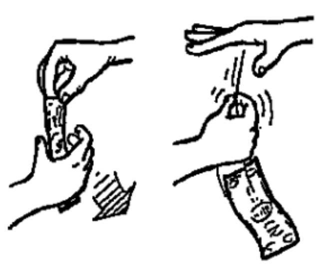
Discussion

Experimental psychologists, exercise physiologists, and even batting coaches may use human reaction times to gauge mental and physical performance. How fast can your nervous and muscular systems work together to catch a falling object?

Procedure

1. <u>Catching the dollar:</u> Rest your forearm on a table, with your hand beyond the edge and your thumb and forefinger 3.0 cm apart. Have your partner hold a dollar bill with the mid-point positioned between your thumb and forefinger.

2. Ask your partner to drop the dollar bill without advance warning. Try to catch it by pinching your fingers shut as quickly as possible. Alternate with your partner. Try releasing the bill with more or less of the bill between their fingers. Does the starting position of the bill affect your chances for success?



3. <u>Catching the ruler:</u> When you are ready to begin your measurements, substitute a metric ruler for the dollar bill. Follow Steps a-c for dropping the ruler:

   a. Position the zero centimeter mark (0.0 cm) of the ruler level with the top of the catcher's open fingers. See Figure 1.

   b. As with the dollar bill drop, the catcher should rest their arm on the edge of a table or desk with their thumb and forefinger 3.0 cm apart.

   c. Tell your partner to catch the ruler with only their thumb and forefinger. Try not to give the catcher any advance notice of the drop.

   d. Measure the position of their fingers on the ruler when they catch it (measure to the nearest millimeter from 0.0 cm to the bottom of their fingers. Example: 12.3 cm).

   e. Each partner should complete 10 trials and record only their own trials on their data table.

Figure 1

4. Calculate reaction times, using the measured distance (d) and the formula:

$$\mathbf{t = 0.0452\sqrt{d}}$$

t = reaction time
d = distance ruler dropped, measured in centimeters (cm)

5. Calculate and record your average reaction time for 10 trials.

Analysis

1. Did your reaction times vary throughout the trials? Explain.

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2. a) Describe factors that could affect someone's response time.

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b) What conditions or distractions might slow your reaction time while driving?

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Measured distance d (cm)	Calculated reaction time $t = 0.0452\sqrt{d}$ (s)
Average reaction time for 10 trials:	

Crash Questions

3. Analyze Figure 2 illustrating an overview of information processing by nervous systems. In general, your nervous system's response to stimuli occurs in three stages: 1) sensory input, 2) integration, and 3) motor output. Imagine while driving you must react quickly and step on the brake pedal. Explain the order information is processed by your central nervous system (CNS) and peripheral nervous system (PNS), and the role your CNS and PNS, along with your senses and muscles, play in reacting to the visual stimuli to hit your vehicle's brakes.

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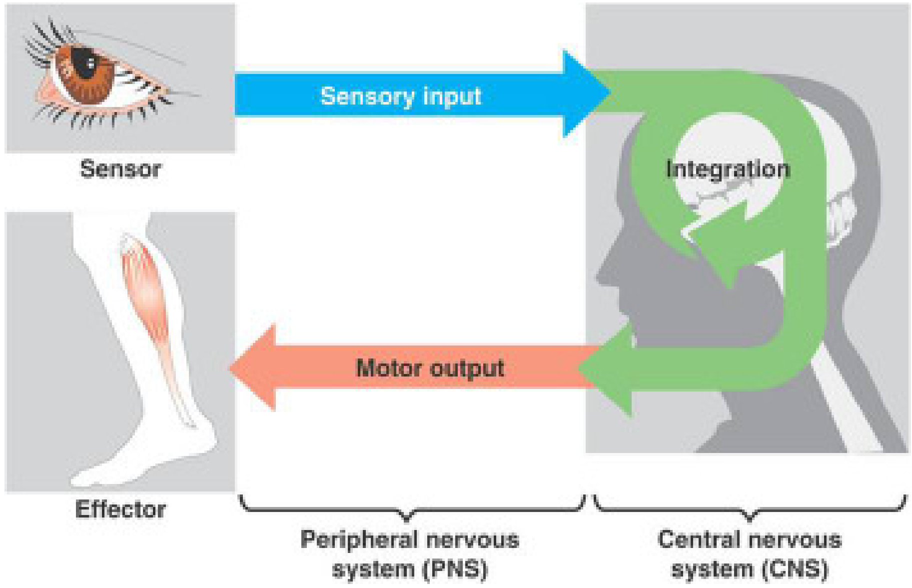

Figure 2
(Campbell N.A., Reece, J.B., BIOLOGY, 7th ed., Pearson Publishing, p.1013)

4. You are driving 72 km/hr (45 mph) and an incident forces you to quickly hit your brakes. Calculate how far your car travels during your average reaction time?

Report your answer in meters and feet (72 km/hr = 20 m/s or 45 mph = 66 ft/s).

The distance your car will travel is found using **d = velocity × time**

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5. How does the distance calculated in question #4 factor in to the total braking distance required to bring your car to a stop?

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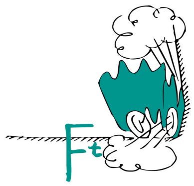


TEACHER LESSON 2

"Crash Course" Activity

Paper Car CRASH!

Crash course definitions

crashworthiness: how well a vehicle protects its occupants in a crash

impulse: product of force and time interval during which the force acts, equals momentum change, $F\Delta t = \Delta(mv)$

momentum: the product of mass and velocity of an object, $p = m \times v$

Key questions

- Can you design and build a fast and heavy race car using only paper and glue?
- Can your paper car carry an egg down a race track and protect it during a crash with a concrete barrier?
- What determines a vehicle's crashworthiness?

Grade levels: 9 - 12

Time required: Varies with ability. Can be done in as little as one school week or extended to incorporate more content knowledge integration, data collection, and laboratory reports.

Objectives

- Students will design a paper car that will travel fast and protect an egg as it crashes into a concrete barrier.
- Students will describe a collision in terms of momentum changes, impulses, impact forces, and impact times.

National Science Education Standards

- Standard A: Science as Inquiry
  - Identify questions and concepts that guide scientific investigations
  - Design and conduct scientific investigations
- Standard B: Physical Science
  - Motion and forces
- Standard E: Science and Technology
  - Abilities of technological design
  - Understanding about science and technology
- Standard F: Science in Personal and Social Perspectives
  - Natural and human-induced hazards

Background information

Newton's first law of motion describes how once an object is moving it will remain moving unless friction or another outside force, like a wall, stops it. This is **inertia** of motion, or **momentum**. The momentum of a moving object is related to its mass and/or velocity. A rolling marble can be stopped more easily than a bowling ball. Both balls have momentum. However, the bowling ball has more momentum than the marble. A moving object has a large momentum if it has a large mass, a large velocity, or both.

Momentum = mass of object × velocity of object

To change an object's momentum the mass, velocity, or both must change. If the mass remains constant, then the velocity changes and the object accelerates. In his second law, Newton said in order to accelerate (or decelerate) a mass a **force** must be applied. The way it's often expressed is with the equation F=ma. The force "F" is what's needed to move mass "m" with an acceleration of "a". The greater the force on an object, the greater its acceleration, or the greater its change in velocity, and therefore, the greater its change in momentum.

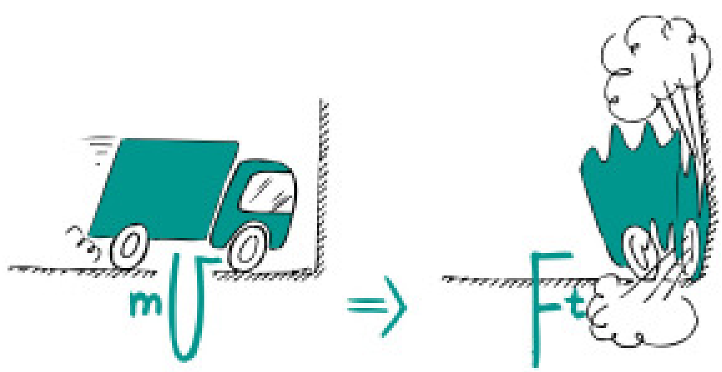
How long the force acts is also important. Apply the brakes briefly to a coasting car, and you produce a small change in its momentum. Apply the same braking force over an extended period of time and you produce a greater change in the car's momentum. So to change something's momentum both force and time are important. The product of force and the time it is applied is called **impulse**.

Impulse = force of impact × time of impact

The greater the impulse exerted on an object, the greater its change in momentum. For example, baseball batters swing hard to maximize the impact force and follow-through to maximize the impact time.

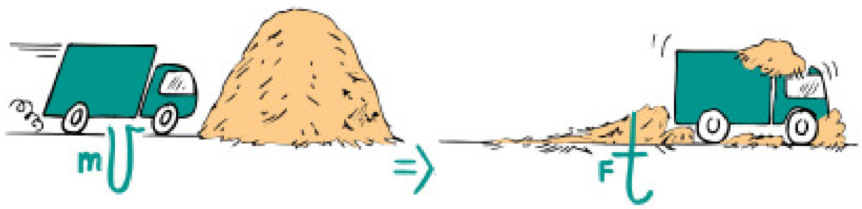
If an object, like a truck, is moving with a large momentum then it will take a large impulse to stop it. Since an impulse is the combination of the impact force and the impact time, two stopping scenarios are possible.

- Case #1: Stop the truck with a large impact force applied over a short time (i.e. truck hits a brick wall with major damage).



Case 1

- Case #2: Stop the truck with a small impact force applied over a long time (i.e., truck hits a hay stack and gradually slows to a stop with very little damage).



Case 2

The amount of damage in a collision is related to the time during which the force stopped the object. Safety features in cars, such as airbags, padded dashboards, and crumple zones stop occupants with less damage by applying a small force over a large time interval. To bring the egg to a stop, the safety features in students' paper cars must change the egg's momentum by providing an impulse comprised of a small impact force applied over a long impact time.

Materials needed:

Teacher provides:

- 10' vinyl gutters* (2), Genova RAINGO® Gutters RW 100
- Gutter connectors* (1), Genova RAINGO® Gutter Slip Joints, RW 105
- wheels* (4 per student)
- axles* (2 per student, 6 cm each)
- drinking straw (1 per student, used only for axle housing)
- paper (2 sheets per student of 8 ½" x 11" standard-weight copy paper)
- ladder, 6' or 8'
- lab stool or smaller ladder (1)
- brick wall or concrete block (1)
- pan balance or digital balance (1)
- masses, 1 set with at least 200 grams
- stopwatches (minimum of 2)
- meter stick or metric tape measurer (1)
- eggs, large Grade A (1 per student)
- student activity sheets (1 per student)

Student provides:

- glue (any type, hot glue is recommended)
- decorations (no stickers or paint)

Optional classroom supplies:

- photogate timer
- calculators
- hot glue guns and glue sticks

*Track and car supplies available from:

- PITSCO (http://pitsco.com/), Lx Wheel, W30846, 100 pack, approxiamate cost $9.00, Axles 1/8" solid rod for axles, W54576, approximate cost $1.50 each.
- RAINGO® Gutters and slip joints available from most large home improvement centers. Manufactured by Genova Products, 7034 East Court Street, Davison, Michigan 48423, approximate costs $8.00 each for 10' section, $4.00 each for slip joint.
- Science Kit & Boreal Laboratories (http://sciencekit.com), Crash & Race Track Kit, WW64631M01, provides track, wheels, and axles, approximate cost $83.00.

Advance preparation and safety considerations

If possible, assemble enough materials to allow every student to build a car. If resources are limited, allow teams of two or three students to work on one car. Cut axles to 6 cm length using small hacksaw or large bolt cutters. Assemble glue guns and glue sticks if you plan on allowing students to work on their cars during class time. Acquire two 10' sections of vinyl gutter, one slip joint connector, and a 6' or 8' ladder.

Hot glue guns can burn skin and clothes. Teacher supervision may be needed with some students.

Scissors can cut skin. Caution students to always direct a sharp edge or point away from themselves and others.

Procedure

1. Ask students to think about how people survive major vehicle collisions. Explain that scientists and engineers apply the laws of physics to reduce damage to both cars and passengers. Define **crashworthiness** (how well a vehicle protects its occupants in a crash). Explain that during this project, they will design and build a crashworthy paper car to protect a raw egg during a collision with a brick wall.
2. Determine if students work alone, with partners, or in small groups. Suggestion: Have high school students brainstorm initial ideas in small groups but require each student to build their own car or with a partner.
3. Distribute two sheets of paper, wheels, axles, and straws per student or team. Colored copy paper is recommended to discourage students from adding paper from an "illegal" source.
4. Distribute copies of student activity sheet.
5. Emphasize the importance of the building criteria. Cars wider than the 6.5 cm will not fit on the crash track. Teacher (or students with supervision) must cut each axle to the proper length to ensure the combined width of both wheels and axle does not exceed 6.5 cm.
6. Assemble crash track. Connect two 10' sections of vinyl gutter with a gutter slip joint connector. Place one end of the track near the top step of the ladder. Place the other end against a brick wall or concrete brick. Support the middle of the track with a lab stool or smaller ladder.
7. Check cars' length, width, and mass. Allow students class time to correct or modify their vehicles before competition day.
8. Have students measure the mass of a large Grade A egg (approximately 60 grams). Tell students to place an egg-equivalent amount of mass in their cars for their test runs. This allows for a test run without the possible mess of broken eggs.
9. Allow students to test run their cars a day prior to the competition. For test runs, do not put the end of the crash track against brick wall or concrete block barrier. Allow cars to roll freely across floor after coming to the end of the track.
10. Have students estimate the distance the egg will move within their car upon impact. This will be the crush distance of the egg. Record the estimate in centimeters on their lab report sheet under crush distance.

11. Optional: Have students measure their car's final velocity using a photogate timer. Attach an index car to a student's car. Place a photogate timer at the end of the track and adjust its height to allow the card to pass through the timer (see Photo 1). Divide the width of the index card by the photogate time measured at the end of the run.

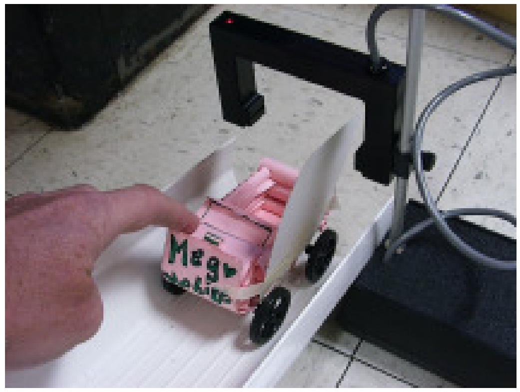


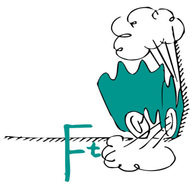
Photo 1

12. Competition day! Place end of track against brick/cement wall or concrete block. For first round crashes, place starting end of track on next to top step of ladder. Have students place an egg in their car. Release car for crash run. Use a stopwatch to record time of run. Cars that protect the egg from braking advance to round two.
13. For round two, raise starting end of track to the top of the ladder. If a third round is necessary, raise the starting end further by pulling the ladder forward a few feet. This will put the track at a greater angle thereby raising the starting end.
14. If a tiebreaker is needed, have students calculate a rough estimate of their cars' momentum. The car with the greatest momentum and an unbroken egg wins.
    a. An accurate calculation of each car's momentum upon impact is difficult unless an accurate photogate time is measured during the crash run. Since acquiring a good reading on the photogate can require several attempts, waiting to record it during the crash run is not recommended. The momentum may be estimated from the previous day's test runs (Step 9).
    b. With photogate: If students used a photogate timer during the test runs to calculate the final velocity, use that final velocity and car's total mass with the egg to calculate its momentum.
    c. Without photogate: If a photogate was not available, a rough estimate of the final momentum can be calculated by multiplying the car's average velocity and its total mass with the egg. Average velocity is calculated by dividing total distance the car traveled by the total time of the run.

Extensions

Have students explore the Insurance Institute for Highway Safety website (www.iihs.org) to answer the following questions:

- How do airbags protect occupants in a crash?
- How many lives have been saved with airbags?
- Do you have a little brother or sister that uses a car seat? How can you reduce their risk of an airbag injury?
- How effective are side airbags with head protection?



Name ______________________________ Period ______ Date __________

STUDENT ACTIVITY 2

"Crash Course" Activity

Paper Car CRASH!

Crash course questions

- How is it possible to build a crashworthy car from paper and glue strong enough to carry and protect an egg during a crash?
- What determines a vehicle's crashworthiness?

Purpose

- to apply your science knowledge and skills to design and build a crashworthy vehicle.

Materials needed

Teacher provides:

- paper (2 sheets)
- wheels and axles
- drinking straw (used only for axle housing)
- egg, large Grade A

Student provides:

- glue (any type)
- decorations (no stickers or paint)

Discussion

Science and engineering inquiries often require a variety of skills to identify problems or needs and to change and improve designs. Traits such as reasoning, insight, energy, creativity, persistence, and openness to new ideas must be combined with a good knowledge base for success in science and engineering. With that in mind, consider the following questions as you begin designing your crashworthy vehicle:

- Should your vehicle be rigid, or is it better if it collapses?
- Should the egg be able to move, or should it be held immobile?
- What kinds of paper structures will absorb the force of impact?
- How can your vehicle be designed to easily remove and inspect the egg?

Procedure and rules

Your challenge is to design and build a fast and heavy race car using only two sheets of paper and unlimited amounts of glue. In addition, your paper car must carry an egg down a race track and protect it during a crash with a concrete barrier. Your teacher will provide the wheels, axles, and axle housing for your car. The car with the greatest momentum and an unbroken egg wins. Read the rules listed below before beginning your design process.

1. Maximum car width no more than 6.5 centimeters (including axles and wheels).
2. Maximum car length no more than 16.5 centimeters.
3. Minimum car mass without the egg is 40 grams.
4. Glue, paper, wheels, axles, and straw-axle housing are the only materials allowed.
   - No cardboard or tape.
   - Entire body of the car must be made of paper and glue.
   - Wheels, axles, and the straw are the only non-paper items.
   - Drinking straw may only be used as axle housing.
   - Designs must allow for easy removal and inspection of the egg.
   - Decorations must not contribute to the structural integrity of the vehicle.
   - No stickers or paint.
5. There will be no physical contact between the device and the designer once the vehicle has been released.
6. The egg will be provided by the instructor and put into the vehicle on competition day.
7. Repairs requiring additional materials will not be allowed once the competition begins.
8. All vehicles must display the following:
   - vehicle name
   - builder's name
   - vehicle's length in centimeters
   - vehicle's mass in grams

Project point values: 67 points total

Category	**Points**	**Description**
Creativity	5	Design or some of its features are unique.
Construction quality	10	Construction shows evidence of quality time and effort in the building process.
Performance	6	Carries the egg the entire length of the track during test runs.
Measurements	6	Meets requirements of length, width, and mass.
Analysis	40	Answers analysis questions thoroughly and accurately.
Total	**67**	
Extra credit	+1	Designs that keep the egg from cracking receive extra credit of 1 point per un-cracked crash on competition day.

Analysis

Submit a report that addresses the questions below.

1. Purpose (2-3 sentences): Provide a brief statement describing the project and how it is relevant to your real-world experiences.

2. Variables (2-4 sentences): Identify and define the quantities you are measuring and the variables that will affect your project's performance.

3. Materials (list): List materials and quantities used to construct your project.

4. Methods (2 paragraphs): Describe how you constructed your project. Summarize the problems you encountered during the building process and how you solved them.

5. Photograph or diagram (1 page): Include a photograph or large hand-drawn picture of your vehicle. Label key design features.

6. Data: Construct a data table that provides the following (include units):
   a. distance traveled by car
   b. total time of run
   c. width of car
   d. length of car
   e. mass without egg
   f. mass with egg
   g. photogate time at end of run (if photogate used)
   h. length of photogate-note flag (if photogate used)

7. Calculations: Show all equations and calculations used to obtain the quantities listed below (if photogate was available, use the final velocity to calculate the momentum; otherwise, use the average velocity but realize this will only provide an estimate of the actual momentum).

   - Photogate used: Calculate final velocity from the photogate then use it to calculate the momentum of the car prior to impact.

     final velocity = width of photogate-index card ÷ photogate time

   - Photogate NOT available: Use average velocity to calculate momentum.

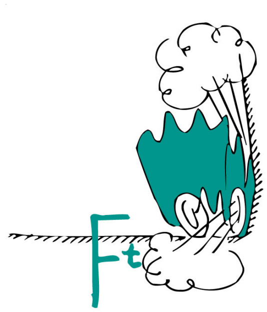
     average velocity = total distance traveled by car ÷ total time of distance traveled

   - Calculate the car's momentum before impact using this equation:

     momentum = (total mass of car with egg) (final or average velocity)

8. Performance assessment (1 paragraph): Citing the measured and calculated data, describe the performance of your car and whether it met your expectations.

9. Conclusion (4-5 paragraphs):
   a. Explain how you designed your car to protect the egg.
   b. Compare your car's performance to another car in the class.
      - What were the strengths and weaknesses of each design?
      - Cite data and calculations to support your assessments.
   c. There is always room for improvement in a design. How would you modify your car to improve its performance?



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