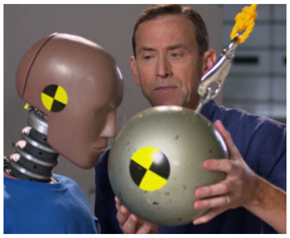
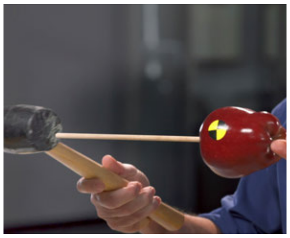
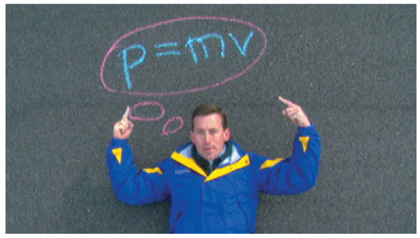

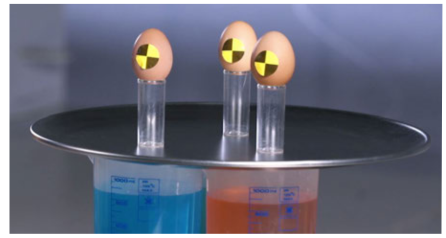

Crash Science in the Classroom

Griff Jones, Ph.D.

Edited by Linda Cronin-Jones, Ph.D.



Grades 5-12

Teacher lesson plans & student activities to accompany **classroom.iihs.org** and the **Understanding Car Crashes** videos

CRASH SCIENCE IN THE CLASSROOM

By
Griff Jones, Ph.D.

Edited by
Linda Cronin-Jones, Ph.D.

Production and graphic design by
E-Learning, Technology and Communications Services
College of Education, University of Florida

Presented by
Insurance Institute for Highway Safety
Highway Loss Data Institute

The Insurance Institute for Highway Safety (IIHS) is an independent, nonprofit scientific and educational organization dedicated to reducing deaths, injuries and property damage from motor vehicle crashes through research and evaluation and through education of consumers, policymakers and safety professionals.

The Highway Loss Data Institute (HLDI) shares and supports this mission through scientific studies of insurance data representing the human and economic losses resulting from the ownership and operation of different types of vehicles and by publishing insurance loss results by vehicle make and model.
Both organizations are wholly supported by over 100 auto insurers and insurance associations. For more information go to www.iihs.org

The **Crash Science in the Classroom** program provides students, parents and educators access to research-based educational resources relevant to crashworthiness and crash avoidance technologies that promote safer behaviors when riding in or driving a vehicle. For more information go to classroom.iihs.org

IIHS collaborated with the University of Florida College of Education's Department of E-Learning, Technology and Communications Services (ETC) to create the Crash Science in the Classroom website. ETC's role included front-end website design, back-end website development, videography, photography and instructional design.
For more information go to education.ufl.edu/etc.

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The Next Generation Science Standards (NGSS) were developed by 26 states, in collaboration with the National Research Council, the National Science Teaching Association and the American Association for the Advancement of Science in a process managed by Achieve, Inc. Neither Achieve, Inc. nor the states and partners that developed the NGSS were involved in this product and do not endorse it. For more information go to www.nextgenscience.org

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Griff Jones is an emeritus clinical associate professor of science education in the College of Education at the University of Florida (UF). As part of his grant work and affiliation with both the elementary and secondary science teacher education programs at UF he has developed and taught numerous undergraduate and graduate level science content and pedagogy courses for pre-service K-12 teachers. Dr. Jones has held joint appointments as a Faculty Fellow with UF's Center for Entrepreneurship and Innovation and as an Affiliate Faculty member for the College of Engineering's Transportation Institute. Dr. Jones specializes in designing hands-on, inquiry-based, interdisciplinary science programs for both K-12 and post-secondary level audiences. He has authored several highly successful and nationally-disseminated science textbooks, curriculum guides, online-course materials, and journal articles regarding innovative science teaching strategies.

Prior to becoming a university faculty member, Dr. Jones was a classroom teacher and science department chair at UF's K-12 P.K. Yonge Developmental Research School for 20 years. During that time, he developed state and nationally-recognized high school honors physics and hands-on elementary science laboratory programs for a diverse range of learners.

Dr. Jones' honors and awards include the Presidential Award for Excellence in Science Teaching from the National Science Foundation for his work in secondary education, the Florida Association of Science Teachers' "Outstanding Science Teacher Award" for his work with elementary students and teachers, and recognition as a district-level Teacher of the Year by the State of Florida Department of Education.

FROM THE AUTHOR

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INTRODUCTION

How often have you been able to say that your teaching actually saved a life? This activity guide and accompanying resources provide an actual opportunity to do just that! Vehicle collisions are the leading cause of teenage deaths in America; and according to the World Health Organization, worldwide, road traffic crashes are the leading cause of death among young people between 10 and 24 years old. Most students don't really understand how science, engineering, and technology can determine the difference between surviving or dying in a car crash. But with the help of this activity guide and resources on the accompanying website (classroom.iihs.org), both you and your students can explore how scientists and engineers use technology at the Insurance Institute for Highway Safety's Vehicle Research Center (VRC) to measure and evaluate crash forces and investigate how these forces affect human anatomy and physiology. As part of this educational program, you and your students will be able to apply the same scientific and engineering principles used at the VRC in your own classrooms by using dramatic crash-testing videos and hands-on inquiry-based activities to investigate the vital connections between science, technology, medicine, mathematics, engineering, and vehicle crash safety. And, to tie all of the relevant crash-related scientific and engineering principles together, this educational program also explains how to incorporate exciting culminating engineering activities into your existing curriculum to promote student awareness and understanding of how engineering and technology are used in the real world to build safer vehicles.

The following are a few frequently asked questions that provide a brief overview and rationale for the development of both the activity guide and the resources on the accompanying educational website.

What is IIHS-HLDI?
The Insurance Institute for Highway Safety (IIHS) is an independent, nonprofit scientific and educational organization dedicated to reducing deaths, injuries and property damage from motor vehicle crashes through research and evaluation and through education of consumers, policymakers and safety professionals. The Highway Loss Data Institute (HLDI) shares and supports this mission through scientific studies of insurance data regarding the human and economic losses resulting from collisions involving different types of vehicles and by publishing insurance loss results by vehicle make and model. Both organizations are wholly supported by contributions from more than 100 auto insurance companies and associations. As part of their goal of saving lives through education, it is the shared mission of these two organizations to provide both students and teachers with access to real-world learning experiences that illustrate how science, technology, engineering, and mathematics (STEM) concepts are used to improve vehicle crashworthiness and crash avoidance technologies.

What is Crash Science in the Classroom?
Crash Science in the Classroom is a free website (classroom.iihs.org) featuring inquiry-based STEM resources to help grade 5-12 students and teachers explore the science behind what happens to both the vehicles and the people involved in crashes and discover why some vehicles are safer than others. Through a collection of award-winning videos, demonstrations, and Next Generation Science Standards–supported activities, students explore physics concepts related to car crashes (e.g., momentum, inertia, energy), the biomechanical effects of car crashes on the human body (e.g., the third collision and cell stress & strain), and conduct crash-related engineering design projects (e.g., designing an egg crash cushion).

What are the goals of the Crash Science in the Classroom website and this activity guide?

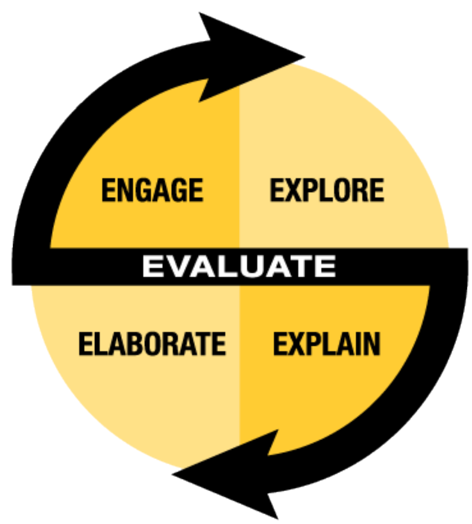
1. Reduce the losses — deaths, injuries, and property damage — from crashes involving teenagers on the nation's roads;

2. Provide students and teachers with access to real-world, IIHS-related STEM experiences relevant to crashworthiness and crash avoidance technologies that are age-appropriate and outcome-oriented;
3. Produce content-rich, pedagogically effective instructional videos and materials aligned with national STEM education reform efforts to increase students' and teachers' STEM content knowledge, practices, and career awareness;
4. Demonstrate how STEM concepts and practices are applied and integrated by IIHS engineers and scientists to evaluate, and thus promote, innovations in crashworthiness and crash avoidance technologies; and
5. Promote awareness of and appreciation for the IIHS-HLDI's mission.

How does the Crash Science in the Classroom website (classroom.iihs.org) help teachers and parents integrate the lessons in this guide into a science curriculum?
When registered and signed in, teachers and parents may access digital versions of the lesson plans and student activity sheets, as well as lesson overviews, answer keys, and more. After clicking the Teacher Tabs available for every Lesson, they will find Lesson Steps that outline the recommended sequence of steps to successfully prepare for and implement each "Understanding Car Crashes" video and Lesson's hands-on activity or demonstration.

The Lesson Steps also direct teachers and parents to each activity's accompanying Introduction and Conclusion videos for students, a Teacher Tips video, as well as the Teacher Lesson Plan that includes key questions, lesson objectives, NGSS correlations, background information, materials lists, step-by-step procedures, and extensions.

Does the website and lesson use best-practice instructional techniques?
Yes, the website and lessons use best-practices pedagogy – primarily the 5E Instructional Model. This research-driven model describes a five-stage inquiry-oriented teaching sequence that can be used for entire programs, specific units and individual lessons. The model consists of the following stages or phases: engagement, exploration, explanation, elaboration, and evaluation. Each phase represents part of the process of helping students sequence their learning experiences to construct their understanding of concepts. This model is the work of Rodger Bybee and the Biological Sciences Curriculum Study (BSCS). See Tables 1 and 2 in Appendix A for specific information (i.e., teacher and student consistent and inconsistent actions) regarding the implementation of the 5E instructional model.



Phases of the 5E model

HOW TO USE THIS ACTIVITY GUIDE

The Activity Guide is divided into four sections. The first section contains an INTRODUCTION which provides a brief overview and rationale for the guide's development.

The second section of the guide contains four VIDEO SHEETS to accompany the "Under Car Crashes: It's Basic Physics" and "Understanding Car Crashes: When Physics Meets Biology" videos, which are viewable as classroom. iihs.org. A Video Concept Organizer sheet and a Video Discussion Question sheet is provided for each video.

Using the Video Concept Organizers

The video concept organizers serve as scaffolding to organize the key science content covered in each video. Students should respond to these lower-order questions ***during*** the videos. If time permits, teachers may find it beneficial to pause the videos periodically and encourage students to brainstorm and collaborate on their answers to these questions.

Using the Video Discussion Questions

The discussion questions are higher-order analysis, synthesis, and evaluation questions intended to stimulate discussion among students ***after*** they have viewed the videos. Depending on the amount of time available and/or the prior knowledge and academic ability levels of students, teachers may want to select a subset of these questions for students to complete in pairs or small groups rather than requiring them to answer every discussion question. Although they are primarily intended to be completed collaboratively, discussion questions could also be completed by individual students as either homework or part of a formal assessment instrument.

The third section of the guide contains LESSONS with 14 Teacher Lesson Plans and Student Activities. The lessons are intended to supplement a science curriculum with inquiry-based STEM activities that demonstrate the basic physics principles of motion and relate them to car crashes and highway safety. Each lesson plan is organized using the same standard format and includes the following components:

Key Question: Identifies the primary focus of the activity in the form of a question that is directly relevant to students' real-world experiences. The key question may be used to initiate and/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 24-30 students. Additional time would be needed to complete any extension activities identified in lesson plans.

Objectives: Identifies desired student learning outcomes in the form of observable, measurable behaviors.

Next Generation Science Standards: Each activity is aligned with the national Next Generation Science Standards (NGSS) Performance Expectations for grades 5-12. Please read more about the standards at nextgenscience.org.

Background Information: Provides current, relevant information regarding the specific science concepts explored in the activity. Key concepts and vocabulary addressed in the lesson are highlighted in bold face type in this section.

Definitions: Lists and defines key science vocabulary/terms used in the lesson.

Materials: Lists all supplies needed to complete the activity.

Advance Preparation: Describes all of the tasks that teachers need to complete to prepare for the activity.

Safety Considerations: Describes any considerations/preparations needed to safely conduct the activity.

Procedure: Includes step-by-step instructions for successful completion of the lesson. Answers to the student activity sheet questions are also provided in this section.

Extensions: When applicable, this section suggests additional activity ideas for exploring the lesson topic further and identifies related activity guide lessons that could be conducted in conjunction with a particular lesson.

The fourth section contains APPENDICES designed to facilitate use of the guide. Appendix A provides additional background information regarding the 5E Instructional Model used to design each activity. Appendix B provides a matrix correlating each lesson to relevant grade 5-12 National Science Education Standards.

VIDEO SHEETS

CONCEPT ORGANIZER QUESTIONS

Name: ____________________ Class: __________ Date: ____________

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"

Concept Organizer

TIME*

Part I: Before the Video

Directions: *Before viewing the video, answer the question below. Be prepared to discuss your answer.*

Why do some spectacular racecar crashes produce only minor injuries?

____

____

Part II: During the Video

Directions: *While viewing the video, complete the fill-in-the blank statements with the correct terms OR circle the correct answers if provided. (Times in left margin indicate when each item is discussed.)*

IIHS's Vehicle Research Center

1:15 **1.** It is a fascinating place where research engineers assess the crash performance of vehicles by running tests and where they evaluate new ________________ to prevent injuries.

Test Track Laws

2:05 **2.** Why did the dummy get left behind? It's called ________________ , the property of matter that causes it to resist any change in it motion.

2:20 **3.** Isaac Newton's First Law of Motion states: A body at rest remains at ____________ _ unless acted upon by an external force; and a body in motion continues to move at a constant ______________ in a straight line unless it is acted upon by an external force.

Crashing Dummies

3:30 **4.** Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing ___________ which slows down the rest of the car.

3:55 **5.** In this case, it is the steering wheel and windshield that apply the _______________ that overcomes the dummy's inertia.

Crash-Barrier Chalkboard

4:30 **6.** Newton explained the relationship between crash forces and inertia in his (Circle one): 1st 2nd 3rd Law of Motion.

4:45 **7.** Fill in the blanks to complete the formula.

Ft = ______________ ⟶ Ft = m∆v m∆v = ____________________

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER QUESTIONS

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"

Concept Organizer

TIME*	
	Surfers, Cheetahs, and Elephants ...oh my!
5:20	***8.*** Momentum is inertia in motion. It's the product of an object's mass and its ________________.
	Soccer Kicks, Slap Shots, and Egg Toss
6:00	***9.*** Impulse is the product of ________________ and the time interval during which the force acts.
6:30	***10.*** The wall applies a ________________ force over a shorter time.
	11. The sheet applies a smaller force over a ________________ time.
	Fighter pilots, astronauts, and crash occupants
7:50	***12.*** People often refer to **g**'s as forces but they are not. A **g** is a standard unit of ______________________________.
8:05	***13.*** People in serious car crashes experience high g's and this can cause ____________ .
9:05	***14.*** Three things that extend the time of impact in a collision are: crumple zones, ________________, and ___________________________________.
	Conserving momentum and energy - It's the law!
10:55	***15.*** Momentum has a directional property, so it is called a ________________ quantity.
12:15	***16.*** Weight vs. Size in car crashes: ______________ helps you in all kinds of crashes. ______________ is primarily an advantage in a crash with another vehicle.
	Newton and energy
13:00	***17.*** Energy is the ability to do ________________ .
13:20	***18.*** Motion related energy is called ________________ energy. Energy due to an object's position or condition is called ________________ energy.
14:20	***19.*** At what point in the pendulum's swing is its potential energy equal to its kinetic energy? _______________________
	Engineering safer vehicles
16:20	***20.*** We use the term _______________________ to describe the protection a car offers its occupants during a crash.
17:20	***21.*** If we can _______________________ the front end of the car without allowing any damage to the occupant compartment then the people inside can be protected against serious injury.
18:45	***22.*** When the ______________________ collapses, you are going to have injuries to the occupants.
22:15	***23.*** The rear seats of most cars lack seat belt systems with crash tensioners and ________________________.

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER ANSWERS

“UNDERSTANDING CAR CRASHES: IT’S BASIC PHYSICS”

Concept Organizer

TIME*

Part I: Before the Video

Directions: Before viewing the video, answer the question below. Be prepared to discuss your answer.

Why do some spectacular racecar crashes produce only minor injuries?
Combination of crashworthiness of vehicle, extended impact time, and energy dissipation away from driver.

> **Teaching Tip:** *Discuss a few students’ answers before viewing, but wait until after viewing to reveal the answer to this question.*

Part II: During the Video

Directions: While viewing the video, complete the fill-in-the blank statements with the correct terms OR circle the correct answers if provided. (Times in left margin indicate when each item is discussed.)

> **Teaching Tip:** *Pause the video every 2-3 minutes to allow student pairs to share/discuss their answers.*

IIHS’s Vehicle Research Center

1:15 **1.** It is a fascinating place where research engineers assess the crash performance of vehicles by running tests and where they evaluate new **technologies** to prevent injuries.

Test Track Laws

2:05 **2.** Why did the dummy get left behind? It’s called **inertia** , the property of matter that causes it to resist any change in it motion.

2:20 **3.** Isaac Newton’s First Law of Motion states: A body at rest remains at **rest** unless acted upon by an external force; and a body in motion continues to move at a constant **speed** in a straight line unless it is acted upon by an external force.

Crashing Dummies

3:30 **4.** Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing **energy** which slows down the rest of the car.

3:55 **5.** In this case, it is the steering wheel and windshield that apply the **force** that overcomes the dummy's inertia.

Crash-Barrier Chalkboard

4:30 **6.** Newton explained the relationship between crash forces and inertia in his (Circle one): 1st (2nd) 3rd Law of Motion.

4:45 **7.** Fill in the blanks to complete the formula.

Ft = **impulse** → Ft = mΔv mΔv = **change in momentum**

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER ANSWERS

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"

Concept Organizer

TIME*	
	Surfers, Cheetahs, and Elephants …oh my!
5:20	*8.* Momentum is inertia in motion. It's the product of an object's mass and its **velocity**.
	Soccer Kicks, Slap Shots, and Egg Toss
6:00	*9.* Impulse is the product of **force** and the time interval during which the force acts.
6:30	*10.* The wall applies a **larger** force over a shorter time.
	11. The sheet applies a smaller force over a **longer** time.
	Fighter pilots, astronauts, and crash occupants
7:50	*12.* People often refer to **g**'s as forces but they are not. A **g** is a standard unit of **acceleration**.
8:05	*13.* People in serious car crashes experience high g's and this can cause **injury**.
9:05	*14.* Three things that extend the time of impact in a collision are: crumple zones, **airbags**, and **break-away light poles**.
	Conserving momentum and energy - It's the law!
10:55	*15.* Momentum has a directional property, so it is called a **vector** quantity.
12:15	*16.* Weight vs. Size in car crashes: **Size** helps you in all kinds of crashes. **Weight** is primarily an advantage in a crash with another vehicle.
	Newton and energy
13:00	*17.* Energy is the ability to do **work**.
13:20	*18.* Motion related energy is called **kinetic** energy. Energy due to an object's position or condition is called **potential** energy.
14:20	*19.* At what point in the pendulum's swing is its potential energy equal to its kinetic energy? **mid-point**
	Engineering safer vehicles
16:20	*20.* We use the term **crashworthiness** to describe the protection a car offers its occupants during a crash.
17:20	*21.* If we can **crumple** the front end of the car without allowing any damage to the occupant compartment then the people inside can be protected against serious injury.
18:45	*22.* When the **safety cage** collapses, you are going to have injuries to the occupants.
22:15	*23.* The rear seats of most cars lack seat belt systems with crash tensioners and **force limiters**.

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER QUESTIONS

Name: ____________________ Class: __________ Date: ____________

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Concept Organizer

TIME*

Part I: Before the Video

Directions: Before viewing the video, answer the question below. Be prepared to discuss your answer.

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

____

____

____

Part II: During the Video

Directions: While viewing the video, complete the fill-in-the-blank statements with the correct terms OR circle the correct answers if provided. (Times in left margin indicate when each item is discussed.)

IIHS's Vehicle Research Center

1:00 ***1.*** **The study of injury ____________________ in crash testing has helped us learn what happens to the human body in passenger car crashes.**

3:05 ***2.*** **Using sophisticated tools like instrumented ____________________, instrumentation in the car, and slow-motion film, engineers can analyze every detail and construct a precise picture of the crash.**

History of crash research

4:20 ***3.*** **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.**

Crash test dummy lab

6:20 ***4.*** **Inside the Side Impact Dummy, the accelerometers give us the ______________ of the mass. The load cell measures force. And the potentiometers measure the ____________________ .**

7:35 ***5.*** **The higher the ____________________ , the more like a human being the crash test dummy is.**

Crash Anatomy

8:30 ***6.*** **he human body contains more than 100 trillion cells. The body is structurally organized into four levels: cells, ______________, organs, and ______________ ______________.**

The third collision

9:55 ***7.*** **The first collision is between the car and the ____________________.**
The second is between the driver and the ____________________.
The third is between the driver's ____________________ and the inside walls of his or her body cavities.

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER QUESTIONS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Concept Organizer

TIME*

11:40

Brain Injury Demonstration

8. Predict which way the balloon or "brain" will move during the impact. I predict the balloon will: (CIRCLE ONE)

A. move forward
B. move backward
C. stay in the same spot

9. Observation: The initial movement of the balloon or "brain" was ________________ .

13:20

Heart Injury Demonstration

10. Predict what will happen to the unsupported section of gel or "aortic arch" during the collision. I predict the gel will: (CIRCLE ONE)

A. move forward
B. move backward
C. stay in the same spot

11. Observation: The unsupported section of gel ________________________ and tears away from the supported gel.

14:10

Stress and Strain

12. Stress produces strain. ________________ is a measure of how much the tissue deforms as a result of the stress.

15:40

Shockwaves

13. Bigger and more concentrated impact ______________________ produce bigger and potentially more damaging shockwaves moving through your body.

16:45

Cell Damage and Death

14. High forces create ___________________ waves, which can cause tissues and organs to stretch, tear, or compress. This starts a cascade of chemical events that ends in cell ____________________.

18:50

Building Safer Racecars

15. List ANY 2 racecar safety features brought about by the study of injury biomechanics:

____

____

21:00

Bed of Nails Demonstration

16. Pressure = _________________________ / Area

22:15

Sundown

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

*These times are for the full-length video. Disregard times if watching individual video chapters.

CONCEPT ORGANIZER ANSWERS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Concept Organizer

TIME*

*These times indicate when each item is discussed for the full-length video. Disregard times if watching individual video chapters.

Part I: Before the Video

Directions: Before viewing the video, answer the question below. Be prepared to discuss your answer.

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

The 1st is between the truck and the wall. The 2nd is between the occupants and the truck's interior. The 3rd is between the occupants' internal organs and the inside walls of their body cavities..

Teaching Tip: *Discuss a few students' answers before viewing, but wait until after viewing to reveal all 3 answers to this question.*

Part II: During the Video

Directions: While viewing the video, complete the fill-in-the-blank statements with the correct terms OR circle the correct answers if provided.

IIHS's Vehicle Research Center

Teaching Tip: *Pause the video every 2-3 minutes to allow student pairs to share/discuss their answers.*

1:00 — 1. The study of injury **biomechanics** in crash testing has helped us learn what happens to the human body in passenger car crashes.

3:05 — 2. Using sophisticated tools like instrumented **crash test dummies**, instrumentation in the car, and slow-motion film, engineers can analyze every detail and construct a precise picture of the crash.

History of crash research

4:20 — 3. 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.

Crash test dummy lab

6:20 — 4. Inside the Side Impact Dummy, the accelerometers give us the **acceleration** of the mass. The load cell measures force. And the potentiometers measure the **displacement**.

7:35 — 5. The higher the **biofidelity**, the more like a human being the crash test dummy is.

Crash Anatomy

8:30 — 6. The human body contains more than 100 trillion cells. The body is structurally organized into four levels: cells, **tissues**, organs, and **organ systems**.

The third collision

9:55 — 7. The first collision is between the car and the **wall**.
The second is between the driver and the **car's interior**.
The third is between the driver's **internal organs** and the inside walls of his or her body cavities.

CONCEPT ORGANIZER ANSWERS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Concept Organizer

TIME*

11:40

Brain Injury Demonstration

8. Predict which way the balloon or "brain" will move during the impact. I predict the balloon will: (CIRCLE ONE)

A. move forward

B. move backward

C. stay in the same spot

9. Observation: The initial movement of the balloon or "brain" was **backward** .

13:20

Heart Injury Demonstration

10. Predict what will happen to the unsupported section of gel or "aortic arch" during the collision. I predict the gel will: (CIRCLE ONE)

A. move forward,

B. move backward

C. stay in the same spot

11. Observation: The unsupported section of gel **moves forward** and tears away from the supported gel.

14:10

Stress and Strain

12. Stress produces strain. **Strain** is a measure of how much the tissue deforms as a result of the stress.

15:40

Shockwaves

13. Bigger and more concentrated impact **forces** produce bigger and potentially more damaging shockwaves moving through your body.

16:45

Cell Damage and Death

14. High forces create **shock** waves, which can cause tissues and organs to stretch, tear, or compress. This starts a cascade of chemical events that ends in cell **death** .

18:50

Building Safer Racecars

15. List ANY 2 racecar safety features brought about by the study of injury biomechanics:

six-point safety harness, rigid safety cages or "tubs," energy-absorbing head surrounds, breakaway parts, energy-absorbing walls

21:00

Bed of Nails Demonstration

16. Pressure = **Force** / Area

22:15

Sundown

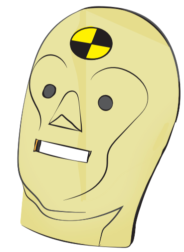
17. Keeping people safe in crashes has to do with extending **impact time** , keeping the occupant compartment **intact** , and tying the occupants to the compartment.

*These times are for the full-length video.
Disregard times if watching individual video chapters.

Name: ______________________ Class: __________ Date: ____________

DISCUSSION QUESTIONS

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"



Part III: After the Video

Directions: *After viewing the video, work alone, in pairs, or in small groups to answer the questions assigned by your instructor in 2-3 sentences each.*

1. Ever tried to stop a 150-pound (68 kg) cannonball fired towards you at 30 mph (48 km/hr.)? No, probably not. But you may have tried to brace yourself in a car collision. How are the two situations similar?

2. Show mathematically why an 80,000-pound (36,000 kg) big rig traveling 2 mph (0.89 m/s) has the SAME MOMENTUM as a 4,000-pound (1,800 kg) sport utility vehicle traveling 40 mph (18 m/s).

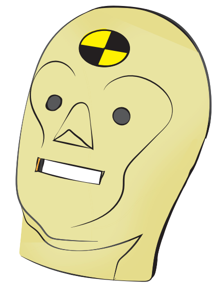
3. During the Egg-Throwing Demonstration, the wall stopped one egg and the bed sheet stopped the other egg.
   A. Explain why one egg broke but not the other.
   B. Explain why BOTH eggs experienced the same impulse

4. Explain why the fortunate race car drivers survived their high speed crashes.

5. Describe 2 or more examples where momentum is reduced by applying a smaller collision force over a longer impact time (in other words, where things "give way" during a collision to lessen the impact force).

DISCUSSION QUESTIONS

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"



6. Which would be more damaging to your car: A. having a head-on collision with an identical car traveling at an identical speed OR B. driving head-on into the Vehicle Research Center's 320,000 pound (145,455 kg) deformable crash barrier? Explain.

7. Show mathematically why a small increase in your vehicle's speed results in a tremendous increase in your vehicle's kinetic energy. For example: doubling your speed from 30 mph to 60 mph (48 km/hr. to 97 km/hr.) results in a quadrupling of your kinetic energy.

8. The Law of Conservation of Energy states: Energy cannot be created or destroyed; it can be transformed from one form to another but the total amount of energy never changes. Car crashes can involve huge amounts of energy. How does the crashworthiness of the car affect the transfer and transformations of energy and, ultimately, protect the occupants?

9. In the video's "shipping box analogy," which safety feature in a car is analogous to the:
A. Cardboard shipping box
B. Packing foam in the box
Explain how each feature functions differently to protect the occupants.

DISCUSSION ANSWERS

“UNDERSTANDING CAR CRASHES: IT’S BASIC PHYSICS”

Teaching Tip: *Select from these higher-order questions for small group discussions, homework, or assessments.*

Part III: After the Video

Directions: *After viewing the video, work alone, in pairs, or in small groups to answer the questions assigned by your instructor in 2-3 sentences each. (NOTE: Answers provided below include additional elaboration/ information you may want to share with students.)*

1. **Ever tried to stop a 150-pound (68 kg) cannonball fired towards you at 30 mph (48 km/hr.)? No, probably not. But you may have tried to brace yourself in a car collision. How are the two situations similar?**

   Both you and the cannonball have momentum based upon mass and velocity. If you are traveling 30 mph and have a mass of 150 pounds, your momentum would equal the cannonball’s. In a major collision, it is impossible to prevent injuries by bracing yourself! No matter how strong you think you are, you are not strong enough to stop your inertia during a collision.

2. **Show mathematically why an 80,000-pound (36,000 kg) big rig traveling 2 mph (0.89 m/s) has the SAME MOMENTUM as a 4,000-pound (1,800 kg) sport utility vehicle traveling 40 mph (18 m/s).**

   Momentum (p) is the product of an object's mass (m) and velocity (v). The formula is p = mv. The product of each is equivalent.

   » *The SI unit for momentum is the kilogram x meter/second (kg x m/s).*

   » *Truck momentum = (36,000 kg)(0.89 m/s) = 32,000 kg x m/s*

   » *SUV momentum= (1,800 kg)(18 m/s) = 32,000 kg x m/s*

3. **During the Egg-Throwing Demonstration, the wall stopped one egg and the bed sheet stopped the other egg.**
   A. Explain why one egg broke but not the other.
   B. Explain why BOTH eggs experienced the same impulse

   A. Impulse = force x time. The egg that hit the wall (crash barrier) experienced a greater impact force (big F) due to the shorter impact time (little t). The egg that collided with the bed sheet experienced a greater time of impact (big T), thereby experiencing a smaller stopping force (little F).

   B. If their momenta are equal before the collisions (same mass and velocity), both eggs experience identical impulses because both are stopped by the collision (Product of f x T is the same as F x t).

4. **Explain why the fortunate race car drivers survived their high speed crashes.**

   The impulse that the wall applied to both cars was identical BUT, remember impulse is the force of impact multiplied by the time of impact. With the fortunate driver, the identical impulse was a product of a small force (little f) extended over a long period of time (big T).

5. **Describe 2 or more examples where momentum is reduced by applying a smaller collision force over a longer impact time (in other words, where things “give way” during a collision to lessen the impact force).**

   Answers will vary. Some examples: Bungee jumping; trampolines; trapeze safety nets; falling on grass compared to concrete; many football players prefer the “give” of natural grass to harder artificial turf.

DISCUSSION ANSWERS

"UNDERSTANDING CAR CRASHES: IT'S BASIC PHYSICS"

6. Which would be more damaging to your car: A. having a head-on collision with an identical car traveling at an identical speed OR B. driving head-on into the Vehicle Research Center's 320,000 pound (145,455 kg) deformable crash barrier? Explain.

Both crashes produce the same result. Either way the car rapidly decelerates to a stop. In a head-on crash of identical cars (same mass) traveling at equal speeds (same velocity), the result is equal impact forces and impact times (according to Newton's Third Law of Motion), and therefore equal changes in momenta. However, using a crash barrier to simulate a head-on collision during a crash test is more cost-efficient since only one car is damaged instead of two!

7. Show mathematically why a small increase in your vehicle's speed results in a tremendous increase in your vehicle's kinetic energy. For example: doubling your speed from 30 mph to 60 mph (48 km/hr. to 97 km/hr.) results in a quadrupling of your kinetic energy.

Velocity is squared in the kinetic energy equation ($KE = \frac{1}{2} mv^2$). Therefore, if the speed is first doubled (2x) then squared (2 x 2 = 4), its kinetic energy must quadruple to keep the equation balanced. $4KE = \frac{1}{2} m^2v^2$

8. The Law of Conservation of Energy states: Energy cannot be created or destroyed; it can be transformed from one form to another but the total amount of energy never changes. Car crashes can involve huge amounts of energy. How does the crashworthiness of the car affect the transfer and transformations of energy and, ultimately, protect the occupants?

In a crash of a well-designed car, some of the kinetic energy of the crash is absorbed by the car's crumple zones. In addition, some of the kinetic energy of the crash is transformed into heat and sound energy, Finally, to protect the occupants ,the safety cage must be strong enough to withstand the remaining kinetic energy of the crash without deforming and collapsing on the occupants.

9. In the video's "shipping box analogy," which safety feature in a car is analogous to the:
A. Cardboard shipping box
B. Packing foam in the box
Explain how each feature functions differently to protect the occupants.

A. The cardboard shipping box is analogous to the car's safety cage.

B. The packing foam in the box is analogous to the airbags and padding in the dashboard and steering wheel.

The safety cage's primary function is to limit intrusions into the occupant compartment. Airbags and dashboard padding reduce the impact force by spreading it out over a longer impact time as they "slowly" collapse. In other words, their softer surfaces collapse slowly compared to hitting a hard surface such as a windshield.

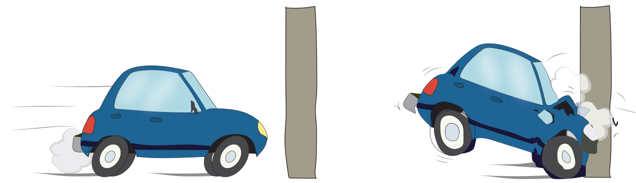
DISCUSSION QUESTIONS

Name: ____________________ Class: __________ Date: __________

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Part III: After the Video

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.*



Before the Video Question

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

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1. **Historically, crash research has required the cooperation and combined knowledge, skills, creativity, and passion of individuals from many different fields/subject areas. Explain how Col. John Stapp's research combined several different fields of study to save human lives.**

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

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

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b. Describe how these measurements can be used to predict whether or not injuries will occur in a crash.

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

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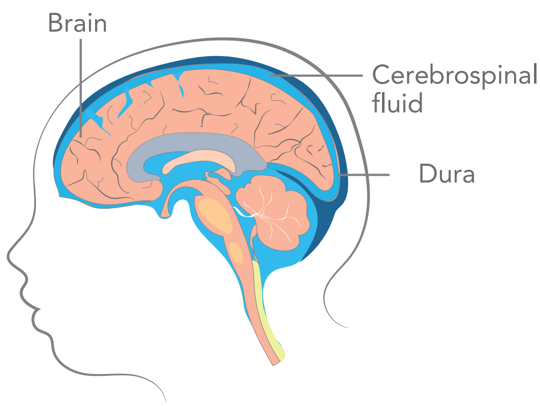
DISCUSSION QUESTIONS

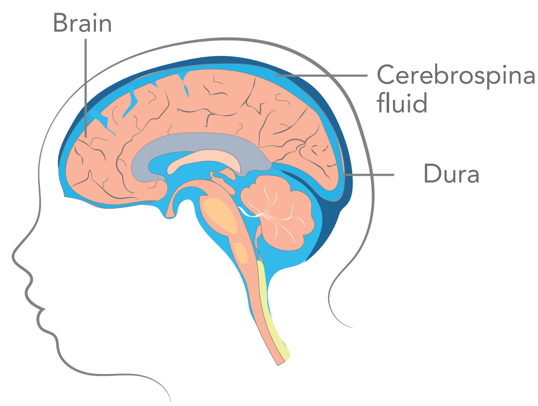
"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

4. In a collision a vehicle occupant may experience a blunt force trauma to his/her chest. Summarize how the thoracic body cavity and major bones in the chest area can protect a person's heart and lungs in a collision.

5. 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's happening to the brain and the cerebral spinal fluid.



BEFORE THE COLLISION



DURING THE COLLISION

6. The strength of any tissue or organ in a collision depends on many factors, including its elasticity and the type of stress it experiences. Distinguish between stress and strain AND explain how stress and strain affect human tissue.

DISCUSSION QUESTIONS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

7. Describe how shockwaves create stress and strain and injure tissue.

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

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9. Analyze the photos of one of Tony Kanaan's IndyCar racecars below. Circle AND label three safety features of the car that help reduce forces on drivers and thus prevent injuries during a crash.

Tony Kanaan's Race Car

Dr. Jones buckling up

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10. Describe how new technologies, such as crash recorders, help engineers build safer racecars.

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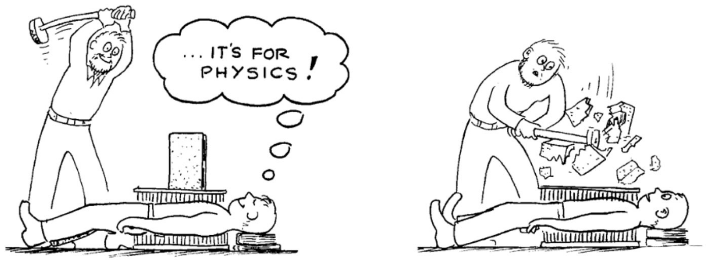
DISCUSSION QUESTIONS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

11. **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. In the diagram above, how are forces from the man's weight, forces from the concrete block, and forces from the impact of the sledgehammer reduced to allow the man to survive the experience?

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

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DISCUSSION QUESTIONS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Driver's seat inside a stock car

Steering wheel and dashboard of a stock car

12. One of the key principles to keeping people safe in vehicle crashes is extending impact time. If the change of momentum occurs over a longer period of time, the resulting force of the impact is smaller. Examine the pictures below of the driver's area of a NASCAR-style racecar. Circle AND label safety features that reduce impact forces by extending the impact time.

DISCUSSION ANSWERS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

Part III: After the Video

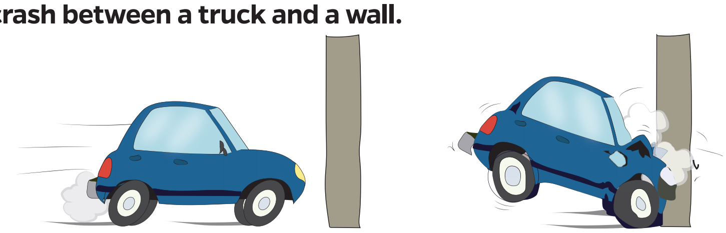
Directions: *After viewing the video, work alone, in pairs, or in small groups to answer the questions assigned by your instructor. (NOTE: Answers provided below include additional elaboration/information you may want to share with students.)*

> **Teaching Tip:** *Use a subset of these higher-order questions for individual homework or assessments after students view the video OR divide the class into small groups of 2-3 students each. Assign each group a different discussion question. Allow 5-10 minutes for group members to discuss/agree on an answer and select a representative from each group to present their answer to the class. Ask group representatives to limit their presentations to 2 minutes.*

Before the Video Question

Describe 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 occupant and the truck's interior. And the third is between the occupant's internal organs and the inside walls of his or her body cavities.



1. **Historically, crash research has required the cooperation and combined knowledge, skills, creativity, and passion of individuals from many different fields/subject areas. Explain how Col. John Stapp's research combined several different fields of study 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, with some costing over $130,000.**

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

   Most dummies measure acceleration, force, and in some cases, distortion of body parts. These measurements can then be compared to similar measurements made in experiments conducted on actual biological tissues (animal or cadaver) to get an idea of how much stress a body part can take before it breaks or is damaged.

   b. Describe how these measurements can be used to predict whether or not injuries will occur in a crash.

   In order to predict whether or not a person would be injured in a crash, you need to know: 1. how strong human bones and tissues are, and, 2. the specific amounts/types of forces that cause bone breakage and tissue damage.

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

   The greater a dummy's biofidelity, the more the crash test dummy resembles an actual human being. Dummies with high biofidelity more accurately represent how a real human being moves and how specific types/amounts of force in a crash affect bones, tissues, and organs in the human body.

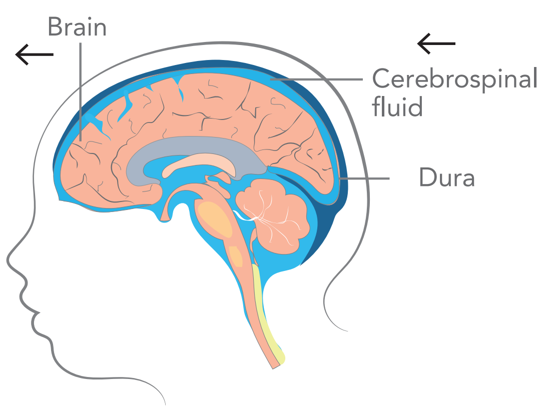
DISCUSSION ANSWERS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

4. **In a collision a vehicle occupant may experience a blunt force trauma to his/her chest. Summarize how the thoracic body cavity and major bones in the chest area can protect a person's heart and lungs in a collision.**

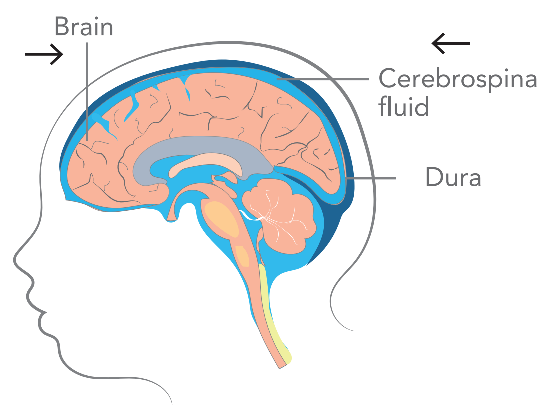
In the thoracic body cavity, the heart and lungs are suspended in fluid that supports their weight and prevents them from being deformed by normal movements. The heart and lungs are additionally protected by the rib cage and sternum.

5. **a. In the two images below, draw arrows to indicate the direction the brain and cerebrospinal fluid (CSF) are moving in BEFORE and DURING a frontal collision resulting in a coup-contrecoup brain injury.**
b. Write captions for each image that summarize what is happening to the brain and cerebrospinal fluid BEFORE and DURING the frontal collision.



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.

6. **The strength of any tissue or organ in a collision depends on many factors, including its elasticity and the type of stress it experiences. Distinguish between stress and strain AND explain how stress and strain affect human tissue.**

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.

7. **Describe how shockwaves create stress and strain and 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.

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

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

DISCUSSION ANSWERS

"UNDERSTANDING CAR CRASHES: WHEN PHYSICS MEETS BIOLOGY"

9. **Analyze the photos of one of Tony Kanaan's IndyCar racecars below. Circle AND label three safety features of the car that help reduce forces on drivers and thus prevent injuries during a crash.**

Tony Kanaan's Race Car

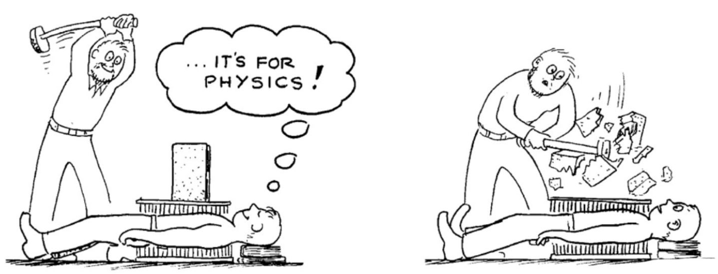
Dr. Jones buckling up

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.

10. **Describe how new technologies, such as crash recorders, help engineers build safer racecars.**

Crash recorders allow engineers to measure acceleration in three directions. These data are used to make more accurate computer models to re-enact the crash, determine where and how injuries occur, and determine vehicle safety design changes to prevent injuries.

11. **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.**



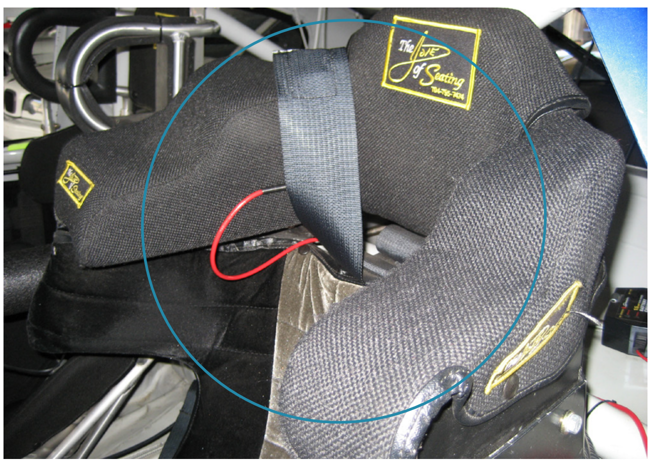
a. In the diagram above, how are forces from the man's weight, forces from the concrete block, and forces from the impact of the sledgehammer reduced to allow the man to survive the experience?

Much of the force from the man's weight and the weight of the block is distributed over the large number of nails that make contact with a large area of his body, thus reducing the pressure on any one nail. The large mass (thus large inertia) of the block keeps it from moving too much downward onto the man when struck with the sledgehammer. And, since the block breaks apart when struck, some of the downward force of the sledgehammer strike is dissipated outward as the block pieces fly away.

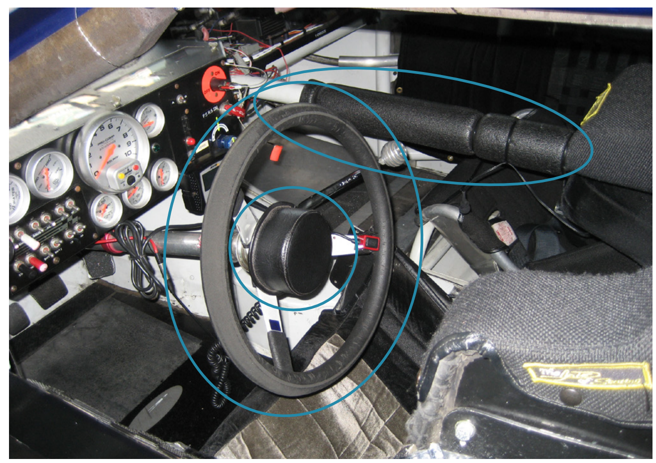
b. How are the same physics concepts applied in the bed-of-nails demonstration utilized to improve a vehicle’s crashworthiness?

Widening seat belts and rounding edges on objects that may come in contact with occupants during a collision reduces pressure by distributing the impact forces over a greater area. Like the breaking concrete block, break-away parts in race cars help dissipate the kinetic energy away from the occupants during a collision.

12. **One of the key principles to keeping people safe in vehicle crashes is extending impact time. If the change of momentum occurs over a longer period of time, the resulting force of the impact is smaller. Examine the pictures below of the driver’s area of a NASCAR-style racecar. 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 wheel, padded steering column, padding around support rods. By hitting the padded areas instead of hard surfaces, the contact time (time during which your momentum is reduced to zero) is extended. A longer contact time reduces the impact force. For example, if the time is extended by a factor of 10, the force of impact is reduced by a factor of 10.

TEACHER LESSON PLANS AND STUDENT ACTIVITIES

TEACHER LESSON PLAN

PENNY FOR YOUR THOUGHTS ON INERTIA

DEFINITIONS

inertia: property of an object to resist any change in its state of motion

mass: quantity of matter in an object; measure of an object's inertia

unbalanced force: an individual force that is not being balanced by a force of equal magnitude and in the opposite direction. Unbalanced forces result in a change in motion.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

- How do magicians pull a tablecloth out from under an entire set of dishes? Is it magic or science?
- How is a magician's tablecloth trick similar to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Grade levels: 5–12
Time required: 30-40 minutes

Objectives

Students will:

- recognize inertial mass as a physical property of matter.
- describe how increasing an object's mass increases its inertia.
- compare the effects of inertia and outside forces on an object's state of motion.
- provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

- MS-PS2-2, 5-PS2-1, 5-PS1-3, 3-PS2-1

Background Information

The origins of **Newton's Laws of Motion** began with the Italian philosopher Galileo Galilei (1564–1642). Galileo broke from the teachings of Aristotle that had been accepted as truth for more than 1,000 years. Where Aristotle and his followers believed moving objects must be steadily pushed or pulled to keep moving, Galileo showed with his experiments that moving things, once moving, continued in motion without being pushed or pulled (forces applied). He called the property of objects to behave this way **inertia**, which is Latin for "lazy" or "inert."

Isaac Newton, born in England on Christmas day in 1642 (the year Galileo died) refined Galileo's Principle of Inertia in terms of unbalanced forces and made it his first law of motion.

Newton's First Law of Motion

In the absence of an unbalanced force, an object at rest remains at rest, and an object already in motion remains in motion at constant speed on a straight line path.

TEACHER LESSON PLAN

PENNY FOR YOUR THOUGHTS ON INERTIA

MATERIALS NEEDED

For each group of 3-4 students

» One 3"x 5" index card

» One 10-16-ounce plastic cup or beaker

» 1–10 pennies

» **OPTIONAL:** additional mix of dimes, nickels, quarters, and half dollars

Per Student

» One copy of the "Penny for Your Thoughts" Student Activity Sheet

Advance Preparation

» Assemble the materials for each group and make copies of the activity sheet. (NOTE: If possible, have other coins available for the groups to try. Their results will vary with the mass of the coins used since more mass results in more inertia.)

» Set aside an additional cup, index card, and penny for use as a demo.

» Watch the Introduction and Conclusion videos at classroom.iihs.org/penny-for-your-thoughts and decide if you want to incorporate them into the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/penny-for-your-thoughts

Procedure

1. Initiate the activity by asking the first Key Question: "How do magicians pull tablecloth out from under an entire set of dishes? Is it magic or science?" Inform students that this activity will help them answer the question. (Don't tell the students yet but the answer is…it's science! The plates have inertia due to their mass. More mass equals more inertia, which equates to a greater resistance to change their state of motion. The plates stay on the table when tablecloth is pulled away since the tablecloth doesn't apply enough horizontal force to overcome the plates inertia.)
2. Next, cover the cup with the index card and center the penny above the cup on top of the card (See Figure 1.) *Optional: Show the activity's Introduction video.*
3. Divide students into groups and distribute the supplies and worksheets. Refer to the worksheet and review Key Question 2, the Objectives of the activity, and the Did You Know? information.
4. Review the activity procedure and challenge students to figure out how to get the penny into the cup without lifting the card and only touching it with one finger.
5. Encourage each student to try the penny challenge. Then, after all students have succeeded with one penny, encourage them to try the same challenge using multiple stacked pennies and/or other coins if available.
6. Review Analysis Question 1 and ask students to describe the successful techniques they used. *Optional: Show the activity's Conclusion video.*
7. State Newton's First Law of Motion and share relevant historical background information regarding early beliefs about motion proposed by Aristotle as well as Galileo's Principle of Inertia.
8. Then, ask students to work collaboratively with their group members to answer the remaining Analysis Questions and the Crash Test Question.
9. Conclude the lesson with a whole-class discussion of responses to the Analysis and Crash Test questions, making sure that students clearly see how Galileo's Principle of Inertia and Newton's First Law of motion apply in this hands-on activity.

PENNY FOR YOUR THOUGHTS ON INERTIA

Answers to Analysis Questions

1. Describe a successful technique.

As shown in Figure 1, the best method is to flick the card horizontally with your index finger thus exerting a horizontal force with no vertical force. Once the card holding up the penny is removed, the vertical force of gravity will cause the penny to drop straight down into the cup.

2. Why does the penny drop in the cup when the card is "flicked" away?

Very little of the sudden horizontal force from your flicking finger is transferred upward to the penny, so the inertia of the penny keeps it over the mouth of the cup. With the card no longer providing an "upward" support force, the downward force of gravity pulls it straight down into the cup.

3. How did the total mass of the coins used affect your success?

Students should have been more successful when trying the activity with coins of more mass (up to a point). More mass equals more inertia, which equates to a greater resistance to movement from the slight sideways force applied by flicking card. But if the mass of the coins is too great, the force of friction between the coins and the card is too large to be overcome by the force of your flicking finger; therefore, the card (and coins) cannot move.

4. How does this activity illustrate Galileo's Principle of Inertia and Newton's First Law of Motion?

The more massive the coin stack, the greater its tendency to resist any change in its state of motion. In this case, the coins are at rest and will stay at rest unless a strong enough force can overcome the inertia of the coins.

5. Should magicians select lighter or heavier dishes for their tablecloth trick? Why?

The heavier (more massive) the plates, the greater their inertia and the better the magician's chance for success because heavier plates can better resist any small sideways force exerted by the pulled tablecloth. But, like the coins on the index card, too many plates with too much mass would increase the force of friction between the plates and the tablecloth making it impossible for the horizontal pulling force to actually remove the tablecloth without also moving the plates.

Answers to Key Questions

How do magicians pull a tablecloth out from under an entire set of dishes? Is it magic or science?

It's science! For this trick you need s a smooth tablecloth, a fast pull, and heavy dishes. The smoothness of the tablecloth means that the friction is small, so the dishes feel very little force to the side. Yanking the tablecloth quickly means that the small frictional force has even less time to act on the dishes. Most importantly, heavy dishes have a lot of inertia, so they will strongly resist any force that attempts to move them. These three effects together allow the magician to perform the tablecloth trick.

How is a magician's tablecloth trick similar to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Both apply the concept of inertia. A crash test dummy is very massive and thus has a lot of inertia (tendency to stay at rest). The small horizontal force applied by the tailgate as the truck accelerates is not enough to overcome the inertia of the dummy. Thus the dummy gets left behind as the tailgate moves out from under it.

TEACHER LESSON PLAN

PENNY FOR YOUR THOUGHTS ON INERTIA

Answers to Key Questions

How do magicians pull a tablecloth out from under an entire set of dishes? Is it magic or science?
It's science! For this trick you need s a smooth tablecloth, a fast pull, and heavy dishes. The smoothness of the tablecloth means that the friction is small, so the dishes feel very little force to the side. Yanking the tablecloth quickly means that the small frictional force has even less time to act on the dishes. Most importantly, heavy dishes have a lot of inertia, so they will strongly resist any force that attempts to move them. These three effects together allow the magician to perform the tablecloth trick.

How is a magician's tablecloth trick similar to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?
Both apply the concept of inertia. A crash test dummy is very massive and thus has a lot of inertia (tendency to stay at rest). The small horizontal force applied by the tailgate as the truck accelerates is not enough to overcome the inertia of the dummy. Thus the dummy gets left behind as the tailgate moves out from under it.

Extension

1. *Have students further explore the classroom.iihs.org website to view the "Broom & Egg" Crash Science Demonstration addressing Newton's First Law of Motion and the concept of inertia.*
2. **Have students conduct the "Pain in the Neck" activity to discover how Newton's first law of motion affects the type and severity of whiplash injuries resulting from rear-end collisions.**

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ___________

CRASH SCIENCE IN THE CLASSROOM

PENNY FOR YOUR THOUGHTS ON INERTIA

MATERIALS NEEDED

For each group of 3-4 students

- One 3"x 5" index card
- One 10-16-ounce plastic cup or beaker
- 1–10 pennies
- **OPTIONAL:** additional mix of dimes, nickels, quarters, and half dollars

Per Student

- One copy of the "Penny for Your Thoughts" Student Activity Sheet

Key Question

- How is a magician's tablecloth trick similar to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Did You Know?

Whether you are attempting the magician's tablecloth trick or slamming on your car brakes to avoid an accident, the laws of physics apply.

Understanding the physical laws of motion can help improve your chances of success in either situation and could even save your life someday!

Procedure

1. Cover the cup with the index card and center the penny above the cup on top of the card (See Figure 1).
2. Try to figure out how to get the penny into the cup without lifting the card and only touching the card with one finger.
3. After each group member has succeeded with one penny, try it with a stack of multiple pennies and/or other coins.

Analysis Questions

1. Describe the successful technique you used.

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2. Why does the penny drop in the cup when the card is "flicked" away?

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STUDENT ACTIVITY

PENNY FOR YOUR THOUGHTS ON INERTIA

Analysis Questions (continued)

3. How did the total mass of the coins used affect your success? (HINT: How are "mass" and "inertia" related?)

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4. How does this activity illustrate Galileo's Principle of Inertia and Newton's First Law of Motion?

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5. Should magicians select lighter or heavier dishes for their tablecloth trick? Why?

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Key Question 2

How is the magician's tablecloth trick similar to a crash dummy falling off the tailgate of an accelerating pickup truck?

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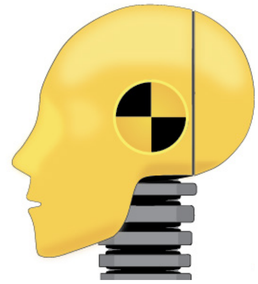
TEACHER LESSON PLAN

PAIN IN THE NECK



DEFINITIONS

Head restraint: (also called a headrest) a vehicle-seat safety device designed to limit the backward movement of an adult occupant's head in a rear-end collision in order to reduce the risk of neck injury.

Newton's First Law of Motion: an object at rest will remain at rest and an object in motion will remain in motion unless acted on by an outside force.

Whiplash: a variety of sprains, strains, and other neck injuries caused by a severe jerk to the head that can occur in rear-end vehicle collisions.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

» What is whiplash?

» How does Newton's first law of motion affect the type and severity of head/neck injuries resulting from rear-end collisions?

» How do well-designed vehicle head restraints help prevent head/neck injuries in a rear-end collision?

Grade levels: 6–12

Time required: one 50-minute class period

Objectives

Students will:

» predict and describe how a simulated crash dummy's head (tennis ball) responds in different vehicle movement scenarios.

» use a model to simulate a rear-end crash test to determine the proper location of an effective head restraint.

» use Newton's First Law of Motion (the concept of inertia) to explain the motion of a crash dummy's head and neck during a rear-end collision in a seat without a head restraint.

» analyze photographs from slow-motion videos of rear-end crash tests to identify the characteristics of head restraints that provide more protection against whiplash injuries in a rear-end collision.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

» 4-PS3-3, MS-PS2-2, HS-PS2-3

Background Information

The term "whiplash" is used to describe a variety of neck injuries that often occur in rear-end collisions. Whiplash injuries are the most frequently reported injuries in U.S. auto insurance claims. Properly placed head restraints can help prevent these injuries by supporting the head and neck and ensuring that the occupant's head moves together with the rest of the body in a way that reduces the stresses and strains on the neck during a rear-end collision. The IIHS Head Restraint & Seat Testing Program, that began in 1995, forced automotive manufacturers to pay attention to head restraint design, and consequently, head restraint ratings have improved considerably since.

Background Information (continued)

IIHS Head Restraints and Seats Tests

The IIHS uses four categories to rate the effectiveness of vehicle head restraints and seats in the event of a crash: "Poor," "Marginal," "Acceptable," and "Good." These ratings are determined by combining the ratings from two different tests: one motionless test and one active crash-test. The first test, called the Geometric Test, measures the distance between the crash dummy's head and the seat's head restraint (also called a headrest) when a vehicle is at rest. Seats and head restraints that receive an "Acceptable" or "Good" rating in the Geometric Test are then subjected to the second rear-end crash-test, called the Dynamic Test.

Test 1 - Head Restraint Geometric Test

For this test, technicians measure the vertical distance between the top of the head restraint to the top of a special crash dummy's head as well as the horizontal distance between the front of the head restraint to the back of the dummy's head (See Figure 1). In the event of a rear-end collision, the closer a dummy's head is to the top of the headrest and the front of the headrest, the less likely it is that whiplash injuries will occur. In Figure 2 below, the "Backset" is the distance between the front of the headrest and the back of the crash dummy's head while the "Height" is the distance between the top of the crash dummy's head and the top of the head restraint. As shown in Figures 1 and 2, to reduce the likelihood of whiplash injuries in a rear-end collision, a "Good" head restraint should be positioned directly behind and very close to the back of an occupant's head.

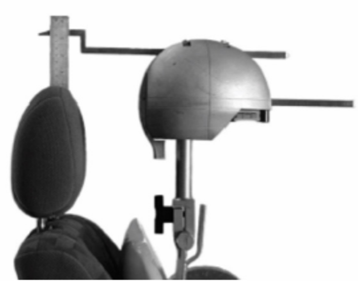
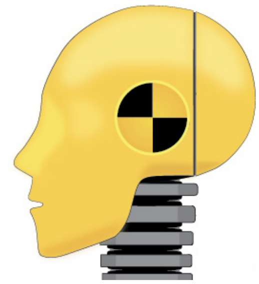
TEST 1 - HEAD RESTRAINT & SEAT GEOMETRIC TEST DUMMY		
		
Dummy in vehicle seat	Vertical distance between the top of the head and the top of the head restraint	Horizontal distance between the back of the head and the front of the head restraint

Figure 1



Background Information (continued)

TEST 1 - GEOMETRIC TEST ZONES AND RATINGS			
Zone	**Backset of headrest**	**Height of headrest**	**Rating**
Zone 1	≤ 7 cm from back of head	≤ 6 cm below top of head to 6 cm above top of head	Good
Zone 2	> 7 to ≤ 9 cm from back of head	> 6 to ≤ 8 cm below top of head	Acceptable
Zone 3	> 9 to ≤ 11 cm from back of head	> 8 to ≤ 10 cm below top of head	Marginal
Zone 4	> 11 cm from back of head	> 10 cm below top of head	Poor

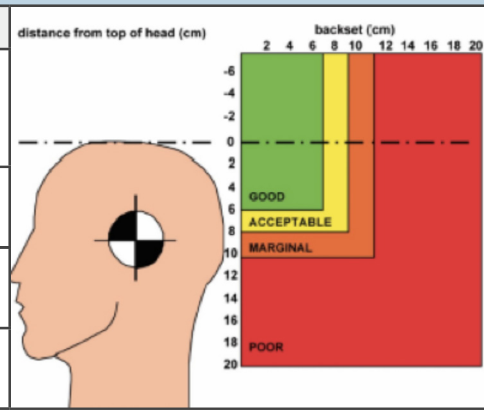


Figure 2

Test 2 – Dynamic Test

In the Dynamic Test, technicians begin by first removing the front seat with its head restraint and seat belt system from the vehicle and attaching it — along with another special type of crash dummy— to a steel sled. The special crash dummy used for rear-impact tests is called the Biofidelic Rear Impact Dummy or BioRID dummy, which represents an average-size man and has a spine composed of 24 articulated vertebra-like pieces (See Figure 3). During the simulated crash, the dummy's spine interacts with the vehicle seat in much the same way as a human spine would. Once the vehicle seat, along with the seat-belted dummy, is bolted to the sled, the sled is hit from behind by an air-powered ram to simulate a stationary vehicle that is rear-ended by another vehicle of the same mass moving forward at a speed of 20 mph (See Figure 4). The sled's sudden forward acceleration re-creates the forces acting on an occupant inside a vehicle during a real-world rear-end crash.

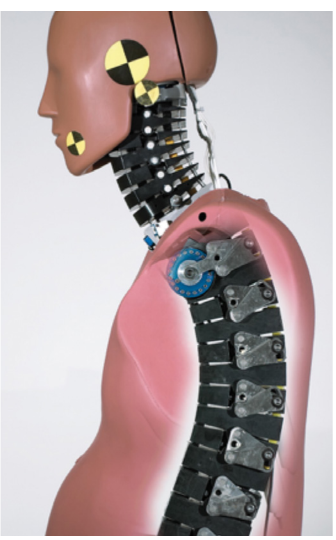
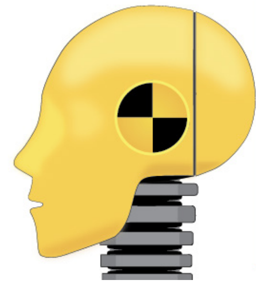


Figure 3

Figure 4



Background Information (continued)

Dynamic Test Rating Criteria

Two sets of criteria are used to evaluate the Dynamic Test performance of a seat/head restraint. The first set (seat parameters) looks at the length of time (in milliseconds) it takes the dummy's head to make contact with the head restraint (must be ≤70 milliseconds to pass) and the magnitude of the torso's acceleration during the crash test (must be ≤9.5 g to pass). The second set of evaluation criteria (neck forces) looks at the maximum forces recorded by the sensors in the dummy's neck during the test (classified as low, moderate or high). Lower neck forces indicate that the head restraint provides greater support to the head and neck in a rear-end collision at low to moderate speed. A seat/restraint that passes at least one of the seat design parameters and has low neck forces earns a dynamic rating of Good (see Figure 5).

Overall ratings

The geometric test rating and the dynamic test rating are combined to produce a seat/head restraint overall rating. A good rating can only be earned with both a good geometric rating and a good dynamic rating (see Figure 6). Though many vehicles have multiple options for seat/head restraint combinations, the Institute typically tests the seat option most likely to be found on car dealer lots.

TEST 2 - DYNAMIC RATINGS DERIVED FROM SEAT PARAMETER AND NECK FORCE RESULTS

Seat parameters	+	Neck forces	=	Dynamic ratings
Pass	+	Low	=	G
		Moderate		A
		High		M
Fail	+	Low	=	A
		Moderate		M
		High		P

Figure 5

G = Good, A = Average, M = Marginal, P = Poor

OVERALL RATINGS DERIVED FROM BOTH GEOMETRIC TEST AND DYNAMIC TEST RATINGS

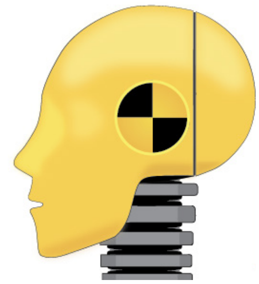
Geometric rating	+	Dynamic rating	=	Overall rating
G	+	G	=	G
		A		A
		M		M
		P		P
A	+	G	=	A
		A		A
		M		M
		P		P
M	+	No dynamic test	=	P
P	+	No dynamic test	=	P

Figure 6

G = Good, A = Average, M = Marginal, P = Poor

TEACHER LESSON PLAN

PAIN IN THE NECK



MATERIALS NEEDED

Per pair of students

- » 1 tennis ball or similar size ball
- » 1 hardcover textbook or clipboard
- » 1 metric ruler

Per student

- » 1 "Pain in the Neck" Student Activity Sheet

Per class

- » Computer with web access
- » Computer projector with speakers

Advance Preparation

- » Make copies of the activity sheet and assemble materials for each pair of students.
- » Cue up the video segment "Inside IIHS: Rear testing for whiplash prevention" located at classroom.iihs.org/pain-in-the-neck or on the IIHS in the Classroom homepage within the Inside IIHS tile (both found at classroom.iihs.org).
- » Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/pain-in-the-neck and decide if they should remain in the lesson.
- » For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/pain-in-the-neck

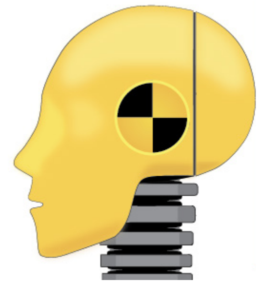
Safety Considerations

- » When completing Scenario 2 on the student activity sheet, students should make sure nothing or no one is directly behind the group's "walker" before they begin.

Procedure

Part 1 - Simulating Crash Dummy Head Responses in Different Vehicle Movement Scenarios

1. Introduce the lesson by asking students if they are familiar with the term "whiplash" and ask them to use hand motions to illustrate how they think the head and neck move when whiplash occurs. Explain that they will work with a partner to conduct a series of simulations to investigate why whiplash injuries often occur in rear-end collisions and apply the physics concept of inertia to explain how properly designed seat/head restraints can help prevent whiplash injuries in rear-end collisions.
2. Divide students into pairs and distribute the activity supplies and copies of the "Pain in the Neck" student activity sheets. Show the "Pain in the Neck" Introduction video at classroom.iihs.org/pain-in-the-neck. Refer to the activity sheet and review the Key Questions, the Purpose of the Activity, and the Did You Know? information.
3. Review the Procedure for Part 1, and, referring to Figure 2 on the student activity sheet, use a student volunteer to help you demonstrate the proper holding position for the book and ball if needed. Remind students that, in all 3 scenarios, the tennis ball represents a crash dummy's head that is not supported by a headrest while the book represents the crash dummy's body that is supported and protected because it is belted into a car seat.
4. Have student pairs complete the 3 scenarios in Part 1, record their predictions and observations, and answer Analysis Question 1. Circulate and assist groups as needed and caution students to remember the Safety Consideration before proceeding with Scenario 2.
5. Have pairs share their predictions and observations for the simulations in Part 1 and review the correct answer to the analysis question. Make sure students realize that "Scenario 1-Standing still and then quickly walking forward" most closely represents the way a crash dummy's head would move in a rear-end collision if the head is not supported by a head restraint.



Procedure (continued)

Part 2 – Simulating a Rear-crash Test in a Seat Without a Head Restraint

6. Next, have student pairs complete the simulation in Part 2 and demonstrate the proper set-up of the book and ball on a tabletop or countertop if needed. Remind students to draw horizontal lines with arrows on their diagrams indicating the movements of both the book and the ball as a result of the simulated rear-end collision as well as a vertical line indicating where they think a head restraint should be placed to better protect the ball in a rear-end collision.

7. Have pairs share their observations of the movement of the book and ball during the simulation as well as their decisions regarding where a head restraint should be placed. Make sure students understand that, since the ball (unsupported head) moves in the opposite direction of the body (the book) after a rear-end collision, the only way to protect the head and ensure that it moves along with the body in the same direction is to place the head restraint behind the ball. If the head is supported from behind, it will allow both the head and the body to move forward together with the vehicle seat when the crash force is applied to the rear of the vehicle.

8. Before asking student pairs to answer Analysis Question 2 in Part 2, review Newton's First Law of Motion and the concept of inertia if needed and make sure students understand that, in terms of Newton's first law, in the event of a rear-end collision involving a stationary vehicle the "outside force" is the crash force applied to the rear-end of the car when a moving vehicle strikes it from behind.

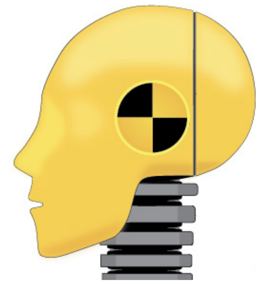
9. Have student pairs examine the diagrams in Figure 4 and complete Analysis Question 2. Then have students share and discuss their explanations. In terms of Newton's First Law of Motion during a rear-end crash test, make sure students understand that:

- **a.** When the crash sled is struck from behind, the crash force (outside force) overcomes the sled's inertia (a body at rest) and accelerates BOTH the sled and the seat with the dummy's body strapped to it forward.
- **b.** Without a head restraint to transfer the crash force to the head and accelerate it forward along with the neck and body, the inertia of the head at rest is not overcome by an outside force, so the head lags behind the forward-moving body.
- **c.** In a real rear-end collision with a vehicle that has no head restraints, the forward-moving neck would eventually stretch to its limit and snap the head forward, resulting in moderate to severe whiplash injuries.

Part 3 – Identifying the Characteristics of Effective Vehicle Seat/Head Restraint Designs

10. Now that students understand the physics behind rear-end crashes, explain that Part 3 of the activity focuses on how the IIHS uses the laws of physics to design and conduct realistic simulations of rear-end crashes and develop tests for rating the effectiveness of seat/head restraint designs.

11. Have the whole class watch the videos: "Pain in the Neck" Conclusion video (running time 1min 12 secs.) and "Inside IIHS: Rear testing for whiplash prevention" (running time 2 min. 23 secs.) located at classroom.iihs.org/pain-in-the-neck/. While viewing the "Inside IIHS" video, instruct students to complete the 3 fill-in-the-blank statements in Part 3 on the activity sheet, pausing the video as needed. Review correct fill-in-the blank responses (head, accelerations, good, neck).



Procedure (continued)

12. Tell students that they are now going to apply what they have learned during this activity to determine the characteristics of a vehicle head restraint that protects against whiplash injuries in a rear-end collision. Instruct students to examine the photographs in Figure 5 of the activity sheet and work with their partners to complete Analysis Questions 3 and 4 in Part 3.

13. Have pairs share their observations of the crash dummy's head and neck position for each frame in Figure 5 and identify the key differences between a "Poor" and "Good" head restraint. Make sure students understand that the most effective head restraints are as close to the back of an occupant's head as possible and close to the top or taller than the top of an occupant's head.

14. If time permits, share and discuss relevant background information regarding the history of the IIHS Head Restraint & Seat Testing Program and the Geometric and Dynamic Head-Restraint Test parameters and rating criteria

Answers to Analysis Questions

Part 1 - Simulating Crash Dummy Head Responses in Different Vehicle Movement Scenarios

4. **Which scenario in the simulations you just completed best represents the way a crash dummy's head (tennis ball) would move if the body was buckled into a seat (the textbook) but the head was unsupported and the stationary vehicle was then hit from behind by another car?**

SCENARIO 1 - Standing still and then quickly walking forward

Part 2 – Simulating a Rear-crash Test in a Seat Without a Head Restraint

5. Using a tennis ball, textbook, and metric ruler, follow the steps below to simulate the effects of a rear-end crash test on a crash dummy's head and body if it is strapped into a seat without a head restraint.

d. **On Figure 3** below, draw one line and arrow from the star on the ball and one line and arrow from the star on the book to show **which direction each item moves during a simulated rear-end collision.**

e. **Draw a vertical line next to the ball indicating where a head restraint should be placed in order to best protect the crash dummy's head in a read-end collision.**

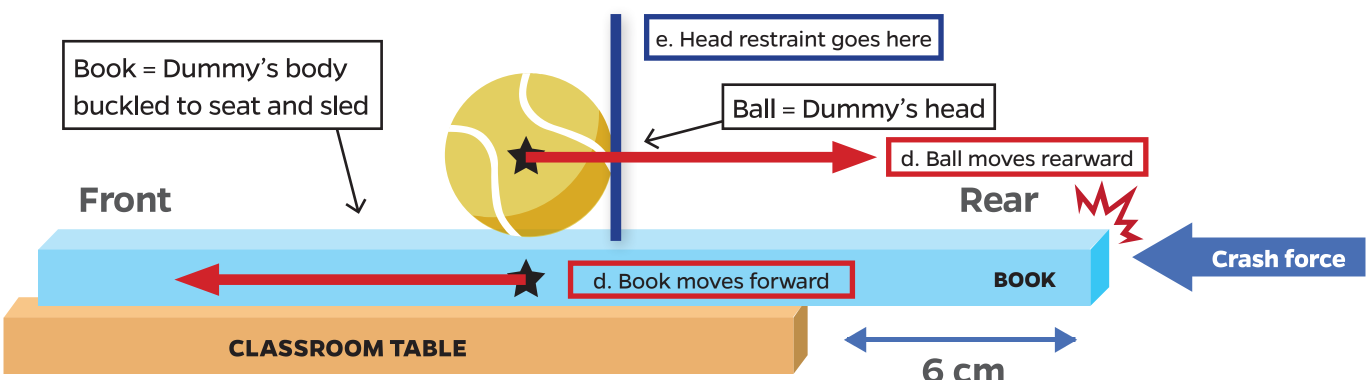
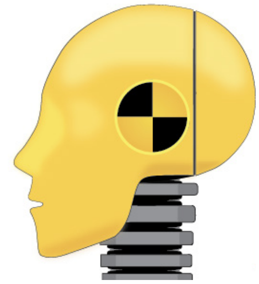


Figure 3



Answers to Analysis Questions (continued)

6. **In the chart below, use the concept of inertia to explain the differences between the movement and positions of the skull and the neck vertebrae BEFORE and DURING a rear-end crash test of a seat without a head restraint.**

SKULL BEFORE REAR-END CRASH	SKULL DURING REAR-END CRASH
» Skull is at rest » Skull is aligned vertically with the neck	» Skull remains in original position at rest » Skull is not vertically aligned with the neck
NECK VERTEBRAE BEFORE REAR-END CRASH	**NECK VERTEBRAE DURING REAR-END CRASH**
» Vertebrae are at rest » Vertebrae are aligned vertically with the skull	» Vertebrae are in forward motion due to outside crash force overcoming their inertia » Vertebrae are no longer vertically aligned with the skull

Part 3 - Identifying the Characteristics of Effective Vehicle Seat/Head Restraint Designs

7. With your class or partner, watch the 2.5-minute video **"Inside IIHS: Rear testing for whiplash prevention"** located at classroom.iihs.org/pain-in-the-neck. While viewing the video, complete the fill-in-the-blank statements below with the correct terms.

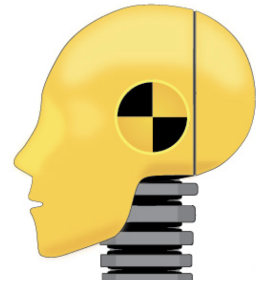
a. "The measurements from the dummy are then used to judge which seats are doing a better job of moving the **head** together with the rest of the body in a way that reduces the stresses and strains within the neck."

b. "The sled is a steel flatbed that runs on rails that can be programmed to produce specific **acceleration** and decelerations."

c. "We've done a study that shows the seats we've rated as **good** do in fact reduce the risk of **neck** injury."

8. For each frame, describe how the positions of the head, neck, and headrest differ for Seat 1 and Seat 2 in Figure 5.

FRAME NUMBER	SEAT 1	SEAT 2
1	» Head and neck are far away from front of head restraint » Head and neck are vertically aligned	» Head and neck are close to front of head restraint » Head and neck are vertically aligned
2	» Head and neck are getting closer to front of head restraint » Head restraint lower than the back of the head » Head and neck are still vertically aligned	» Head is in contact with front of head restraint » Top of head restraint is even with the center back of the head » Head and neck are still vertically aligned
3	» Head and neck are leaning backward » Back of head is touching head restraint	» Head and neck are still vertically aligned » Head and neck are in contact with front of head restraint
4	» Head and neck have snapped forward » Head and neck are far away from head restraint	» Head is in contact with front of head restraint » Head and neck are still vertically aligned



9. Based on your analysis of these images, identify the characteristics of a head restraint that provides more protection against whiplash injuries in a rear-end collision by circling the best responses.

a. Horizontal distance between the head rest and the back of the dummy's head

Circle one: *Head rest close to the back of the dummy's head*

b. Vertical height of the head rest relative to the top of the dummy's head

Circle one: *Head rest near the top or above the top of the dummy's head*

Extension

1. Have students further explore the classroom.iihs.org website to view the Crash Science Demonstrations entitled "Broom & Egg" and "Apple on Rod" addressing Newton's First Law of Motion and the concept of inertia.

2. Have students visit the IIHS.org website to investigate the Head Restraint & Seat Rating and Technical Measurements for a vehicle of their choosing. To find a specific vehicle's rating, click on "Vehicle Ratings" at the top of the iihs.org webpage. Start typing the name of the manufacturer (e.g., Ford) and or model (e.g., Explorer) in the search field and a list of choices will appear. Students may also specify the model's year (e.g., 2019) if desired. Select the vehicle and click on "Head Restraints & Seats" to see the ratings. Then click on "Technical measurements for this test" to further investigate the data. Have students note the units of measurement for distance (millimeters), acceleration (g units), contact time (milliseconds) and force (Newtons).

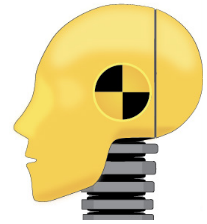
This activity was adapted from The Humanized Physics Project's "This is a pain in the neck: Newton's 1st Law," Department of Physics, Doane College. Used with permission.

STUDENT ACTIVITY

Name: ____________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

PAIN IN THE NECK



MATERIALS NEEDED

Per pair of students

- 1 tennis ball or similar size ball
- 1 hardcover textbook or clipboard
- 1 metric ruler

Per student

- 1 "Pain in the Neck" Student Activity Sheet

Key Question(s)

- What is whiplash?
- How does Newton's first law of motion affect the type and severity of head/neck injuries resulting from rear-end collisions?
- How do well-designed vehicle head restraints help prevent head/neck injuries in a rear-end collision?

Purpose

- To investigate how a body responds to crash forces in a rear-end collision
- To explain how Newton's first law of motion (the concept of inertia) applies to the movements of a crash dummy's head and neck during a rear-end collision
- To identify the characteristics of seat/restraint designs that receive "Poor" versus "Good" IIHS ratings

Did You Know?

Neck sprains and strains, commonly known as whiplash, are the most frequently reported injuries in U.S. auto accident insurance claims. The term "whiplash" is used to describe a variety of neck injuries that often occur in rear-end crashes. In this activity you will work with a partner to investigate the science behind rear-end collisions and learn how well-designed vehicle head restraints prevent whiplash injuries in these types of crashes.

Procedure

Part 1 - Simulating Crash Dummy Head Responses in Different Vehicle Movement Scenarios

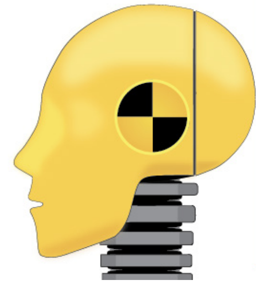
1. Watch the "Pain in the Neck" Introduction at classroom.iihs.org/pain-in-the-neck.

2. Next, work with a partner and follow the steps below to investigate how a crash test dummy's head responds to three different types of vehicle movement using a tennis ball to represent the dummy's head and a book (or clipboard) to represent the dummy's body seat-belted into a vehicle's front seat. Then, use your observations and work together to answer the analysis question.

3. Decide which role each of you will perform: "walker" or "recorder/observer."

   a. Walker: Hold the book or clipboard horizontally with the ball in the center on top of the book and walk forward or backward as described in each scenario. See Figure 1.

   b. Recorder: Record your team's agreed-upon predictions, observe the movement of the ball relative to the book as the walker completes each simulation, and record these observations on both the walker's and the recorder/observer's Pain in the Neck Activity Sheets.



Procedure (continued)

4. Complete the predictions and observations for Scenarios 1, 2, and 3.

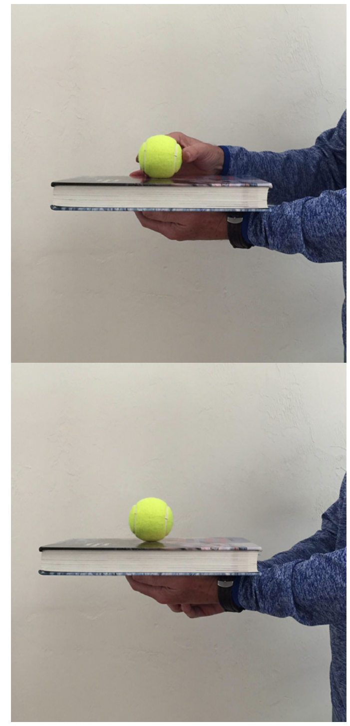


Figure 1

Scenario 1

a. Predict what direction the ball will move when the "walker" quickly walks the book **forward**.
We predict the ball will move: *(circle one)*

forward backward

b. **With the "walker" standing still and the tennis ball sitting motionless on top of the textbook, the "walker" should then take a few quick steps forward with the book. Observe which direction the ball moves.**
We observed the ball will move: *(circle one)*

forward backward

Scenario 2

c. Predict what direction the ball will move when the "walker" quickly walks the book **backward**.

We predict the ball will move: *(circle one)* forward backward

d. ***SAFETY NOTE: Before the "walker" steps backward, make sure nothing or no one is directly behind him/her.*** Standing still with the tennis ball sitting motionless on top of the textbook, the "walker" should then take a few quick steps **backward** with the book. Observe which direction the ball moves.

We observed the ball moving: (circle one) forward backward

Scenario 3

a. Predict what direction the ball will move when the "walker" steadily walks **forward** with the ball on the book and then suddenly stops.

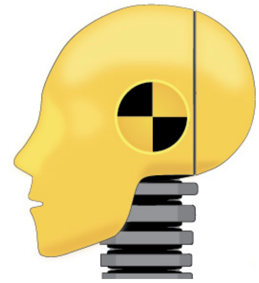
We predict the ball will move: *(circle one)* forward backward

b. While keeping the ball on top of the book with a light touch of his/her hand, the "walker" should then steadily walk **forward** at a constant pace as they gently let go of the ball so the ball remains motionless in the same spot on top of the book. Then the "walker" should stop suddenly. Observe which direction the ball moves.

We observed the ball moving: (circle one) forward backward

STUDENT ACTIVITY

PAIN IN THE NECK



Analysis Question

4. Which scenario in the simulations you just completed best represents the way a crash dummy's head (tennis ball) would move if the body was buckled into a seat (the textbook) but the head was unsupported and the stationary vehicle was then hit from behind by another car?

Circle one:

a. SCENARIO 1 - Standing still and then quickly walking forward
b. SCENARIO 2 - Standing still and then quickly walking backward
c. SCENARIO 3 - Steadily walking forward and then stopping suddenly

Part 2 - Simulating a Rear-crash Test in a Seat Without a Head Restraint

5. When the IIHS conducts rear-end crash tests of seats and head restraints, the front seat is removed from a vehicle and bolted to a steel sled. A special dummy is then belted into the seat. *This special dummy, called a BioRID rear-impact dummy (see Figure 2), has a spine composed of 24 articulated vertebra-like pieces that produce the same movements that occur in human necks and spines during real-world rear-end vehicle crashes.* The sled is then hit from behind by an air-powered ram while the sled is standing still.

Using a tennis ball, textbook, and metric ruler, follow the steps below to simulate the effects of a rear-end crash test on a crash dummy's head and body if it is strapped into a seat without a head restraint. Then, after your teacher reviews Newton's First Law of Motion and the concept of inertia, use your observations from this simulation and work together to answer the analysis question.

a. Place the textbook on top of a table or counter with about 6 cm of the bottom of the book hanging off the edge of the table. See Figure 3.

b. Place the tennis ball in the center on top of the book.

c. Strike the end of the book hanging off the edge of the table with the open palm of your hand and observe what happens to both the book and the ball.

d. On Figure 3 below, draw one line and arrow from the star on the ball and one line and arrow from the star on the book to show which direction each item moves during a simulated rear-end collision.

e. Draw a vertical line next to the ball indicating where a head restraint should be placed in order to best protect the crash dummy's head in a read-end collision.

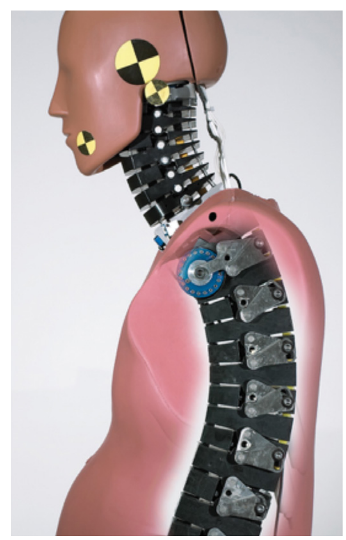
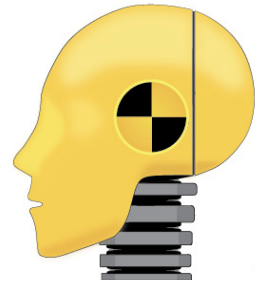


Figure 2

PAIN IN THE NECK



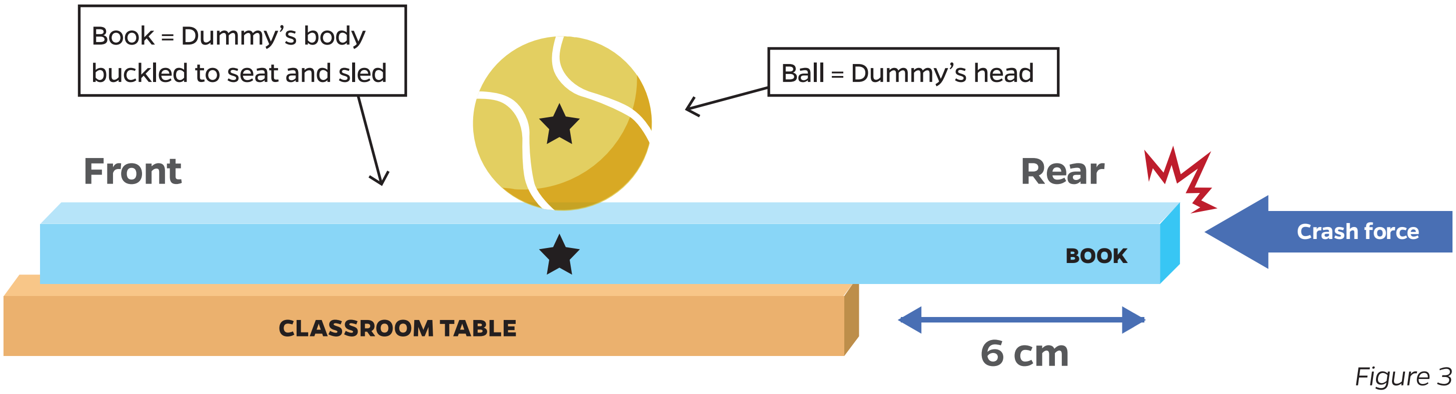


Figure 3

Analysis Question

6. The drawings in Figure 4 below depict the skull and 7 neck vertebrae in the BioRID dummy BEFORE and DURING a rear-end crash test using a vehicle seat that does not have a head restraint. According to Newton's First Law of Motion, an object at rest will remain at rest and an object in motion will remain in motion unless acted on by an outside force. This is also known as the concept of inertia. In the chart below, use the concept of inertia to explain the differences between the movement and positions of the skull and the neck vertebrae BEFORE and DURING a rear-end crash test of a seat without a head restraint.

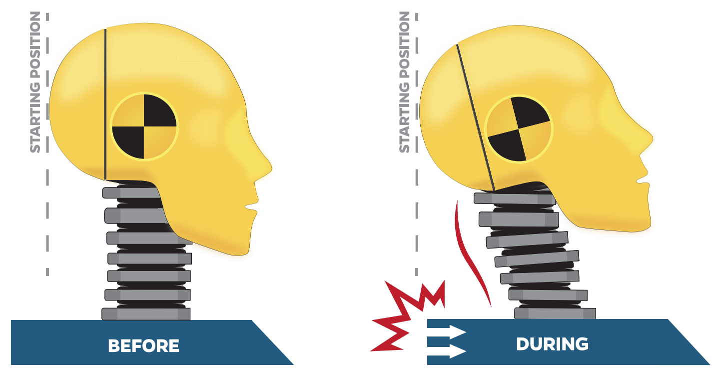


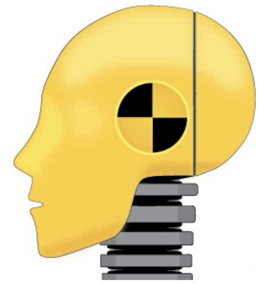
Figure 4

SKULL BEFORE REAR-END CRASH	SKULL DURING REAR-END CRASH

NECK VERTEBRAE BEFORE REAR-END CRASH	NECK VERTEBRAE DURING REAR-END CRASH

STUDENT ACTIVITY

PAIN IN THE NECK



Part 3 - Identifying the Characteristics of Effective Vehicle Seat/Head Restraint Designs

Properly designed seats and head restraints can significantly reduce both the number and severity of whiplash injuries in the event of a rear-end collision. Watch the video segment and examine the photographs provided to learn more about how the IIHS determines the characteristics of effective seat/head restraint designs. Then work with your partner to answer the analysis questions.

7. With your class or partner, watch the "Pain in the Neck" Conclusion video and the "Inside IIHS: Rear testing for whiplash prevention" video (both located at classroom.iihs.org/pain-in-the-neck). While viewing the "Inside IIHS" video, complete the fill-in-the-blank statements below with the correct terms.

a. At running time 00:35, David Zuby (Chief Research Officer) states:

"The measurements from the dummy are then used to judge which seats are doing a better job of moving the ______________________________ together with the rest of the body in a way that reduces the stresses and strains within the neck."

b. At running time 00:50, Ronnie Wells (Engineering Technician) states:

"The sled is a steel flatbed that runs on rails that can be programmed to produce specific ______________________________ and decelerations."

c. At running time 02:05 David Zuby states:

"We've done a study that shows the seats we've rated as ______________________________ do in fact reduce the risk of ______________________________ injury."

PAIN IN THE NECK

8. Figure 5 below contains a series of photographs from slow-motion videos of rear-end crash tests of vehicle seats/head restraints from two different vehicles: one with a "Poor" rating and one with a "Good" rating. Compare the four picture frame sequences for the tests of Seat 1 and Seat 2 to answer the analysis questions. (HINT: Look closely at the positions of the crash dummy's head compared to the head restraint during each frame of the sequence.)

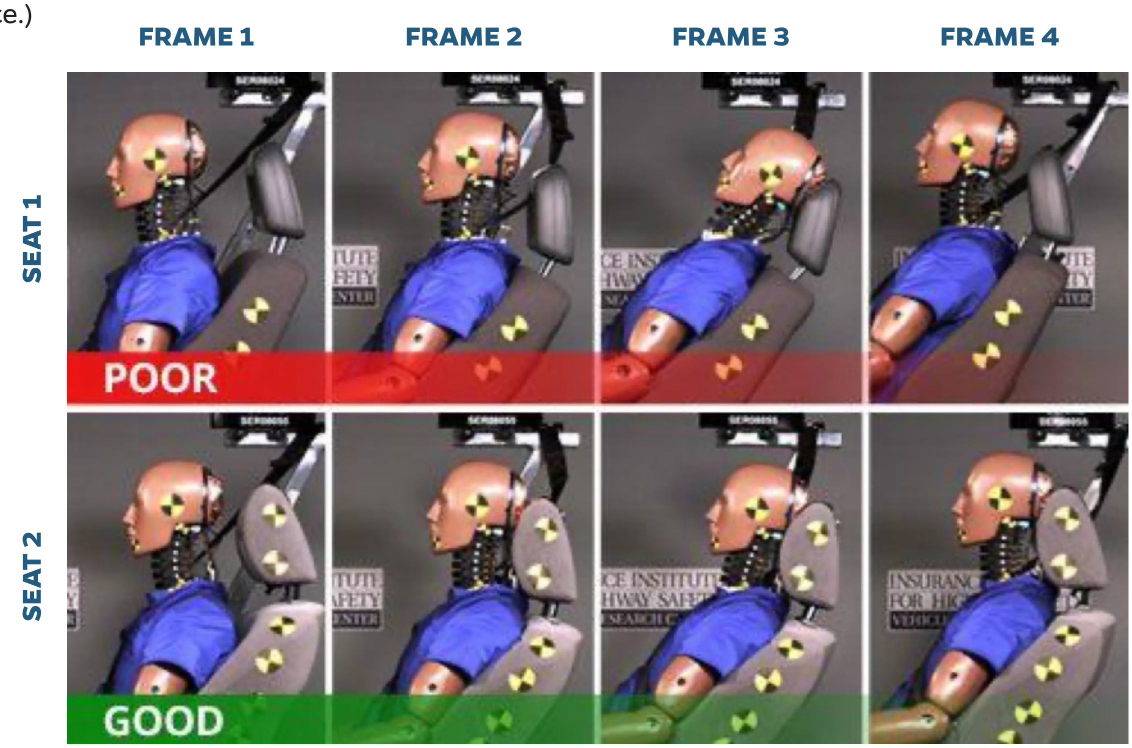
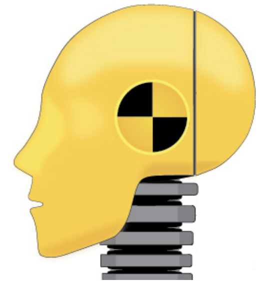


Figure 5 - Rear-End Crash Test Slow-Motion Video Images

For each frame, describe how the positions of the head, neck, and headrest differ for Seat 1 and Seat 2 in Figure 5.

FRAME	SEAT 1	SEAT 2
1		
2		
3		
4		



9. Based on your analysis of these images, identify the characteristics of a head restraint that provides more protection against whiplash injuries in a rear-end collision by circling the best responses.

a. Horizontal distance between the head rest and the back of the dummy's head

Circle one: Head rest close to the back of the dummy's head

Head rest farther away from the back of the dummy's head

b. Vertical height of the head rest relative to the top of the dummy's head

Circle one: Head rest well below the top of the dummy's head

Head rest near the top or above the top of the dummy's head

TEACHER LESSON PLAN

MOMENTUM BASHING

DEFINITIONS

momentum: the inertia of moving objects; product of the mass and the velocity of an object (p = mv)

velocity: the speed of an object and its direction of motion

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

- What determines if one car has more momentum than another in a two-car collision?
- Does increasing an object's mass increase its momentum or "bashing power?"

Grade levels: 5–12
Time required: 30–40 minutes

Objectives

Students will:

- conduct an experiment to determine if increasing an object's mass increases its momentum.
- explain how two vehicles of different masses can achieve the same momentum.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

- HS-PS2-1, MS-PS2-2, 5-PS2-1, 3-PS2-2, 3-PS2-1

Background Information

Scientific inquiry is a process engaged in by both individuals and a broader "scientific community." One of the first groups to formally represent the scientific community was the Royal Society of London for Improving Natural Knowledge, founded in 1660. The group evolved from informal meetings of scientists at which they discussed and performed simple scientific experiments. A young and soon-to-be-famous member of the Royal Society named Isaac Newton engaged this scientific community in exploration of the topic of motion and collisions. And, using knowledge gained from this collective group exploration as well as his own observations, Newton eventually developed and published his very significant three laws of motion in 1686.

Newton's Second Law of Motion states that if you wish to accelerate (e.g., speed up the rate of movement of) an object, you must apply a force to it. **Newton's First Law of Motion** says that an object at rest will stay at rest and an object in motion will remain in motion unless friction or another outside force, like a wall, stops it. As discussed in Activity 1, this tendency of objects to resist any change in their state of motion is called inertia and the inertia of moving objects is called **momentum**.

TEACHER LESSON PLAN

MOMENTUM BASHING

MATERIALS NEEDED

For each group of 3-4 students

- One 30.5 cm (1 foot) wooden or plastic ruler with center groove
- Four marbles, all the same size
- One 5-ounce (148 ml) paper cup
- One pair of scissors
- Two meter sticks or metric measuring tapes
- One book to support the ruler track (3–4 cm thick)
- One calculator

Per Student

- One copy of the “Momentum Bashing” Student Activity Sheet

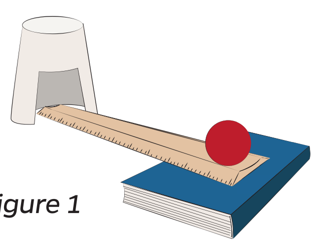


Figure 1

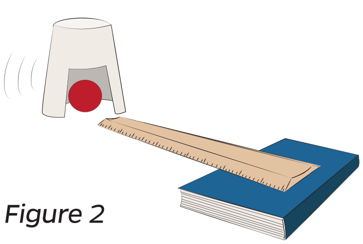


Figure 2

Background Information (continued)

The momentum (p) of a moving object is related to both its mass (m) and its velocity (v) and is represented mathematically as $p = mv$. A moving object has more momentum if it has a large mass, a large velocity, or both. The motion of objects with less momentum is easier to stop than objects with more momentum. Thus, a moving marble can be stopped more easily than a moving bowling ball. Both balls have momentum, but, a moving bowling ball has more momentum than a marble with the same velocity because the bowling ball has more mass. Similarly, if two bowling balls with the same mass have different velocities, the bowling ball moving with more speed will be harder to stop than the bowling ball which is moving more slowly. If EITHER the velocity or the mass of an object changes, its momentum changes. For more information on momentum see Background Information from “Momentum Bashing 2” and “Egg Crash! Building a Collision Safety Device” lessons.

Advance Preparation

- Make copies of the student activity sheet and assemble materials for each group.
- To save time, pre-cut the openings in the paper cups by cutting 3 cm wide and 3 cm tall sections from the top of each cup. See Figure 1.
- Watch the activity’s Introduction and Conclusion videos at classroom.iihs.org/momentum-bashing-1/ and decide if you want to incorporate them in the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/momentum-bashing-1/

Procedure

1. Refer to the Background Information regarding our understanding of the laws of motion and explain how scientific knowledge evolves over time by building on and revising earlier knowledge generated by both individual scientists and communities of scientists who share their work. Explain that this lesson will help students build on their existing knowledge of force, inertia, and velocity to better understand what happens in a vehicle crash.
2. Ask the following engagement question: The term momentum is often used by sports commentators or political analysts to describe a team’s or candidate’s performance, yet this term is used a bit differently in physics. Can you explain the difference?
3. Divide students into groups and distribute the supplies and worksheets. Refer to the worksheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information. Optional: Show the activity’s Introduction video.
4. Review the Procedure for the activity, refer to Figures 1 and 2, and demonstrate how to cut the cup and set up the support track if needed. (NOTE: Long, flat tables or tile floors work well!)

MOMENTUM BASHING

Procedure (continued)

5. Remind students to work together with their group members to complete three trials for each number of marbles, measure to the nearest tenth of a centimeter, and average their results. (NOTE: To promote cooperative learning, you could assign group roles such as "recorder/averager," "measurer," and "track operator.") Circulate and assist groups as needed.
6. Have groups share and compare their results and try to generate their own "original" conclusions regarding the relationship between an object's mass and its momentum based on the data they collected. Students should be able to draw the general conclusion that increasing the number of marbles (i.e., increasing mass) increases momentum.
7. Review the physics definition of momentum (inertia of moving objects) and the formula for momentum ($p = mv$). Review the concept of velocity (speed and direction of a moving object), if needed. Optional: Show the activity's Conclusion video.
8. Next, ask students to work collaboratively with their group members to answer the Analysis Questions.
9. Conduct a whole-class discussion of responses to the Analysis Questions and the two Key Questions.

NUMBER OF MARBLES	TRIAL 1 (CM)	TRIAL 2 (CM)	TRIAL 3 (CM)
1	*5.0*	*5.0*	*5.7*
2	*12.5*	*13.0*	*12.5*
3	*19.5*	*19.2*	*19.0*
4	*24.0*	*24.1*	*24.8*

Sample data table for distance cup moved (with ruler height at 3.0 cm)

Answers to Analysis Questions

1. **Describe the relationship between the number of marbles hitting the cup and the distance the cup moves.**

   As the number of marbles increases, the distance the cup moves increases. The average increase in distance traveled by the cup when an additional marble is added is typically between 6 and 7 cm.

2. **As the marbles collided with cup, did you encounter any problems with the marbles staying in the cup? If yes, describe what happened.**

   Yes, as the marbles collided with the cup, the cup would often spin causing some of the marbles to roll out of the cup.

3. **Explain how marbles escaping the cup during the collision affected your results. In other words, is evidence of this experimental error reflected in your data?**

   If the marbles escape the cup during the collision, they take "their" momentum with them. This reduces the momentum transferred to the cup therefore the cup does not travel as far as it would if all of the marbles stayed in the cup during the collision. Many students find the average distance gained with the fourth marble is less than the average distance gained by the second and third marble (e.g., a 5.8cm change in distance for 3-4 marbles compared to a 6.8cm change for 1-2 marbles and a 6.5cm change for 2-3 marbles).

MOMENTUM BASHING

Answers to Analysis Questions (continued)

4. How could you revise this activity to increase the momentum of the collision with the cup using only ONE marble?

Since momentum is the product of mass times velocity, if the total mass of marbles used cannot change, the only way to increase momentum would be to increase the velocity of the marble. The more kinetic energy the marble has, the greater its velocity will be when it collides with the cup, thus the greater its momentum would be. Increasing the starting height of the marble (i.e., increasing the height of the ruler) increases the initial potential energy and thus increases the resulting kinetic energy of the marble when it is released. More kinetic energy will result in greater velocity and thus greater momentum of the marble.

5. Explain why an 80,000-lb big rig traveling 2 mph has the same momentum as a 4,000-lb sport utility vehicle (SUV) traveling 40 mph. (Or in the approximate metric units, explain why a 36,000-kg big rig traveling 3 km/h has the same momentum as an 1800-kg SUV traveling 60 km/h.)

Since momentum is the product of mass and velocity, the truck's large mass and slow speed is matched by the SUV's smaller mass but greater speed.

$$\text{momentum} = \text{mass x velocity}$$
$$p = mv$$
$$\text{Big Rig's momentum} = \text{SUV's momentum}$$
$$mv = mv$$
$$(80{,}000\text{ lbs.})(2\text{ mph}) = (4{,}000\text{ lbs.})(40\text{ mph})$$
$$160{,}000\text{ (lbs.)(mph)} = 160{,}000\text{ (lbs.)(mph)}$$

Or in approximate metric units: (36,000 kg)(3 km/h) = (1800 kg)(60 km/h)

The SI unit for momentum is the kilogram x meter/second or in metric symbols (kg x m/s). To correctly calculate the momenta of the truck and SUV, you must convert their velocity from kilometers/hour to meters/second.

Truck momentum = (36,000 kg)(0.89 m/s) = 32,000 kg x m/s
SUV momentum = (1,800 kg)(18 m/s) = 32,000 kg x m/s

Extensions

» Have students conduct "Momentum Bashing 2" and revise this investigation to increase the momentum of the collision by changing the marbles' velocity instead of mass. Using the same equipment from "Momentum Bashing," students can investigate the relationship between the release height of the marble and the distance the cup moves.

» Have students discover the Law of Conservation of Momentum by exploring the results of an activity conducted with two colliding objects. (See Student Activity "Conservation: It's the Law").

STUDENT ACTIVITY

Name: ______________________ Class: ___________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

MOMENTUM BASHING

MATERIALS NEEDED

For each group of 3-4 students

» One 30.5 cm (1 foot) wooden or plastic ruler with center groove

» Four marbles, all the same size

» One 5-ounce (148 ml) paper cup

» One pair of scissors

» Two meter sticks or metric measuring tapes

» One book to support the ruler track (3–4 cm thick)

» One calculator

Per Student

» One copy of the “Momentum Bashing” Student Activity Sheet

Key Questions

» What determines if one car has more momentum than another in a two-car collision?

» Does increasing an object’s mass increase its momentum or “bashing power?”

Purpose

» To determine if increasing an object’s mass increases its momentum

» To explain how two vehicles of different masses can achieve the same momentum

Did You Know?

To better understand what happens in a vehicle crash, it helps to see how force, inertia, and velocity are related to a property called momentum. In physics, the amount of momentum an object has is often referred to as “oomph” or “bashing power.” In this activity you will investigate how an object’s mass affects its momentum.

Procedure

1. Use scissors to cut a 3.0 cm wide and 3.0 cm long section from the top of the paper cup.

2. Place the grooved ruler with one end on a textbook (approximately 3.0 cm high) and the other end resting on the table top or floor.

3. Place the 3.0 cm square opening of the cup just over the end of the ruler resting on the desk/floor.

4. Place a meter stick or measuring tape alongside the cup with the “zero” end of the meter stick or tape lined up with the opening in the cup to measure the distance it moves when struck by the released marbles.

5. Position ONE marble in the groove at the end of the ruler resting on the book. (See Figure 1 for completed set-up.)

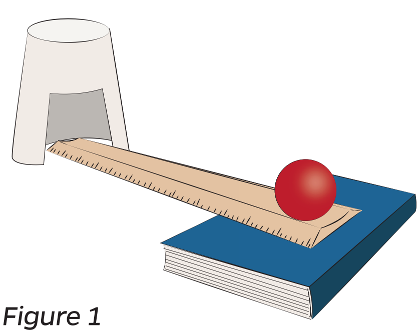


Figure 1

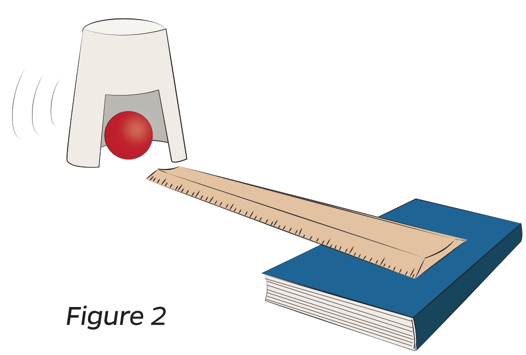


Figure 2

MOMENTUM BASHING

Procedure (continued)

6. Release the marble and observe the collision between the marble and the cup (Figure 2).
7. Use the meter stick/tape to measure and record the distance the cup moved (to the nearest 0.1 cm).
8. Repeat and perform three trials each using 1, 2, 3, and 4 marbles while keeping the height of the grooved ruler constant.
9. Use a calculator to compute the average distance traveled by the cups for each number of marbles and record all measurements in the data table below.

MOMENTUM BASHING DATA TABLE

NUMBER OF MARBLES	DISTANCE CUP MOVES (CM)			AVERAGE DISTANCE CUP MOVES (CM)
	TRIAL 1	TRIAL 2	TRIAL 3	
1				
2				
3				
4				

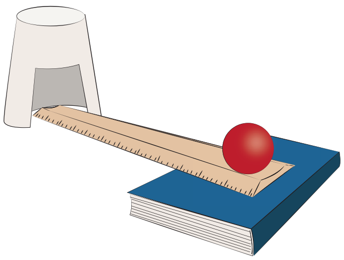
Analysis Questions

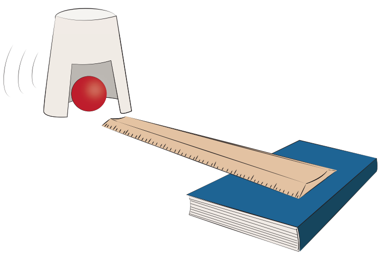
1. **Describe the relationship between the number of marbles hitting the cup and the distance the cup moves.**

2. **As the marbles collided with cup, did you encounter any problems with the marbles staying in the cup? If yes, describe what happened.**

MOMENTUM BASHING

Analysis Questions (continued)





3. **Explain how marbles escaping the cup during the collision affected your results. In other words, is evidence of this experimental error reflected in your data?**

4. **How could you revise this activity to increase the momentum of the collision with the cup using only ONE marble?**

5. **Explain why an 80,000 pound big rig traveling 2 mph has the SAME MOMENTUM as a 4,000 pound sport utility vehicle (SUV) traveling 40 mph.**

TEACHER LESSON PLAN

MOMENTUM BASHING 2

DEFINITIONS

speed: how fast something moves, calculated by dividing distance traveled by time of travel

velocity: the speed of an object and its direction of motion

variable: any factor that can be controlled, changed, or measured in an experiment

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

» How does changing an object's velocity change its momentum or "bashing power"?

» What determines if one car has more momentum in a two-car collision?

Grade levels: 5–12
Time required: 40-50 minutes

Objectives

Students will:

» conduct an experiment to determine if increasing an object's velocity increases its momentum.

» create and complete a data table.

» construct and interpret graphs of data to illustrate the relationship between velocity and momentum.

» evaluate experimental designs to determine and address sources of experimental error.

» explain what factors determine if one vehicle has more momentum than another in a two-vehicle collision.

Next Generation Science Standards*

Motion and Stability: Forces and Interactions

» HS-PS2-1, MS-PS2-2, MS-PS3-1, 3-PS2-2, 3-PS2-1

Engineering Design

» 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3

Background Information

See "Momentum Bashing" and "Egg Crash! Designing a Collision Safety Device" for background information on momentum. In this activity, students will revise the previous lesson, "Momentum Bashing," to investigate how an object's velocity (specifically its speed) affects its momentum. In this guided-inquiry lesson, students will identify and operationally define variables, generate an initial hypothesis, write an experimental procedure, design and complete a data table, and construct a line graph.

Three areas of potential confusion that might arise in this activity are: (1) the distinction between independent and dependent variables, (2) operational definitions of variables, and (3) the difference between speed and velocity.

TEACHER LESSON PLAN

MOMENTUM BASHING 2

MATERIALS NEEDED

For each group of 3-4 students

- One 30.5 cm wooden or plastic ruler with center groove
- One marble
- One 5-ounce (148 ml) paper cup
- One pair of scissors
- Two meter sticks or metric measuring tapes
- Books or papers to support the ruler track at 4 different heights (e.g., 1 cm, 2cm, 3cm, 4cm)
- Three to four sheets of notebook paper
- One sheet of graph paper
- One calculator

Per Student

- One copy of the "Momentum Bashing 2" Student Activity Sheet

Background Information (continued)

(1) An independent variable is a variable that is deliberately changed or manipulated by the experimenter (e.g., increasing the velocity of the marble). A simpler term for an independent variable is "manipulated" variable. A dependent variable is a variable that changes in response to changes in the independent variable (e.g.., distance the cup moves after it is hit by the moving marble). A simpler term for a dependent variable is "responding" variable. Controlled variables are all of the other variables that could potentially affect the outcome of the experiment but are kept from doing so by the investigator (e.g.., size of the marble, length of the ramp, and/or size of the cup).

(2) An operational definitions of a variable specifically identifies how a variable will be quantified and what units will be used to measure it. For example, in this activity, students will investigate how changing the velocity of a marble affects it momentum. Thus, the manipulated variable is the velocity of the marble. However, students won't actually be determining the velocity of the marble since they won't be able to calculate the actual "speed" of the marble. Instead, they can change the velocity of the marble by changing the height of the ruler track and they should discover that the higher the initial starting height of the marble, the greater the velocity of the marble. Similarly, students won't actually be calculating the momentum of the marble when it strikes the cup, but they can measure the distance traveled by the cup when the marble collides with it and discover that cups struck by marbles with greater velocities (and thus more momentum) are pushed greater distances. Thus, an operational definition for the manipulated variable will be "starting height of the marble in centimeters" and an operational definition for the responding variable will be "distance the cup moves in centimeters." All other variables in the experiment need to be controlled and students should be able to list several controlled variables, including: same marble (i.e., same mass), same cup, same ruler track, same initial distance of the cup away from the starting point of the marble, same surface for conducting the experiment, releasing the marble from the same spot at the elevated end of the ruler.

(3) In everyday conversation the terms "speed" and "velocity" are often used interchangeably. However, scientists and engineers distinguish between the two. Speed is a measure of the rate of movement of an object per unit of time (e.g., kilometers per hour or feet per second). Velocity is a measure of BOTH the speed of an object AND the direction in which it is traveling (e.g., 30 kilometers per hour, east). This distinction only becomes truly important when the direction of motion is a concern or changes. Technically, momentum is the product of an object's mass and its velocity, but students will probably describe their observations in this activity in terms of changes they can see in the "speed" of the marble when it is released from different heights.

TEACHER LESSON PLAN

MOMENTUM BASHING 2

Advance Preparation

» Make copies of the student activity sheet and assemble sets of materials for each group.

» Locate and make copies of grade-appropriate graph paper.

» Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/momentum-bashing-2 and decide if you want to incorporate them into the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/momentum-bashing-2.

Procedure

1. Ask students to recall their findings from "Momentum Bashing" and review the definition and formula for determining the momentum of an object. Remind students that "Momentum Bashing" investigated how changing the mass of an object affected its momentum and explain that this activity is going to focus on how changing the velocity of an object affects it momentum. Review the distinction between speed and velocity.

2. Divide students into groups and distribute the supplies and worksheets. Refer to the worksheet and review the Key Questions, the Purpose of the activity, and the "Did You Know" information. Optional: Show the activity's Conclusion video.

3. Review the Procedure for the activity and discuss/review key information regarding manipulated, responding, and controlled variables, operational definitions of variables, constructing data tables, and constructing graphs as needed. Encourage students to think like scientists and engineers (See Figure 1) as they design and complete their experiments.

THINK LIKE A SCIENTIST!

SHARE everything and be:

Curious	Open-Minded
Creative	Persistent
Honest	Skeptical
Objective	Tolerant

Figure 1

4. Instruct groups to FIRST write out their complete experimental procedure, including identifying manipulated, responding, and controlled variables, operationally defining variables, formulating a hypothesis, and writing out a step-by-step procedure. Circulate and assist groups as needed and check each group's written procedure before allowing them to move on to the next step.

5. Once groups' experimental procedures have been checked, instruct groups to prepare their data tables and fill in the names of all variables and all of the pre-determined values for the manipulated variable (See Sample Data Table in Figure 2). Circulate and assist as needed and once you have checked each group's data table, let them begin conducting the actual experiment.

FIGURE 2: SAMPLE DATA TABLE

Marble's Starting Height vs. Distance Cup Moves

MARBLE'S STARTING HEIGHT (CM)	DISTANCE CUP MOVES (CM)			AVERAGE DISTANCE CUP MOVES (CM)
	TRIAL 1	TRIAL 2	TRIAL 3	
2	*7.5*	*8.0*	*8.0*	*7.7*
4	*13.5*	*14*	*13.5*	*13.7*
6	*25*	*24*	*23*	*24.0*
8	*30*	*29*	*31*	*30.0*

TEACHER LESSON PLAN

MOMENTUM BASHING 2

Procedure (continued)

6. Next, remind students that a line graph is a special type of data "picture" that helps experimenters see the relationships between manipulated and responding variables. Have groups construct graphs of their data and review the following hints for constructing a best-fit line if needed:

- » The line should be a straight line or a smooth curve illustrating a trend; NOT simply connecting dots.
- » All points should lie either on the line or near the line.
- » For points near the line, there should be an approximately equal number of points on either side of the line OR the sum of the distances of the points away from the line should be equal for points above the line and below the line. Share samples of best fit lines in the figures below if needed.

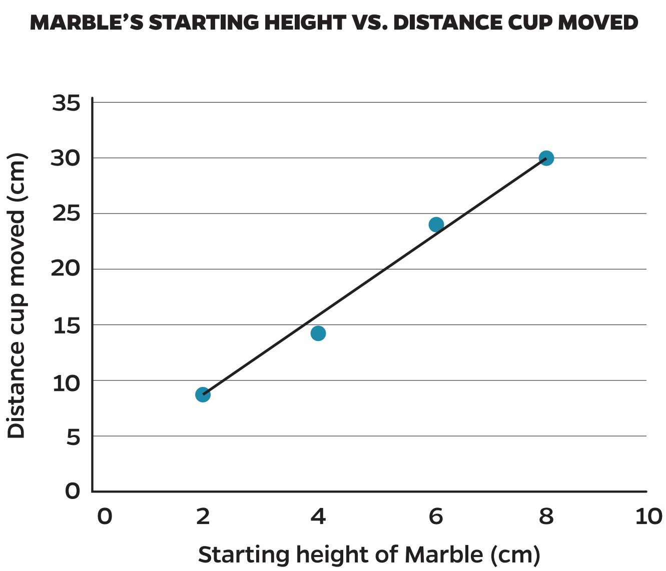


Figure 3 - Straight Best-Fit Line

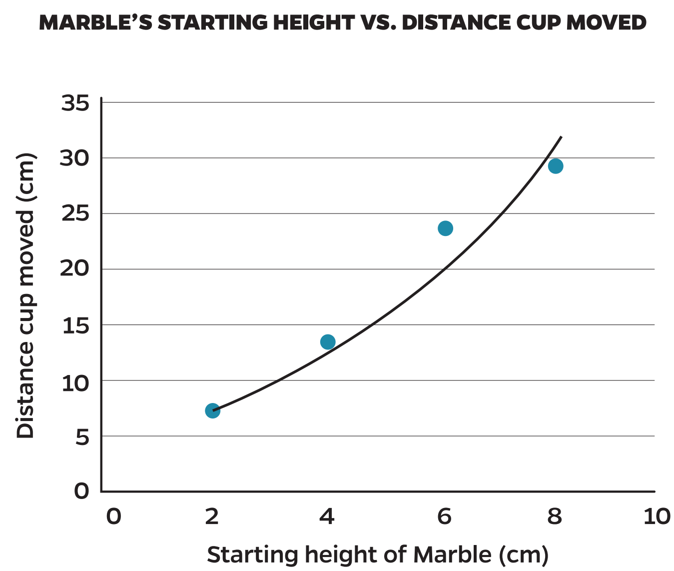


Figure 4 - Smooth Curve Best-Fit Line

7. Have groups share and compare their results and discuss the relationship they observed between velocity and momentum. Next, ask students to work collaboratively with their group members to answer the Analysis Questions. Optional: Show the activity's Conclusion video.

8. Conduct a whole-class discussion of responses to the Analysis Questions.

Answers to Analysis Questions

1. Using your group's Data Table and Graph, describe the relationship observed between the starting height of the marble and the distance the cup moves.

The general method for describing the relationship between variables on a graph is to state what happens to the responding variable as the manipulated variable changes. For this activity, a statement of relationship might read: "The distance the cup moves increases as the starting height of the marble increases." OR "As the starting height of the marble increases, the distance the cup moves increases." EITHER approach is correct!

MOMENTUM BASHING 2

Answers to Analysis Questions (continued)

2. How is the marble's starting height related to the marble's final velocity before impacting the cup?

Increasing the marble's final velocity as follows: Increasing the marble's starting height increases its energy of position or gravitational potential energy (PE). (The higher it is above the ground, the more PE it has). As the marble rolls down the ruler toward the ground, most of the PE is converted to energy of motion or kinetic energy (KE). The more KE a moving object has, the greater its velocity.

3. Explain how a marble's final velocity affects its momentum.

Increasing the marble's final velocity directly increases its momentum since momentum is the product of an object's mass multiplied by its velocity. Thus, marbles traveling at a greater velocity have more momentum when they collide with the cup.

4. For two identical cars of the same mass, what would determine if one car has more momentum than another in a two-car collision?

The only two factors that can change a car's momentum are its mass or its velocity (p = mv). If the masses of two cars are equal, the only way one car could have more momentum than another of equal mass would be if one of the cars was traveling at a greater velocity when they collided.

5. Given a choice, in which type of vehicle would you feel SAFEST in a two-car collision at 35 miles per hour and why?

A. Small two-door sports car
B. Medium size four-door sedan
C. Large SUV
D. Semi tractor trailer truck

D. Semi tractor trailer truck - With velocity held constant, larger, more massive vehicles with appropriate safety devices generally offer the best protection to occupants because they will have more momentum than a smaller vehicle in a two-car collision. In a two-car collision, the vehicle with the greater momentum continues forward longer and pushes the vehicle with less momentum backwards. Occupants in the larger car will feel/experience less of a change in their momentum and will experience less overall force of impact during the time of the collision. Thus, larger and "heavier" vehicles tend to be safer than smaller, lighter vehicles.

Extensions

1. Have students discover the Law of Conservation of Momentum by exploring the results of two colliding objects in the lesson "Conservation: It's the Law."

2. Ask students to visit the IIHS website (iihs.org) and click on TOPICS (listed at the top of the page) then select "Vehicle size and weight." Have students read the report explaining how car size and weight are crucial to protecting people in crashes.

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

MOMENTUM BASHING 2

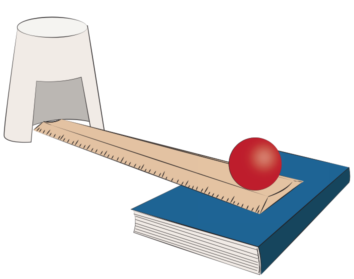
MATERIALS NEEDED

For each group of 3-4 students

- One 30.5 cm wooden or plastic ruler with center groove
- One marble
- One 5-ounce (148 ml) paper cup
- One pair of scissors
- Two meter sticks or metric measuring tapes
- Books or papers to support the ruler track at different heights
- Three to four sheets of notebook paper
- One sheet of graph paper
- One calculator

Per Student

- One copy of the "Momentum Bashing 2" Student Activity Sheet



Key Questions

- How does changing an object's velocity change its momentum or "bashing power"?
- What determines if one car has more momentum than another in a two-car collision?

Purpose

- To determine how changing an object's velocity changes its momentum
- To collect data and construct a graph illustrating the relationship between velocity and momentum

Did You Know?

During "Momentum Bashing," you investigated the effect of an object's mass on its momentum. However, during the investigation, you identified flaws and sources of error in the experiment's design. Specifically, when you rolled three or four marbles into the cup they often caused the cup to spin, thereby allowing marbles to escape and reduce the momentum transferred to the cup. According to the formula for momentum ($p = mv$), another way to change momentum besides changing mass is to change velocity. So, in this activity, you will use the same set of materials from "Momentum Bashing" to design and conduct an experiment to investigate the effect of an object's velocity on its momentum while keeping the mass of the object constant.

Procedure

Before planning and conducting an experiment to determine the effect of an object's velocity on its momentum, discuss ways you could use the materials listed above to change the velocity of a marble with your group members. Then

1. **Write the Experimental Procedure**

On a separate sheet of paper, work with your group members to revise the Activity 2 "Momentum Bashing" procedure using the materials listed above. Include the following items in your experimental procedure:

- Identify your independent (manipulated) and dependent (responding) variables
- Identify your controlled variables. (Remember, controlled variables are variables that could affect the outcome of the experiment but are kept from doing so by you. The more variables you control, the more reliable your results. Try to control at least three variables that could affect the outcome of your experiment.)
- Operationally define your manipulated and responding variables. (NOTE: You can choose four different values of your manipulated variable and conduct three trials for each value. e.g. Starting heights of 1 cm, 2cm, 3cm, and 4cm.)

STUDENT ACTIVITY

MOMENTUM BASHING 2

Procedure (continued)

1. Write the Experimental Procedure (continued)

- Write a hypothesis predicting what you think the relationship is going to be between the manipulated and responding variables in your experiment. (HINT: As ___________ increases, ___________ will increase/decrease/stay the same).
- Number the steps in your procedure.
- Describe your procedure in detail so that another group could follow it and replicate the experiment.
- Draw pictures to help show important steps in the procedure.

2. Create and Complete a Data table

After identifying and operationally defining your manipulated and responding (independent and dependent) variables, you can create the template for a Data Table to be completed during your experiment. Follow the guidelines listed below to create and complete a data table for your experiment:

- Provide the specific names of the manipulated and responding variables AND the specific units used to measure each variable.
- Sequentially order your four pre-determined manipulated variable values in the far left column.
- Clearly label columns for each trial number and the overall averages for the three trials.
- Record the values measured for each responding variable in each trial during the experiment.
- Calculate averages for the responding variable after all data have been recorded.

3. Create a Graph of Data from the Data Table

Use the graph paper provided to create a line graph of the data collected from your experiment. Clearly indicate the names of the manipulated and responding variables AND the units used for each on each axis. Follow the guidelines listed below when creating your graph:

- Make the graph large.
- Title the graph and label both axes.
- Place the manipulated variable on the x-axis and the responding variable on the y-axis.
- Divide each axis into 4-6 gradations that start slightly lower than the lowest data point recorded and end slightly higher than the highest data point recorded (e.g, 5, 10, 15, 20, 25 cm)
- Plot one dot for each matched data pair from the data table.
- After all data pairs have been plotted, draw a best-fit line (straight line or smooth curve) illustrating the relationship between the two variables shown on the graph.

STUDENT ACTIVITY

MOMENTUM BASHING 2

Analysis Questions

1. Using your group's Data Table and Graph, describe the relationship observed between the starting height of the marble and the distance the cup moves.

2. How is the marble's starting height related to the marble's final velocity before impacting the cup?

3. Explain how the marble's final velocity affects its momentum.

4. For two identical cars of the same mass, what would determine if one car has more momentum than another in a two-car collision?

5. Given a choice, in which type of vehicle would you feel SAFEST in a two-car collision at 35 miles-per-hour and why?

A. Small two-door sports car

B. Medium size four-door sedan

C. Large SUV

D. Semi tractor trailer truck

TEACHER LESSON PLAN

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

DEFINITIONS

momentum: the inertia of moving objects; product of the mass and the velocity of an object ($p = mv$)

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

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

» How do people survive major vehicle collisions?

» How do the laws and principles of physics demonstrate the effectiveness of seat belts and airbags?

Grade levels: 5–12
Time required: 50 minutes

Objectives

Students will:

» describe a collision in terms of changing momentum, impulse, impact force, and impact time.

» observe and document the effectiveness of safety devices such as seat belts and airbags by designing, building, testing, and evaluating a safety device to protect an egg during a collision.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

» HS-PS2-1 HS-PS2-3, MS-PS2-2, 4-PS3-1

Engineering Design

» HS-ETS1-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, 3-5-ETS1-1, 3-5-ETS1-2, 3-5ETS1-3

Background Information

When Newton described the relationship between force and inertia, he spoke in terms of two other physics concepts: momentum and impulse. Newton defined momentum as the product of an object's mass and velocity (see "Momentum Bashing"). Newton defined impulse as the quantity needed to change an object's momentum.

To change an object's momentum, the mass of the object, the velocity of the object, or both have to change. If the velocity of an object increases (accelerates) while its mass remains constant, its momentum also increases. In his second law, Newton said that in order to accelerate (or decelerate) a mass, a force must be applied. This notion is often expressed using the equation $F=ma$. A force "F" is needed to move a mass "m" with an acceleration of "a." The greater the force applied to an object, the greater its acceleration (i.e., the greater its change in velocity) and the greater its change in momentum.

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

MATERIALS NEEDED

For each group of 2-3 students

- 10 sheets of 8.5” x 11” copier paper
- One meter of masking tape
- One pair of scissors
- One raw, grade A medium or large egg (plus a few extra for accidental breakage before testing!)
- **OPTIONAL:** One plastic “Easter” egg for conducting practice “dry” runs with the collision safety devices

Per Student

- One copy of the “Egg Crash! Designing a Collision Safety Device” Student Activity Sheet

For the entire class

- 15-20 sheets of newspaper
- Two to three meter sticks
- One stepladder (2 meters/6 feet tall)
- Hard-surfaced floor, walkway, or playing surface (e.g., basketball court)

Background Information (continued)

In addition to changing momentum by changing the amount of force applied to a moving object, changing the amount of time a force acts on an object also changes momentum. Applying the brakes briefly to a moving vehicle slightly reduces its momentum. Applying the same braking force over an extended period of time greatly reduces the vehicle’s momentum. Similarly, slamming on the brakes of a moving vehicle for a short period of time reduces the vehicle’s momentum much more than lightly tapping on the brakes for that same period of time. The product of a force and the time it is applied to an object is called impulse. Impulse is mathematically represented as impulse = force x time interval

The greater the impulse exerted on a moving object, the greater its change in momentum. The amount of damage/injury that occurs in a collision is directly related to the impulse of a collision. Lengthening the time during which a “stopping” force is applied to a vehicle (and its occupants) in a collision reduces the final “net” force acting on the vehicle and its occupants when they finally come to a stop. Seat belts and airbags are examples of two major safety features that apply these laws of physics to reduce injuries in collisions. Both features help lengthen the amount of time between when the stopping force is first applied to a vehicle (e.g., crashing a car head-on into a wall) and when the occupants inside the car actually collide with the dashboard, steering wheel, or other vehicle structure.

Advance Preparation

- Assemble sets of collision safety device “building supplies” (paper, masking tape, scissors, and plastic eggs, if available) for each group. Set raw eggs aside until it is time for actual collision safety device testing.
- Select and prepare a “crash site” to test students’ devices by spreading newspaper on the floor to cover an area of approximately one square meter. Place the meter sticks and a ladder next to the “crash site.”
- Watch the activity’s Introduction and Conclusion videos at classroom.iihs.org/egg-crash and decide if you want to incorporate them into the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/egg-crash

Safety Considerations

- Scissors can cut skin. Caution students to direct sharp edges or points away from themselves and others.
- Follow all general stepladder safety procedures. See the safety notes attached to the ladder or osha.gov.
- Make sure students wash their hands thoroughly with soap and water after handling raw eggs, especially if they crack or break.

TEACHER LESSON PLAN

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

Procedure

1. Ask the following engagement question: If you were running, tripped and knew you were going to fall, would you rather fall on hard concrete floor or soft grass? Why?

2. Ask students to share any personal experiences they have had or stories they have heard about people surviving major vehicle collisions with little to no personal injury. Then ask them how they think people are sometimes able to survive and walk away from major vehicle collisions. Students will often describe such survivors as "lucky." Now, ask students if they really think surviving a major vehicle crash is just luck or if it is determined by the laws of physics.

3. Explain that scientists and engineers regularly use and apply the laws of physics in order to design vehicle structures and added features in order to minimize the physical damage to vehicles and injury to vehicle occupants in the event of a collision. Tell students that, as part of the engineering design process, scientists and engineers often build models to simulate collisions and test the potential effectiveness of different vehicle safety designs and added safety features. Explain that during this activity, students will be working in groups to design, build, test, and evaluate the effectiveness of a "collision safety device" (landing pad) to protect a raw egg during a collision with a hard surface (floor).

4. Divide students into groups and distribute all collision safety device building supplies (except raw eggs) and worksheets. Refer to the worksheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information. Optional: Show the activity's Introduction video.

5. Review the Design Challenge, Engineering Design Parameters, and Procedure for the activity. Encourage groups to conduct test runs of their devices using plastic "Easter" eggs if available. Remind groups that their safety device must protect their raw egg from repeated collisions from increasing heights (i.e., greater momentum). Also emphasize the fact that even a slight crack in their egg represents an injury and will disqualify them from the next round of competition. Finally, remind them that they are also disqualified if their egg is damaged from bouncing or rolling out of their landing pad once it lands.

6. Refer to the worksheet and instruct groups to complete the two "Pre-Testing" Analysis Questions together as a group (i.e., a drawing and description of their completed device.)

7. Allow groups 20 minutes to build and test their devices with plastic eggs only. After the design/testing time limit has expired, bring everyone to the testing area and distribute a raw egg to each group.

Do not allow any pre-testing of devices using actual raw eggs!

8. Before testing, have each group make a brief 30-second to 1-minute "sales pitch" for their safety device explaining the rationale for their design and why they think it will protect the egg. Next, determine the order of testing for the devices or ask groups to volunteer. Finally, before beginning actual testing, ask students to predict which safety device they think will win and why.

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

Procedure (continued)

9. Complete all groups' test drops for Round 1 before beginning Round 2 with groups whose devices were successful in Round 1. Continue this cycle, increasing the drop height by 0.5 meters in each round, until you reach a drop height at which only one safety device is successful and is declared the winner. Follow the Safety Considerations for ladder use and remind students to wash their hands thoroughly after handling raw or broken eggs. (NOTE: Occasionally, especially at greater heights, all remaining groups will be eliminated in the same round. In this case, declare a tie for all of the groups who were successful at the PREVIOUS round's drop height and determine the winner based on the device that was made with the least amount of paper.)

The suggested drop heights for Rounds 1-4 are: 1.0 m, 1.5 m, 2.0 m, 2.5 m.

10. After the winning Collision Safety Device has been determined, clean up the test area and have groups bring their landing pads back to the classroom for further analysis. Use the Background Information provided to discuss/review the key physics concepts and principles illustrated in this simulation (momentum, impulse, impact force, and impact time). Make sure students understand the relationships between these concepts and review formulas as needed. Optional: Show the activity's Conclusion video.

11. Instruct students to work collaboratively with their group members to answer the "Post-Testing" Analysis Questions and conduct a whole-class discussion of responses. Make sure students realize that, in addition to airbags and seat belts, other important vehicle collision safety features that have been developed by applying these same physics concepts and principles include: frontal crumple zones, padded dashboards, bumpers, and collapsible steering columns.

Answers to Analysis Questions

1. **Overall, which types of Collision Safety Device features were the <u>most</u> and <u>least</u> effective in this simulation and why?**

Answers will vary, but typically, the most successful devices have one or more of the following key design features:

» *Wide landing pad area to compensate for errors in aiming/sighting eggs*

» *High sides to keep eggs from bouncing or rolling out. Wide-mouthed "funnel" designs often work especially well.*

» *Increased distance between the top landing pad surface and the floor to make sure the egg does not fall or push all the way through the landing pad and make contact with the floor, especially when dropped from greater heights.*

» *Sturdy support structures to withstand multiple drops*

» *Layers of crumpled paper, rolled paper tubes, or other air-filled areas to increase impact time.*

» *Flexible landing pads that have some "give" when struck by the falling egg (similar to falling on soft grass rather than hard concrete).*

2. **As the drop height increased with each round, the amount of momentum the eggs experienced in their collisions with the landing devices also increased. Identify at least 2 Collision Safety Device design features that were especially important/useful for successful drops of eggs from greater heights (i.e., collisions with greater momentum).**

Answers will vary, but any design feature that helped increase impact time (slow the egg down gradually) and reduce the impact force would reduce the egg's momentum.

Answers to Analysis Questions (continued)

3. Often, even groups with well-designed and soundly-constructed Collision Safety Devices are not successful when eggs are dropped from greater heights. Identify at least 2 other reasons egg drops from greater heights are more challenging regardless of the quality of the landing pad.

"Operator error" increases dramatically as drop heights increase. Smaller "targets" are harder to line up with the eggs as the distance between the egg and the landing pad increases and it is harder to hold/release eggs so that they drop straight down from greater heights.

4. After your class discussion/review of the concepts of momentum, impulse, impact force, and impact time, use all four of these terms to explain how your group's Collision Safety Device could be modified to better simulate the safety benefits of vehicle airbags.

To safely bring the egg to a stop, the device must decrease the egg's momentum during the collision by providing an impulse, which is the product of two variables —impact force x impact time. The more the device "slows down" (i.e., increases the impact time of) the collision, the smaller the final impact force on the egg will be. Airbags increase impact time and result in less injury because they stop occupants by applying a smaller impact force over a larger time interval compared to the large impact force experienced by vehicle occupants who have nothing to slow down the time between the initial crash of the vehicle and their body's crash into the steering wheel, dashboard, window, or other component inside the vehicle.

5. Compare the impulses, impact forces, and impact times in the following two scenarios:
A. Speeding Race Car #1 comes to a stop by hitting the wall of the track head on.
B. Speeding Race Car #2 comes to a stop by skidding a great distance and scraping its side along the wall of the track

Assuming both cars have equal momentum before the crash, both race cars experience the SAME impulse or change in momentum when they come to a stop. Race Car #1 experiences a big impact force ("big" F) over a short impact time ("little" t) while Race Car #2 experiences a small impact force (little" f) over a longer time of impact ("big" T).

6. According to the National Highway Traffic Safety Administration, thousands of people are alive today because of the addition of airbags to vehicles that contain seat belts. Explain why airbags alone are NOT safe alternatives to seat belts, but instead are to be used along WITH seat belts to prevent or reduce injury.

Designed to work with seat belts, airbags provide additional protection, especially to people's heads and chests, in serious crashes. In cases of sudden, hard braking or other violent maneuvers before a crash, the seat belts keep people in an upright position against the seat back which allows space for the airbags to inflate between the occupants and the hard interior surfaces.

Extension

Have students visit the IIHS.org website to investigate how air bags work and how automakers are finding new ways to integrate airbags into vehicles. To find information on airbags, ask students to select "Airbags" from the TOPICS drop-down menu located at the top of the IIHS.org site.

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

MATERIALS NEEDED

For each group of 2-3 students

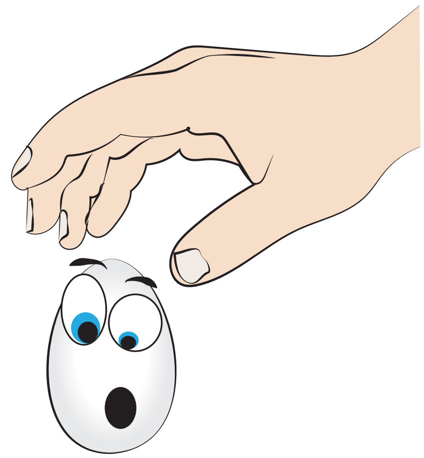
- 10 sheets of 8.5” x 11” copier paper
- One meter of masking tape
- One pair of scissors
- One raw, grade A medium or large egg (plus a few extra for accidental breakage before testing!)
- **OPTIONAL:** One plastic “Easter” egg for conducting practice “dry” runs with the collision safety devices

Per Student

- One copy of the “Egg Crash! Designing a Collision Safety Device” Student Activity Sheet

Key Question(s)

- How do people survive major vehicle collisions?
- How do the laws and principles of physics demonstrate the effectiveness of seat belts and airbags?



Purpose

- To design, build, test, and evaluate the effectiveness of a safety device (landing pad) to protect an egg during a collision with a hard surface
- To describe a collision in terms of changing momentum, impulse, impact force, and impact time

Did You Know?

Just as scientists and engineers design and test prototypes of potential collision safety devices in simulations, as part of this activity, you will work in groups to design, build, test, and evaluate the effectiveness of a “collision safety device” to protect a raw egg during a collision with a hard surface. This experience should help you observe and document the laws and principles of physics that help scientists and engineers design “EGGcellent” real-world safety devices for vehicles!

Design Challenge

Using no more than 10 sheets of 8.5” x 11” copier paper and one meter of masking tape, follow the parameters listed on the back of this sheet to design, build, and test a landing pad/”collision safety device” to protect a raw egg dropped onto the landing pad from above.

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

"Collision Safety Device" Engineering Design Parameters

1. The landing pad can be made using less, but no more, than 10 sheets of paper.

   Keep track of the amount of paper used to build your safety device. In the event of a tie, the device constructed with the fewest sheets of paper will be declared the superior safety device.

2. Your landing pad must be free-standing and moveable. During testing, groups cannot support their devices by holding them, propping them up against walls or any other structures, or taping them to the floor or another structure.

3. Nothing may be attached to the egg.

4. Scissors may not be part of the device.

5. Drop height will be measured from the bottom of the egg at the release point to the floor.

6. Eggs must be dropped by a member of each group's design team.

7. Eggs that miss the landing pad when dropped will be eliminated even if they do not crack or break.

8. Eggs will be inspected before and after each drop. Any egg with a crack will be eliminated.

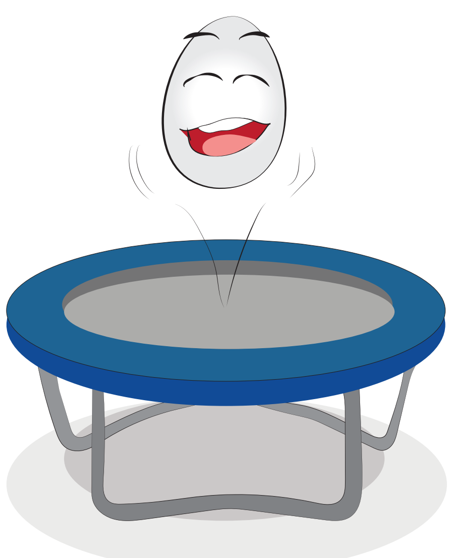
   Eggs that survive the initial impact with the landing pad but are then ejected (roll or bounce off the device) will be eliminated even if they do not crack or break.

9. In between rounds, groups whose eggs crack or break by accident or carelessness will still be eliminated.

10. In order to simulate car collisions with greater momentum, eggs will be dropped from successively greater heights at each round (1.0 m, 1.5 m, 2.0 m, 2.5 m)

11. All collision safety devices must be completed within the initial 20-minute construction time limit.

12. Groups may not make any repairs/adjustments/improvements to their devices once the testing process begins. If your device is damaged in one round, it must be used "as is" with no repair in successive rounds.



EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE

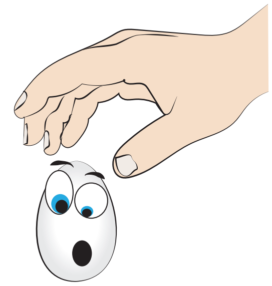
Pre-Testing Analysis Questions

1. Draw and label a diagram of your group's Collision Safety Device in the space below.

2. Briefly describe your team's Collision Safety Device and the reasoning behind your design. In other words, explain WHY you chose the particular design features of your device.

STUDENT ACTIVITY

EGG CRASH! DESIGNING A COLLISION SAFETY DEVICE



Post-Testing Analysis Questions

1. Overall, which types of Collision Safety Device features were the most and least effective in this simulation and why?

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2. As the drop height increased with each round, the amount of momentum the eggs experienced in their collisions with the landing devices also increased. Identify at least 2 Collision Safety Device design features that were especially important/useful for successful drops of eggs from greater heights (i.e., collisions with greater momentum).

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3. Often, even groups with well-designed and soundly-constructed Collision Safety Devices are not successful when eggs are dropped from greater heights. Identify at least 2 other reasons egg drops from greater heights are more challenging regardless of the quality of the landing pad.

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4. After your class discussion/review of the concepts of **momentum**, **impulse**, **impact force**, and **impact time**, use **all four** of these terms to explain how your group's Collision Safety Device could be modified to better simulate the safety benefits of vehicle airbags.
(HINT: To reduce the chances of injury, should the momentum, impulse, impact force, and impact time of a vehicle occupant's collision with the interior of the vehicle be increased or decreased?)

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Post-Testing Analysis Questions (continued)

5. Compare the impulses, impact forces, and impact times in the following two scenarios:

A. Speeding Race Car #1 comes to a stop by hitting the wall of the track head on.

B. Speeding Race Car #2 comes to a stop by skidding a great distance and scraping its side along the wall of the track.

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6. According to the National Highway Traffic Safety Administration, thousands of people are alive today because of the addition of airbags to vehicles that already contain seat belts. Explain why airbags alone are NOT safe alternatives to seat belts, but instead are intended to be used along with seat belts to prevent or reduce injury.

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TEACHER LESSON PLAN

CONSERVATION: IT'S THE LAW!

MOMENTUM TRANSFER

Key Question(s)

- How do crash forces affect the motion of two colliding objects?
- How does the momentum of objects change before and after a collision?
- Where does the energy of moving objects "go" in a collision?

Grade levels: 5–12
Time required: 50 minutes

Objectives

Students will:

- apply Newton's third law of motion to describe how changing initial crash factors affects impact forces.
- describe a collision in terms of changes and transfers in momentum.
- infer how the law of conservation of momentum is applied in collisions.
- explain how the law of conservation of energy is applied in collisions.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

- HS-PS2-2, MS-PS2-2, MS-PS2-1

Energy

- HS-PS3-2, HS-PS3-3, MS-PS3-5, 4-PS3-1, 4-PS3-3

Background Information

A **collision** is an event in which two or more particles or bodies exert forces on each other in a relatively short time transferring kinetic energy and momentum between them. As in any interaction, collisions involve interacting forces between the objects. **Newton's third law of motion** states that in every interaction, there is a pair of equal magnitude forces acting in opposite directions on the two interacting objects. For example, for a force applied by an object A on object B, object B exerts back an equal-sized force but in the opposite direction.

This idea of forces always coming in pairs was used by Newton to derive the law of conservation of momentum. In the collision between object A and object B, equal forces also act between the two objects for the same amount of time. Since equal forces act in equal times, the impulses experienced by the two objects are also equal in magnitude and opposite in direction therefore the change in momentum for both objects must be equal. (See the Egg Crash! Lesson for background information on impulse and change in momentum.) In other words, equal but opposite changes in momentum leave the total momentum unchanged or conserved.

In any collision between two objects, two important physics laws of conservation govern the outcome of the collision: the **law of conservation of momentum** and the law of conservation of energy. The law of conservation of momentum states that the total amount of momentum of two or more moving objects involved in a collision is the same immediately after the collision as it was immediately before the collision.

DEFINITIONS

collision: an event in which two or more particles or bodies exert forces on each other in a relatively short time transferring kinetic energy and momentum between them.

kinetic energy: the energy of motion

law of conservation of energy: in a given system, the total amount of energy in the system always stays the same; energy cannot be created or destroyed, it can only be transferred or transformed

law of conservation of momentum: in a collision between two or more objects, the total amount of momentum of the objects immediately before the collision is the same as the total amount of momentum of the objects immediately after the collision

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

CONSERVATION: IT'S THE LAW!

MATERIALS NEEDED

For each pair of students

- Seven glass marbles, all the same size
- One 92-cm (3-foot) piece of dark gray "foam-type" pipe insulation (3/8" tubular polyethylene used to insulate 3/4" pipe), without adhesive
- 30-cm of masking tape
- One meter stick
- Three to five books to support the pipe insulation track
- One pencil

Per Student

- One copy of the "Conservation: It's the Law!" Student Activity Sheet

Background Information (continued)

In a collision, the total amount of momentum lost by one object is gained by the other object(s) involved in the collision. In other words, momentum can transfer from one object to another.

The law of conservation of energy states that energy cannot be created or destroyed; it may be transferred or transformed from one form to another, but the total amount of energy in a given system never changes. During a collision, ALL of the kinetic energy (energy of motion) of two or more colliding objects has to go "somewhere." The kinetic energy of one object can be transferred to other objects or it can be transformed into other forms of energy such as heat and sound.

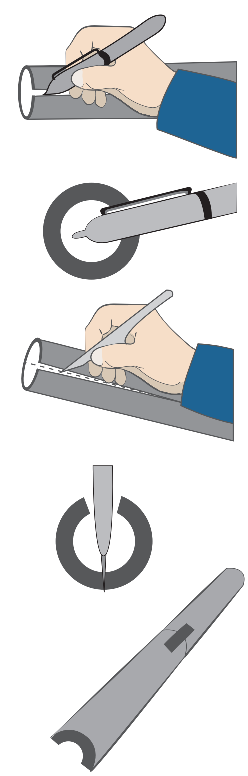
Advance Preparation

- Purchase pipe insulation from a large home improvement or hardware store (costs approximately $1 per 6-foot section).
- One side of the insulation is usually scored along its length for easy separation but the opposite side needs to be cut with scissors or a knife to create two open-faced "U-shaped" rollways for the marbles (see Figure 1).
- After creating the rollways, cut each one in half to create two 3-foot sections. Each section of 6-foot pipe insulation will then yield four pieces of track.
- Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/conservation-its-the-law and decide if you want to incorporate them into the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/conservation-its-the-law.

Procedure

1. Ask the following engagement question: When studying vehicle crashes at the Insurance Institute for Highway Safety's Vehicle Research Center, some of the most dramatic crash tests involve rear-end collisions between one moving vehicle and one stationary vehicle. When these two vehicles collide, where does all of the energy of the moving vehicle "go?" Explain that in this activity students are going to crash marbles on a track to investigate this question.

2. Divide students into pairs and distribute the supplies and worksheets. Refer to the worksheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information. Optional: Show the activity's Introduction video.



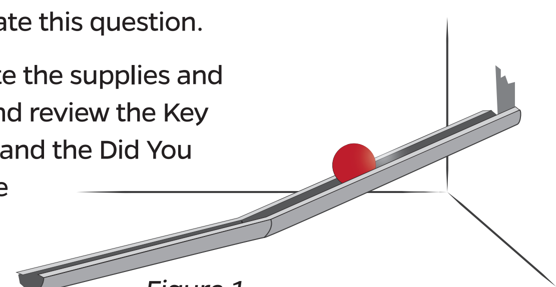


Figure 1

Procedure (continued)

3. Review the Procedure for Part A (Assembling the marble collision test track). Refer to Figure 1, and show students a sample of a complete marble test track set-up if needed. (NOTE: Long, flat tables or tile floors work well!) Once all test tracks have been assembled, instruct students to test their tracks for straight alignment by rolling a marble along the entire length of the track. Tell students to straighten and re-tape their tracks until the marble moves smoothly along the entire length of the track when released.

4. Next, walk students through the Procedure for Parts B and C of the activity and review the instructions for completing Data Tables 1 and 2. Inform older students they will be making and recording two types of observations: quantitative (e.g., information about quantities of marbles) and qualitative (e.g., descriptive information from their senses such as sights and sounds of marble colliding).

5. Circulate and assist groups as needed. (HINT: When releasing multiple marbles, students can create a starting gate barrier below the bottom-most marble on the starting ramp with a pencil and lift the pencil up when they are ready to release the marbles.)

6. When all groups have completed the activity, conduct a whole-class discussion of responses to Analysis Questions 1-6. Students should be able to draw the following general conclusions:
   - The greater the release height of a marble, the greater the impact forces.
   - The greater the release height of a marble, the more momentum it has on impact with the row of stationary marbles.
   - The greater the mass of marbles released (i.e., the greater the number of marbles released), the greater the impact forces.
   - The greater the mass of marbles released, the more momentum the set of released marbles has on impact with the row of stationary marbles.
   - The greater the release height of a marble, the greater the incoming speed of the marble before the collision and the greater the outgoing speed of the marble knocked away after the collision.
   - Regardless of the height of release, qualitatively, the incoming speed of the released marble equals the outgoing speed of the marble knocked away.

7. Conduct a whole-class discussion of responses to Analysis Questions 7-9. If necessary, for Question 7 review the definition of Newton's Third Law of Motion and make sure students understand that when two objects collide, there is a pair of equal magnitude forces acting in opposite directions on the two interacting objects. Explain to students that the moving marble(s) experiences a force that causes it/them to slow down and the stationary row experiences a force that causes it to speed up. In other words, the equal force on both causes both objects to accelerate. If the objects were the same mass their accelerations would be equal. In this case, the stationary row of six marbles is more massive so its acceleration is less than the moving marble(s).

8. Next, discuss the responses to Analysis Question 8. Explain that Isaac Newton used his idea of forces always coming in pairs to derive the law of conservation of momentum. Help students realize that the equal forces also act between the two objects for the same amount of time. Since equal forces act in equal times, the impulses (impulse = impact force x impact time, see Egg Crash Lesson for background information on impulses) experienced by the two objects are also equal in magnitude and opposite in direction therefore the change in momentum for both objects must be equal.

CONSERVATION: IT'S THE LAW!

Procedure (continued)

If necessary, review the definition of the Law of Conservation of Momentum and make sure students understand that, in any collision between two or more objects, the total amount of Momentum IN (before the collision) = the total amount of Momentum OUT (after the collision). You may also want to explain that, in the absence of friction, if the masses of two colliding objects (such as marbles) are the same, the incoming and outgoing speeds of the marbles would also be exactly the same.

9. To conclude the lesson, use the background information provided to introduce students to the Law of Conservation of Energy and conduct a whole-class discussion of responses to Analysis Question 9. Make sure students understand that ALL of the kinetic energy of the released marble(s) before the collision is either transferred to the stationary marbles or transformed into other forms of energy such as heat or sound; thus no energy is "lost."

10. Option for Older Students: If time permits, explain there are two general types of collisions in physics: elastic and inelastic. In perfectly elastic collisions, the colliding objects bounce perfectly away from each other without generating heat or being permanently damaged. When colliding objects become tangled or stuck together, the collision is an inelastic collision. Whenever outside forces do not interfere, momentum is conserved for all collisions, elastic and inelastic.

Answers to Analysis Questions

1. **Based on your observations (e.g., sights and sounds of the collisions) and the results in Data Table 1, how does the number of marbles released and the height of release affect the impact forces between the moving marbles and the row of stationary marbles?**

The greater the number of marbles, as well as the greater the release height, the greater the impact forces. Students should cite evidence of greater impact forces such as louder collisions between the marbles, marbles ejecting from the track, or greater numbers of marbles knocked away from the row.

2. **Based on your results in Data Table 1, what is the relationship between the number of marbles released and the number of marbles knocked away in each collision?**

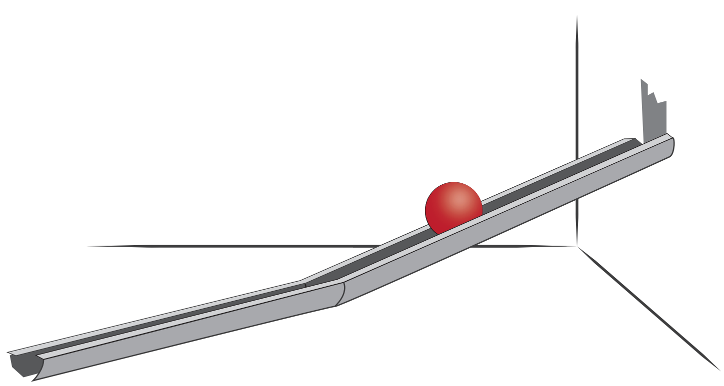
Regardless of the release height of a marble or multiple marbles, the total number of released marbles equals the total number of marbles knocked away from the row.

3. **Based on your results in Data Table 1, how does the number of marbles released affect the total amount of momentum of the moving marbles in a collision?**

The greater the number of marbles (i.e., the greater the mass of the marbles), the greater the amount of momentum of the moving marbles.

4. **Based on your results in Data Table 2, what is the relationship between the height of release of the marble and the speed of the marble before it collides with the row of stationary marbles?**

The greater the release height, the greater the marble's speed before the collision.



Answers to Analysis Questions (Continued)

5. **Based on your results in Data Table 2, what is the relationship between the speed of the released marble and the speed of the marble knocked away?**

   The speed of the released marble before impact equals the speed of the marble knocked away.

6. **Based on your results in Data Table 2, how does the height of release affect the momentum of a moving marble in a collision?**

   The greater the release height, the greater the marble's momentum.

7. **Recall that Newton's third law of motion involved the idea of forces always coming in pairs. With this thought in mind, explain why this statement in FALSE: "A 3000 kg truck collides with a 1500 kg stationary car. The car experiences the greater collision force."**

   Newton's third law describes how for every action, there is an equal and opposite reaction. This action-reaction pair of forces are equal in size and in opposite directions (and act on different objects). The size of the force on the car equals the size of the force on the truck. The direction of the force on the car is opposite to the direction of the force on the truck. The effects (e.g., change in velocity) are different on each due to their different masses.

8. **Recall that momentum is the product of an object's mass and its velocity. The more massive an object, the more momentum it has. With this thought in mind, explain how your observations and data in Part B illustrate the Law of Conservation of Momentum in a collision.**

   In part B, the number of marbles released (i.e., the mass of marbles released) always equals the number of marbles knocked away (i.e., the mass of marbles knocked away). This observation indicates that the momentum of the released marbles before the collision is equal to the momentum of the marbles knocked away after the collision.

9. **Marbles moving at a greater speed have more kinetic energy (energy of motion). With this thought in mind, explain how your observations and data in Part C illustrate the Law of Conservation of Energy in a collision.**

   In Part C, the faster the speed of the released marble, the faster the speed of the marble knocked away. Thus, the total amount of kinetic energy of the released marble is equal to the amount of kinetic energy transferred to the marble knocked away (assuming no energy was transformed into heat or sound energy).

Extensions

1. Have students further explore the classroom.iihs.org website to view the "Bowling Ball Pendulum" Crash Science Demonstration addressing the law of conservation of energy.
2. Have students conduct the "Ball of Energy" activity to discover how a small increase in a vehicle's velocity produces a more dangerous crash.

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

CONSERVATION: IT'S THE LAW!

MOMENTUM TRANSFER

MATERIALS NEEDED

For each pair of students

- Seven glass marbles, all the same size
- One 92-cm (3-foot) piece of dark gray "foam-type" pipe insulation (3/8" tubular polyethylene used to insulate 3/4" pipe), without adhesive
- 30-cm of masking tape
- One meter stick
- Three to five books to support the pipe insulation track
- One wooden pencil

Per Student

- One copy of the "Conservation: It's the Law!" Student Activity Sheet

Key Question(s)

- How do crash forces affect the motion of two colliding objects?
- How does the momentum of objects change before and after a collision?
- Where does the energy of moving objects "go" in a collision?

Purpose

- To apply Newton's third law of motion to collisions
- Use data to describe a collision in terms of changes and transfers in momentum
- To infer how the law of conservation of momentum is applied in collisions
- To explain how the law of conservation of energy is applied in collisions

Did You Know?

In the previous activities, you explored how engineers use Newton's Laws of Motion and the concepts of momentum and impulse to study the physics of car crashes. Engineers at the IIHS's Vehicle Research Center also rely on two other important laws of physics that have been called the most powerful tools for studying the field of mechanics, namely the Law of Conservation of Energy and the Law of Conservation of Momentum. In this activity you will study collisions between marbles to observe these two laws in action.

Procedure

Part A. Marble Collision Test Track Assembly

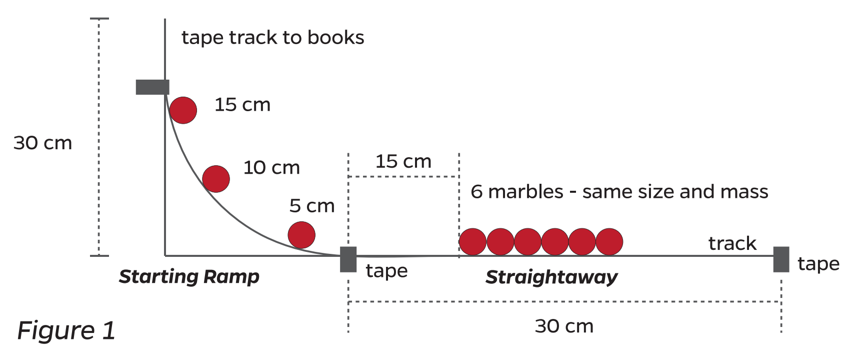


Figure 1

1. With books as a support, create an elevated "starting ramp" for the marble collision test track by using two small pieces of masking tape to secure the left and rights sides of one end of the track to the stack of books at a height of 25–30 cm. At the bottom of this elevated starting ramp, create a 60-cm long straightaway on a flat, hard surface (floor or table top) and use small pieces of tape on the left and ride sides at each end of the straightaway to secure it to the floor or table top. (See Figure 1 above).

CONSERVATION: IT'S THE LAW!

Procedure (continued)

2. Using three more small pieces of tape and the meter stick, measure and mark the following three marble release heights on the outside of the starting ramp as indicated in Figure 1: 5.0 cm, 10.0 cm, 15.0 cm. Make measurements straight up from the surface of the table or floor and place the small tape pieces so that the top of each tape piece is 5.0, 10.0, and 15.0 cm above the table or floor.

Part B. Observing Newton's Third Law and the Transfer of Momentum

1. Place six marbles side by side in the groove of the track with the first marble about 15 cm away from the bottom of the starting ramp (See Figure 1).
2. Push the six marbles together and make sure they are all touching.
3. Hold the seventh marble at the top of the tape piece marking 5.0 cm on the starting ramp.
4. Release the marble and allow it to roll down the track and collide with the row of six marbles. Observe what happens and record how many marbles roll away from the row after the collision in Data Table #1.
5. Place the six marbles back in the starting position shown in Figure 1 and complete additional test collisions by releasing the seventh marble from the 10.0 and 15.0 centimeter marks on the starting ramp. Record the number of marbles that roll away from the row after collisions at each of these heights in Data Table 1.
6. Repeat steps 1 through 5 again with collisions using the following combinations of marbles:
   - » Two moving marbles and five stationary marbles
   - » Three moving marbles and four stationary marbles
   - » Two moving marbles and one stationary marble

Data Table 1

NUMBER OF MARBLES RELEASED	HEIGHT OF RELEASE	NUMBER OF MARBLES IN ROW	NUMBER OF MARBLES KNOCKED AWAY FROM ROW
	5.0 cm	6	
1	10.0 cm	6	
	15.0 cm	6	
	5.0 cm	5	
2	10.0 cm	5	
	15.0 cm	5	
	5.0 cm	4	
3	10.0 cm	4	
	15.0 cm	4	
	5.0 cm	1	
2	10.0 cm	1	
	15.0 cm	1	

Part C. Observing the Law of Conservation of Momentum

1. Place six marbles side by side in the groove of the track with the first marble about 15 cm away from the bottom of the starting ramp again (See Figure 1).
2. Push the six marbles together and make sure they are all touching.
3. Hold the seventh marble at the top of the tape piece marking 5.0 cm on the starting ramp.

MOMENTUM TRANSFER

MOMENTUM TRANSFER

Procedure (continued)

4. Release the marble and allow it to roll down the track and collide with the row of six marbles. Observe the speed of the released marble just before it collides with the row of six marbles as well as the speed of the marble knocked away from the row after the collision. Record these qualitative observations of the speed of the released marble and the marble knocked away (slow, medium, or fast speed) in Data Table #2.

Data Table 2

HEIGHT OF RELEASE OF ONE MARBLE	SPEED OF RELEASED MARBLE BEFORE IMPACT (SLOW, MEDIUM, FAST)	SPEED OF MARBLE KNOCKED AWAY (SLOW, MEDIUM, FAST)
5.0 cm		
10.0 cm		
15.0 cm		

5. Place the six marbles back in the starting position shown in Figure 1 and complete additional test collisions by releasing the seventh marble from the 10.0 and 15.0 centimeter marks on the starting ramp. Record qualitative observations of the speed of the released marble and the marble knocked away at these two release heights in Data Table 2.

Analysis Questions

1. Based on your observations (e.g., sights and sounds of the collisions) and the results in **Data Table 1**, how does the number of marbles released and the height of release affect the impact forces between the moving marbles and the row of stationary marbles?

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2. Based on your results in **Data Table 1**, what is the relationship between the number of marbles released and the number of marbles knocked away in each collision?

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3. Based on your results in **Data Table 1**, how does the number of marbles released affect the total amount of momentum of the moving marbles in a collision?

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4. Based on your results in **Data Table 2**, what is the relationship between the height of release of the marble and the speed of the marble before it collides with the row of stationary marbles?

CONSERVATION: IT'S THE LAW!

ENERGY TRANSFER

Analysis Questions (continued)

5. Based on your results in **Data Table 2**, what is the relationship between the speed of the released marble and the speed of the marble knocked away?

6. Based on your results in **Data Table 2**, how does the height of release affect the momentum of a moving marble in a collision?

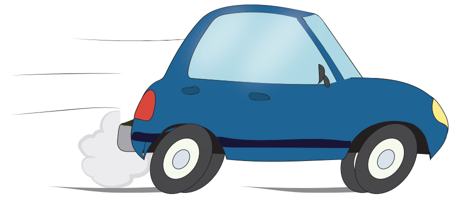
7. Recall that Newton's third law of motion involved the idea of forces always coming in pairs. With this thought in mind, explain why this statement in FALSE: "A 3000 kg truck collides with a 1500 kg stationary car. The car experiences the greater collision force."

8. Recall that momentum is the product of an object's mass and its velocity. The more massive an object, the more momentum it has. With this thought in mind, explain how your observations and data in Part B illustrate the Law of Conservation of Momentum in a collision.

9. Marbles moving at a greater speed have more kinetic energy (energy of motion). With this thought in mind, explain how your observations and data in Part C illustrate the Law of Conservation of Energy in a collision.

TEACHER LESSON PLAN

BALL OF ENERGY



DEFINITIONS

gravitational potential energy (PE): stored energy due to the relative position of an object above the ground; measured in joules (J)

kinetic energy (KE): of motion; measured in joules (J)

mechanical energy: the ability to do work; "the stuff" that makes things move; PE and KE are both types of mechanical energy

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

» What happens to all of the energy in a falling ball when it hits the ground?

» How is the maximum kinetic energy of a moving object related to its maximum velocity?

» What happens to the energy in a moving vehicle when it crashes into another object?

» Why does a small increase in a vehicle's velocity result in a more dangerous crash?

» Where does the energy of moving objects "go" in a collision?

Grade levels: 9–12

Time required: 50 minutes

Objectives

Students will:

» determine the maximum gravitational PE, maximum KE, and maximum velocity of a thrown ball.

» explain the relationship between a moving object's maximum KE and its maximum velocity.

» explain how KE is transferred or transformed when a ball hits the ground and when a vehicle crashes into another object.

» explain how small increases in a vehicle's velocity produce exponentially more energetic, and more dangerous, vehicle crashes.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

» HS-PS2-2

Energy

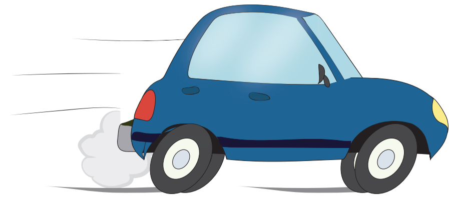
» HS-PS3-1, HS-PS3-2, MS-PS3-5

Background Information

Analyzing the physics of vehicle crashes can help students better understand the concepts of energy transfer and transformation, especially for mechanical energy. Mechanical energy is defined as the ability to do work. Two types of mechanical energy are kinetic energy and potential energy. Kinetic energy is the energy of motion while gravitational potential energy is the energy stored in an object at rest. The amount of gravitational potential energy stored in an object depends on the amount of work done to lift it to whatever its position is above the ground. The higher an object is raised above the ground, the greater its potential energy.

TEACHER LESSON PLAN

BALL OF ENERGY



MATERIALS NEEDED

Per group of 3 students

- One tennis ball or rubber racquet ball (NOTE: To minimize the risk of accidental student injury, use only "soft" balls rather than hard balls like golf balls.)
- One stopwatch
- One calculator
- One clipboard

Per Student

- One copy of the "Ball of Energy" Student Activity sheet

Per Class

- At least one pan balance with metric gram masses or at least one electronic balance
  NOTE: If balances are not available, just provide students with the average mass values for the specific type of ball they are using: tennis ball mass = 0.058 kg or racquet ball mass = 0.040 kg. If using a pan balance, mass measurements will need to be rounded to the nearest gram.

Background Information (continued)

Underlying all forms of energy and motion is a basic law of physics: the Law of Conservation of Energy. This fundamental law has nothing to do with saving energy, but instead describes what happens to energy when it is used. This law states that energy cannot be created or destroyed; it may be transferred or transformed from one form to another, but the total amount of energy in a given system never changes.

Energy is a tough concept to illustrate and explain because the only time it can really be seen, felt, or heard is when it is being transferred or transformed. For us to concretely "see" energy, something has to happen to transfer or transform energy (like throwing a ball upward as high as possible and then letting it hit the ground). Throwing a ball up in the air primarily involves the transfer of mechanical energy from your hand to the ball and then the transfer of mechanical energy to the ground and transformation of mechanical energy to sound and heat once it lands.

In order to calculate the total amount of mechanical energy transferred to a thrown ball you need to calculate both the ball's energy of motion (KE) and its gravitational potential energy (PE). The formula for calculating KE is $\frac{1}{2} mv^2$ where m = the mass of the ball in kilograms and v = the velocity of the ball in meters per second. An object's energy of motion (KE) is much more dependent on its velocity than its mass. As indicated in the formula, doubling an object's velocity will quadruple its KE because velocity is squared. Thus, tripling velocity increases KE by a factor of nine while a fourfold increase in velocity increases KE by a factor of 16. Because of this relationship between velocity and kinetic energy, in vehicle crashes, even small increases in velocity causes an exponentially large increase in KE resulting in more dangerous crashes.

Although it is typically not a factor in vehicle crashes, when throwing a ball up in the air, the total mechanical energy of the ball also includes the gravitational potential energy (PE) resulting from your hand lifting the ball above the ground and the potential energy gained as the ball travels up. The formula for calculating gravitational PE is mgh where m = the mass of the ball in kilograms, g = acceleration due to gravity which is 9.81 m/s^2, and h = the height of the ball above the ground in meters. For the sake of simplicity in this activity, students will not determine the amount of potential energy resulting from their hands lifting the ball above the ground.

Advance Preparation

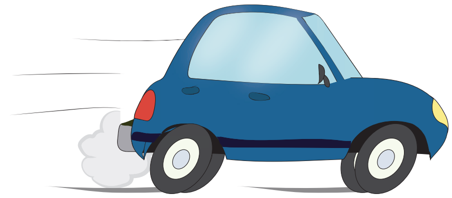
» Locate an area on the school grounds with a large open field large enough for groups to spread out about 10 meters apart.

» Assemble the materials for each group and make copies of the activity sheet.

» Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/ball-of-energy and decide if you want to incorporate them into the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/ball-of-energy

BALL OF ENERGY



Procedure

1. Initiate the activity by asking students which type of vehicle crash they think is more "dangerous:" a crash between two vehicles traveling at 20 miles per hour or a crash between two vehicles traveling at 40 miles per hour. Next, ask students which of these two crashes is more dangerous: a crash between two vehicles traveling at 40 miles per hour or a crash between two vehicles traveling at 80 miles per hour. (NOTE: Although most students will realize that an 80 mph crash is significantly more dangerous than a 40 mph crash, many students will not understand that even a 40 mph crash is extremely dangerous when compared to a 20 mph crash.) Explain that during this activity, students will explore the relationship between velocity and energy of motion (kinetic energy) to better understand why higher speed crashes are so much more dangerous than lower speed crashes.

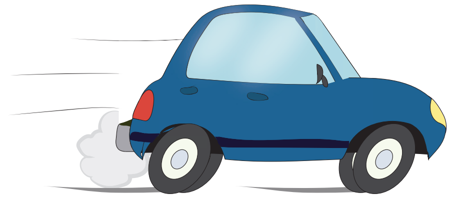
2. Divide students into groups of three and distribute the supplies and worksheets. Refer to the worksheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information. Optional: Show the activity's Introduction video.

3. Review the Procedure for the activity and instruct groups to identify specific roles for each group member (measurer, thrower, and recorder). Then, remind them to measure the mass of their balls using a balance BEFORE going outside. If balances are not available, provide the following approximate mass values: tennis ball 58 g (0.058 kg) or racquet ball 40 g (0.040 kg).

4. Explain that while they are outside, each group only has to make one actual measurement (total time the ball is in the air). Using the stopwatches provided, students should measure the total time the ball is in the air by starting the stopwatch the instant the ball leaves the thrower's hand and stopping it as soon as the ball hits the ground. Explain that, once the total air time has been measured, all remaining values in Table 2 will be calculated by dividing the total air time in half. In other words, half of the total air time is the time it took the ball to go "up" and the other half of the total air time is the time it took the ball to come "down." Remind groups to complete the ball throw five times and record the total times for each trial in Table 2.

5. Take students outside to the open field area and use one of the balls to demonstrate and review the safe upward-throwing procedure and rules:
   - » Groups must spread out so that they are at least 10 meters away from each other on all sides.
   - » Balls must ONLY be thrown vertically and should not be aimed at other people or objects.
   - » Each group should designate one "thrower" and agree on a consistent throwing style for each trial. Balls can be thrown under-handed (i.e., softball-pitch style) or over-handed (i.e., baseball-pitch style) as long as each group's ball is thrown using the same style each time.

6. Once groups have finished their five ball throws and recorded total air times for each throw, return to the classroom or have students sit outside in their groups and instruct them to use calculators to calculate all of the remaining values in Table 2 using the variable symbols, definitions, formulas, and calculation procedures provided in Table 3. Remind students that, in order to simplify the required calculations during this activity, they will not consider the small amount of potential energy the ball acquired when the thrower raised it above the ground before throwing it up in the air. Similarly, they will also not factor in the effect the small amount of air resistance had on the ball's energy levels.



Procedure (continued)

7. Upon returning to the classroom, check each group's measurements and calculations and review pertinent background information regarding mechanical energy, gravitational potential energy, and kinetic energy. If desired, show the activity's Conclusion video. In addition, make sure students understand that, in the ball throwing activity, the total amount of mechanical energy stayed the same throughout the ball's entire flight; but at different points in its flight, the relative amount of PE and KE in the ball changed. On the way up it lost KE and gained PE and on the way down it lost PE and gained KE. Understanding this key concept (i.e., $KE_{max} = PE_{max}$) allows us to calculate the maximum crash velocity of the ball (v_{max}) by algebraically deriving v_{max} from the equation $KE_{max} = PE_{max}$. For physics students or others interested in how v_{max} is derived, review the algebraic steps in Figure 1.

8. Finally, ask students to work collaboratively with their group members to answer the Analysis Questions and conduct a whole-class discussion of their responses to the Analysis Questions.

9. Conclude the activity by asking the same questions you asked at the beginning of the lesson:
   - » Which type of vehicle crash is more dangerous: a crash between two vehicles traveling at 20 miles per hour or a crash between two vehicles traveling at 40 miles per hour?
   - » Which of these two crashes is more dangerous: a crash between two vehicles traveling at 40 miles per hour or a crash between two vehicles traveling at 80 miles per hour.
   - » Make sure students understand that even small changes in a vehicle's velocity result in exponential increases in a vehicle's kinetic energy. Thus, a vehicle traveling 80 miles per hour (4 times faster than 20 miles per hour) will have 16 times more kinetic energy!

Figure 1

DERIVING V_{max} FROM $KE_{max} = PE_{max}$

$$KE_{max} = PE_{max}$$
$$\tfrac{1}{2}\, mv^2_{max} = mgh_{max}$$
$$mv^2_{max} = 2\, mgh_{max}$$
$$v^2_{max} = 2gh_{max}$$
$$v_{max} = \sqrt{2gh}_{max}$$

Sample Completed Data Tables

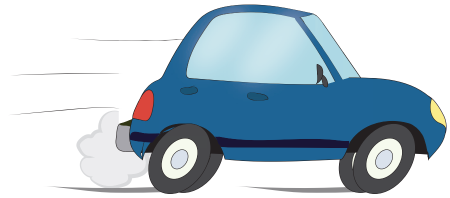
Table 1 - Information about the Ball

BALL TYPE	MASS OF BALL (KG)
Tennis Ball	0.058

Table 2 - Measurements and Calculations Related to the Ball Throw

	MEASUREMENTS	CALCULATIONS					
TRIAL #	TOTAL AIR TIME (s)	t_{up} (s)	t_{down} (s)	$d_{up} = \frac{1}{2} gt_{up}^2$ (m)	$PE_{max} = mgh_{max}$ (J)	$KE_{max} = PE_{max}$ (J)	v_{max} (m/s)
1	2.30	1.15	1.15	6.49	3.69	3.69	11.3
2	3.06	1.53	1.53	11.5	6.54	6.54	15.0
3	2.75	1.38	1.38	9.34	5.31	5.31	13.5
4	3.38	1.69	1.69	14.0	8.00	8.00	16.6
5	3.50	1.75	1.75	15.0	8.53	8.53	17.2

BALL OF ENERGY



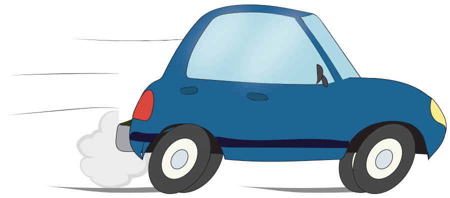
Sample Completed Data Tables (continued)

Table 3 - Variable Symbols, Definitions, Formulas, and Calculation Procedures

SYMBOL	DEFINITION	FORMULA	CALCULATION PROCEDURES AND UNITS
t_{up}	Time up	½ total air time	Divide the total air time by 2 (t_{up} = total air time ÷2). Measured in seconds (s)
t_{down}	Time down	½ total air time	$t_{up} = t_{down}$ (neglecting air resistance)
g	Acceleration due to gravity	$9.81\ m/s^2$	The rate of acceleration of any object moving under the sole influence of gravity (also known as free fall). Measured in meters per second per second (m/s^2).
d_{up}	Maximum distance up	$\frac{1}{2} g t_{up}^2$	Square the time up and multiply it by g (acceleration due to gravity). Then divide this total by 2 to determine the maximum distance upward (maximum height) the ball achieves during the throw. In this activity's calculations, $d_{up} = h_{max}$. Measured in meters (m).
PE_{max}	Maximum gravitational potential energy	mgh_{max}	Gravitational potential energy (PE) is energy due to the relative position of an object above the ground and is measured in joules (J). $PE_{max} = mgh_{max}$ where m = the mass of the ball in kilograms, g = acceleration due to gravity, and h = maximum height above ground (same as d_{up}). For the ball thrown in this activity, its maximum potential energy is at the top of it flight when it is at its greatest distance above the ground, which is why we use the value for maximum distance up (d_{up}) for h_{max}.
KE_{max}	Maximum kinetic energy	$KE_{max} = PE_{max}$	According to the Law of Conservation of Energy, for the thrown ball "system," the kinetic energy of motion (KE) during the ball's downward journey equals the potential energy the ball gains on its upward journey. Both KE and PE are measured in joules (J). If air resistance is neglected, the maximum potential energy gained by the ball on its upward journey is converted entirely to kinetic energy during its downward journey; therefore $PE_{max} = KE_{max}$.
v_{max}	Maximum crash velocity	$\sqrt{2gh}_{max}$	If velocity of an object cannot be directly measured, maximum crash velocity can be calculated using this formula: $v_{max} = \sqrt{2gh}_{max}$. Multiply g times h_{max} (same as d_{up}) then multiply that number by 2. Finally, take the square root of this total to determine the maximum crash velocity of the ball. Velocity is measured in meters/second (m/s).

TEACHER LESSON PLAN

BALL OF ENERGY



Answers to Analysis Questions

1. According to the Law of Conservation of Energy, energy cannot be created or destroyed. Instead, it can be transferred to other objects in the same form OR it can be transformed from one type of energy to another (such as sound energy or heat energy). What do you think happened to all of the kinetic energy in the falling ball once it hit the ground?

Some of the ball's kinetic energy was transferred to the soil and made the soil move and compact; some of the ball's kinetic energy was transformed into sound energy; and a small amount of heat energy was generated upon impact with the ground. The important idea to remember is that ALL of the kinetic energy of the falling ball went "somewhere" when it landed—none of it was "lost."

2. The formula for determining the kinetic energy of any moving object is: $KE = 1/2mv^2$. If a car had a mass of 1,500 kg, use this formula to determine the total amount of kinetic energy it would have upon crashing into a wall at the following velocities:

A. 20 miles per hour (which is equal to 8.94 m/s)

KE = 59,943 Joules

B. 40 miles per hour (which is equal to 17.88 m/s)

KE = 239,771 Joules

3. For analysis question 1, how many times greater is the kinetic energy of the car traveling at 40 miles per hour compared to the car traveling at 20 miles per hour?

4 times greater (239,771 Joules ÷ 59,943 Joules)

4. This example shows that when the velocity of a vehicle doubles (for example from 20 mph to 40 mph), its kinetic energy quadruples. Why?

As the formula for kinetic energy indicates, a car's crashing energy or KE is dependent upon the square of it velocity ($KE = ½ mv^2$).

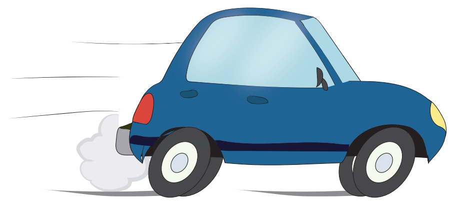
5. At the Insurance Institute for Highway Safety's Vehicle Research Center, one of their head-on vehicle crash tests involves having a car with a single crash test dummy "driver" crash into a 320,000 pound stationary barrier at 40 miles per hour. Based on what you now know about the Law of Conservation of Energy and energy transfer and transformation, what do you think happens to all of the kinetic energy of the vehicle when it crashes into the barrier?

Some of the kinetic energy is transferred to the barrier; some of the energy is transformed into sound; some of the energy is transformed into heat; and some of the energy is transferred throughout the car, including into the occupants of the car.

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

BALL OF ENERGY



MATERIALS NEEDED

Per group of 3 students

- One tennis ball or rubber racquet ball
- One stopwatch
- One calculator
- One clipboard

Per Student

- One copy of the "Ball of Energy" Student Activity sheet

Per Class

- At least one pan balance with metric gram masses or at least one electronic balance

Key Question(s)

- What happens to all of the energy in a falling ball when it hits the ground?
- How is the maximum kinetic energy of a moving object related to its maximum velocity?
- What happens to the energy in a moving vehicle when it crashes into another object?
- Why does a small increase in a vehicle's velocity result in a more dangerous crash?
- Where does the energy of moving objects "go" in a collision?

Did You Know?

In vehicle crashes, the more kinetic energy a vehicle has, the greater the risk of injury to a vehicle's occupants. And, as you already realize, damage to vehicles and injuries to vehicle occupants are both much greater in "high speed" crashes than they are in "low speed" crashes. In this activity, you will explore the relationship between an object's kinetic energy and it final crashing velocity to determine why high speed crashes are so dangerous.

Purpose

- To determine the maximum gravitational PE, maximum KE, and maximum velocity of a thrown ball
- To explain the relationship between a moving object's maximum KE and its maximum velocity
- To explain how KE is transferred or transformed when a ball hits the ground and when a vehicle crashes into another object
- To explain how small increases in a vehicle's velocity produce exponentially more energetic, and more dangerous, vehicle crashes

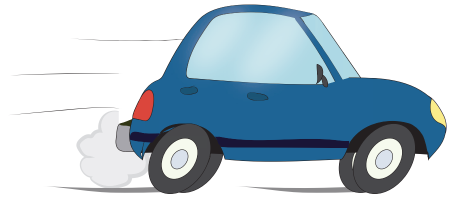
Procedure

1. Identify a specific group member to perform each of the following roles: measurer, thrower, and recorder. The "measurer" is responsible for using a balance to determine the mass of the ball and using the stopwatch to measure the total time the ball is in the air for each trial. The "thrower" is responsible for actually throwing the ball into the air using the same throwing style for each trial. And the "recorder" is responsible for recording all measurements in the data tables on the Ball of Energy Activity Sheet. After all measurements have been recorded, you should then work together as a group to complete the calculations and answer the Analysis Questions.

2. Before going outside, have the "measurer" measure the mass of your group's ball in kilograms and have the "recorder" record it in Table 1. If a balance is not available, your teacher will provide you with the average mass of your ball type for use in your calculations.

STUDENT ACTIVITY

BALL OF ENERGY



Procedure (continued)

3. Once you are outside, have reviewed the safety procedures and rules, and are in position, have the "measurer" use a stopwatch to time the ball from the instant the "thrower" releases it to the instant it hits the ground. The "recorder" should record this time in seconds as Total Air Time in Table 2.

4. Complete the ball throwing activity five times and record the total air time for each trial in Table 2.

5. After all 5 trials are completed, use a calculator and the information provided in Table 3 to work collaboratively with your group members and complete all of the calculations required in Table 2 and work with your group members to answer the Analysis Questions.

Data Tables

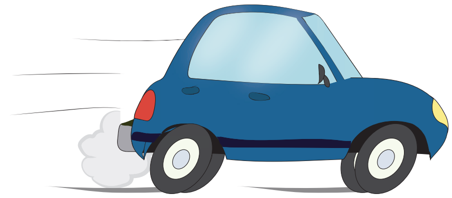
Table 1 - Information about the Ball

BALL TYPE	MASS OF BALL (KG)

Table 2 - Measurements and Calculations Related to the Ball Throw

	MEASUREMENTS	CALCULATIONS					
TRIAL #	TOTAL AIR TIME (s)	t_{up} (s)	t_{down} (s)	$d_{up} = \frac{1}{2} g t_{up}^2$ (m)	$PE_{max} = mgh_{max}$ (J)	$KE_{max} = PE_{max}$ (J)	v_{max} (m/s)
1							
2							
3							
4							
5							

BALL OF ENERGY



Data Tables (continued)

Table 3 - Variable Symbols, Definitions, Formulas, and Calculation Procedures

SYMBOL	DEFINITION	FORMULA	CALCULATION PROCEDURES AND UNITS
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t_{down}	Time down	½ total air time	$t_{up} = t_{down}$ (neglecting air resistance)
g	Acceleration due to gravity	9.81 m/s^2	The rate of acceleration of any object moving under the sole influence of gravity (also known as free fall). Measured in meters per second per second (m/s^2).
d_{up}	Maximum distance up	$\frac{1}{2} g t_{up}^2$	Square the time up and multiply it by g (acceleration due to gravity). Then divide this total by 2 to determine the maximum distance upward (maximum height) the ball achieves during the throw. In this activity's calculations, $d_{up} = h_{max}$. Measured in meters (m).
PE_{max}	Maximum gravitational potential energy	mgh_{max}	Gravitational potential energy (PE) is energy due to the relative position of an object above the ground and is measured in joules (J). $PE_{max} = mgh_{max}$ where m = the mass of the ball in kilograms, g = acceleration due to gravity, and h = maximum height above ground (same as d_{up}). For the ball thrown in this activity, its maximum potential energy is at the top of it flight when it is at its greatest distance above the ground, which is why we use the value for maximum distance up (d_{up}) for h_{max}.
KE_{max}	Maximum kinetic energy	$KE_{max} = PE_{max}$	According to the Law of Conservation of Energy, for the thrown ball "system," the kinetic energy of motion (KE) during the ball's downward journey equals the potential energy the ball gains on its upward journey. Both KE and PE are measured in joules (J). If air resistance is neglected, the maximum potential energy gained by the ball on its upward journey is converted entirely to kinetic energy during its downward journey; therefore $PE_{max} = KE_{max}$.
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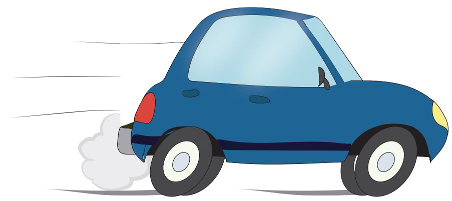
STUDENT ACTIVITY

BALL OF ENERGY



Answers to Analysis Questions

1. According to the Law of Conservation of Energy, energy cannot be created or destroyed. Instead, it can be transferred to other objects in the same form OR it can be transformed from one type of energy to another (such as sound energy or heat energy). What do you think happened to all of the kinetic energy in the falling ball once it hit the ground?

2. The formula for determining the kinetic energy of any moving object is: $KE = 1/2mv^2$. If a car had a mass of 1,500 kg, use this formula to determine the total amount of kinetic energy it would have upon crashing into a wall at the following velocities:

A. 20 miles per hour (which is equal to 8.94 m/s)

B. 40 miles per hour (which is equal to 17.88 m/s)

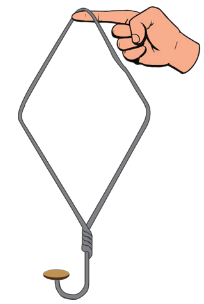
3. For analysis question 1, how many times greater is the kinetic energy of the car traveling at 40 miles per hour compared to the car traveling at 20 miles per hour?

4. This example shows that when the velocity of a vehicle doubles (for example from 20 mph to 40 mph), its kinetic energy quadruples. Why?

5. At the Insurance Institute for Highway Safety's Vehicle Research Center, one of their head-on vehicle crash tests involves having a car with a single crash test dummy "driver" crash into a 320,000 pound stationary barrier at 40 miles per hour. Based on what you now know about the Law of Conservation of Energy and energy transfer and transformation, what do you think happens to all of the kinetic energy of the vehicle when it crashes into the barrier?

TEACHER LESSON PLAN

TWIRLING PENNY



Key Question(s)

» What forces keep a penny on a twirling hanger?

» How does Newton's Second Law of Motion help to explain how seatbelts protect occupants during rollover crashes or accidents occurring when vehicles drive around sharp curves?

» How do banked curves on highways help vehicles safely negotiate these turns?

Grade levels: 8–12
Time required: one 50-minute class period

Objectives

Students will:

» calculate the magnitude and direction of net force acting on an object.

» identify the forces acting on an object in circular motion.

» explain how a penny stays on the tip of a twirling hanger using Newton's Second Law of Motion.

» apply the concepts of centripetal force, inertia, and friction to explain what happens to the position of an unbelted back-seat passenger when a car turns swiftly on a flat, curved road.

» use Newton's second law of motion and the concept of centripetal force to describe how seatbelt use and banked curves reduce vehicle accidents and occupant injuries and fatalities on curved roads.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

» HS-PS2-1, MS-PS2-2, 5-PS2-1, PS2.A

Background Information

Newton's First and Second Laws

Commonly, Newton's first law is often stated as follows: "An object at rest will remain at rest and an object in motion will remain in motion unless acted on by an outside force." Technically, Newton's first law should say: "An object at rest will remain at rest and an object in motion will remain in motion in a straight line at a constant speed unless acted upon by a net force."

DEFINITIONS

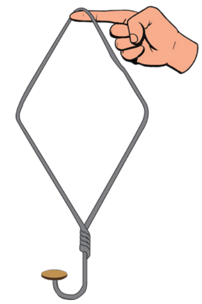
"Centrifugal" force: There is actually no such force as centrifugal force. Rather, it is a term that has been inaccurately used by people to describe the feeling of being pulled outward when moving in a circular motion (such as driving rapidly around a sharp turn in a vehicle or riding a rapidly spinning amusement park ride).

Centripetal force: an inward pushing or pulling force that causes an object to follow a circular path of motion. Objects will not move in a circular path without a centripetal force acting on them.

Friction: the force that resists the motion of any two objects in contact with each other.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

TWIRLING PENNY



DEFINITIONS (CONTINUED)

Inertia: the tendency of a resting or moving object to resist any change in its state of motion.

Net force: the sum of all of the directional forces acting on an object at rest or in motion.

Speed: how fast an object moves; calculated by dividing the distance traveled by the time of travel.

Support force: the upward force that balances the weight of an object on a surface.

Velocity: refers to both how fast an object moves as well as its direction of movement. The velocity of an object can be changed by either changing an object's speed or changing its direction of motion.

Background Information (continued)

Commonly, Newton's second law is represented using the equation F = ma and translated as "The force acting on an object is the product of the object's mass and its acceleration." For purposes of this lesson, a better equation for representing Newton's second law is a = F/m. One accurate translation of this rearranged equation is: "In order to accelerate an object of a given mass, a net force must be applied." The amount of acceleration produced by the net force acting on an object is directly proportional to the magnitude of the net force and in the same direction as the net force. So, another way to interpret this equation is: "The greater the net force applied to an object of a given mass, the greater that object's acceleration."

Net force, Newton's First and Second Laws and Circular Motion

A net force is simply the total of all of the applied forces acting on an object. Since force is a vector quantity (i.e., it has both magnitude and direction), net forces depend on both the magnitudes and directions of all of the applied forces acting on an object. For example, an object experiencing a downward applied force of 10N and an upward applied force of 5N would have a net force of 5N downward, so the object will accelerate downward (See Figure 1). If the net force acting on an object is zero, the object will no longer accelerate in any direction.

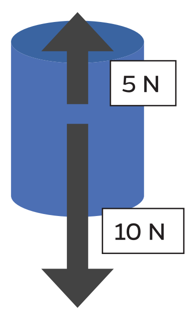
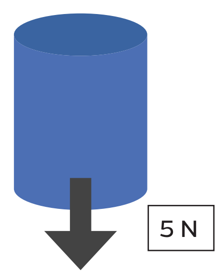
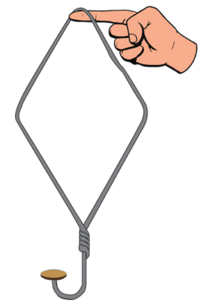
APPLIED AND NET FORCES ON AN OBJECT	
	
Applied forces	Net force

Figure 1

TWIRLING PENNY



Background Information (continued)

Considering Newton's first law and objects at rest or objects in motion: If an object is at rest, is a net force required to accelerate an object to produce circular motion? The answer is "Yes." For any type of motion, including circular motion, in order to accelerate, an object must have a net force greater than zero acting on it.

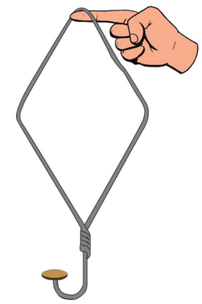
If an object is already in circular motion, will that object stay in circular motion at a constant speed if no net force is continuously applied to it? The answer is "No." This is a very common misconception among students if they are not taught the difference between speed and velocity. Velocity involves speeds and direction. When an object is in circular motion, even at a constant speed, the object still undergoes an acceleration since its direction is changing. To maintain circular motion (in which an object is constantly changing direction as it moves), a net force greater than zero must be applied continuously. The type of force that allows objects to move in a circular motion is called centripetal force.

Regarding Newton's second law, it is important for students to understand that, in order for an object to remain motionless, the sum of all of the applied forces (both their magnitudes and directions) must be balanced so that the net force acting on the object is zero. For example, if a penny is resting on a horizontal surface, such as the tip of a coat hanger, the only way that penny can remain motionless on the hanger tip is if the upward support force exerted by the tip of hanger is the same magnitude as the downward force of gravity acting on the penny (i.e., the penny's weight).

Centripetal force vs. Centrifugal force

If an object is moving in a circular motion at a constant speed, the direction of the net force is continually changing so that it is always directed toward the center of the circle of motion. This "center-seeking" force is referred to as centripetal force. The term centripetal is derived from the Latin terms *centrum* which means "center" and *petere* which means "to seek." "Centripetal" is merely an adjective that can be used to describe the direction of any type of force directed toward a fixed center.

Rather than understanding that circular motion is caused by an inward centripetal net force, students often have a strong misconception that circular motion is produced by an outward pushing force often referred to as centrifugal force. In reality, centrifugal forces do not exist; but most students have experienced a sensation of being pulled outward while sitting unbelted in a vehicle going around a sharp curve or riding on a rapidly spinning circular amusement park ride. This feeling of being pulled outward is actually caused when there is no net centripetal force to pull or push your body toward the center of the vehicle's circle of motion. Without a properly adjusted seat and fitted seat belt, as the vehicle changes the direction of its motion from a straight line to a curve, that centripetal force acting on the vehicle is not transferred to the occupant. As a result, the occupant continues moving in a straight line due to its inertia while the car turns, resulting in the occupant's body slamming into the door or window of the car. In other words, if an occupant is not wearing a seat belt on a curve, the car turns while the occupant stays on a straight-line collision course with the interior of the car!



Background Information (continued)

The Physics of Circular Motion, Driver Safety, and Road Design

According to data from the National Highway Traffic Safety Administration 13% of Americans do not wear seat belts and people not wearing seat belts account for half of all traffic fatalities. Many of those fatalities occur when unbelted vehicle occupants are ejected from a vehicle or collide with the inside of a vehicle when making turns or driving around curves at high speeds. In many of these types of crashes, the vehicle actually rolls over when the driver loses control. Occupants who are not wearing their seatbelts and are ejected from a vehicle during a rollover crash are four times more likely to die. Occupants who are ejected in non-rollover crashes are twice as likely to die.

When a vehicle drives around a smooth curve on a flat road, the friction created between the tires and the road provides the centripetal force that holds the vehicle in a curved path. If the force of friction (and the resulting centripetal force) is not strong enough (for example if the road surface is slick and oily), the tires will slide sideways and the vehicle will begin to skid off to the left or right of the road.

If curves are too sharp or vehicle speeds are too high, vehicles are at greater risk of skidding, losing control, and rolling over because there is not enough friction created between the tires and the road, thus the centripetal force is not strong enough to hold the vehicle on a curved path.

On sharply-curved roads or racetracks, one technique for creating additional centripetal force beyond the centripetal force created by tire/road friction is a banked turn. In a banked turn, the outer edge of the road is higher than the inner edge. In order to understand how banked turns create additional centripetal force on a curve, students need to understand the concept of a support force.

Support Force

On a flat curve, the upward force that balances the weight of a car on the road is the road's support force (also known as the normal force). On a flat curve, all of the road's support force is straight up (perpendicular to the surface of the road) and exactly balanced with the perpendicular downward force (i.e. the weight) of the car (See Figure 2).

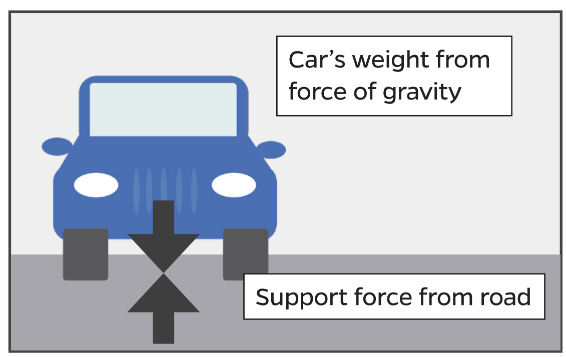
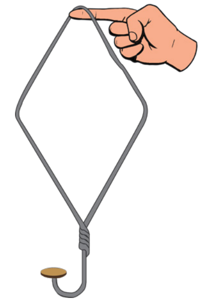


Figure 2

TEACHER LESSON PLAN

TWIRLING PENNY



Background Information (continued)

Support Force (continued)

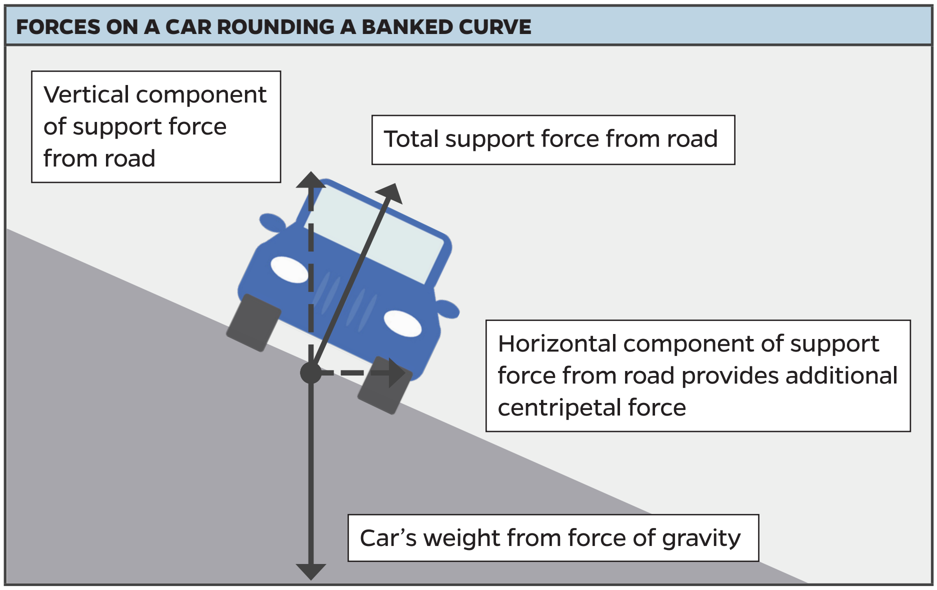


Figure 3

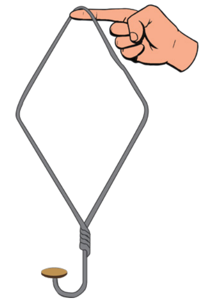
On a banked curve, the magnitude of the road's support force still equals the weight of the car. However, since the height of the road is different on each side (inner vs. outer), the overall support force exerted by the road does not all point straight up. Instead, the overall support force is at an angle and the support force is actually composed of two separate components: one part of the force points straight upward from the road while the other part points toward the inner side of the curve (i.e., it points toward the center of the circle of motion of the vehicle). That inward pointing portion of the support force provides an additional centripetal force (See Figure 3). This additional centripetal force provided by the banked road helps a vehicle move through the turn without sliding or skidding.

Figure 4

In addition to using banked turns on highways and vehicle racetracks, this engineering design concept can also be applied to bicycle racetracks. Oval bicycle racetracks with high-speed turns are called velodromes (See Figure 4). To create strong centripetal forces, the angles of the banked turns on velodrome tracks can be extreme. For example, Olympic and World Championship velodromes have a total circumference of 250 m (820 ft.) with banked turns of approximately 45˚. For comparison, the Indy 500 track oval is 2.5 miles in circumference with banked turns of approximately 9˚.

TEACHER LESSON PLAN

TWIRLING PENNY



MATERIALS NEEDED

Per pair of students

» 1-3 pennies

» 1 metal coat hanger

Per student

» 1 "Twirling Penny" Student Activity Sheet

» 1 pair of safety glasses or goggles

Per class

» Computer with web access

» Computer projector with speakers

OPTIONAL MATERIALS

Per class

» 1 metal file to grind the tips of coat hangers

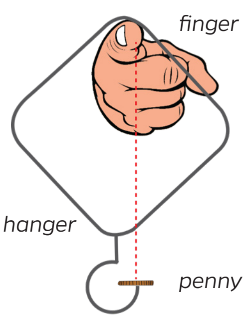


Figure 5

Advance Preparation

» Make copies of the student activity sheet and assemble materials for each pair of students.

» Pull the flat, bottom part of each coat hanger outward to form a diamond shape.

» Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/twirling-penny and decide if they should remain in the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/twirling-penny

» Optional: If the tips of the hangers are rough or uneven, use a metal file to grind the tips flat.

Safety Considerations

» When conducting the twirling hanger/penny activity, all students should wear safety glasses until ALL groups have finished twirling their hangers.

» When conducting the twirling hanger/penny activity, groups need to space themselves a few meters apart to ensure that no one is in the path of a twirling hanger.

Procedure

Part 1 - Calculating Net Force

1. Introduce the lesson by dangling one of the diamond-shaped coat hangers from your index finger so that the tip of the hanger's hook is pointing upward towards your finger. If needed, adjust the bend of the hanger's hook so the tip is pointing straight upward towards your finger (See Figure 5). Hold up a penny and ask students to predict what they think would happen if you placed the penny on the tip of the coat hanger and spun the hanger around in a circle. Next, ask students to raise their hands if they have heard the terms "centrifugal force" and "centripetal force" and solicit volunteers to explain each of these terms in their own words. Then tell students that only one of those forces is actually real and explain that they are going to do an inquiry activity to learn more about the actual forces involved in circular motion and how engineers apply the physics of circular motion to design safer curved roads.

2. Distribute a "Twirling Penny" activity sheet to each student. Show the "Twirling Penny" Introduction video at classroom.iihs.org/twirling-penny and review the Key Questions, the Purpose of the Activity and the Did You Know? information.

3. Refer to relevant background information and briefly review Newton's First Law of Motion. Then share the more accurate version of Newton's First Law: "An object at rest will remain at rest and an object in motion will remain in motion in a straight line at a constant speed unless acted upon by a net force." Ask students to describe what they think the term "net force" means.

Procedure (continued)

TEACHER LESSON PLAN

TWIRLING PENNY

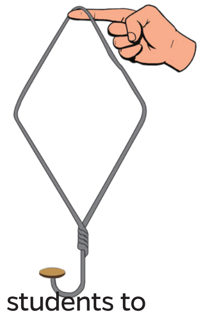


TABLE 1 - TIPS FOR SUCCESSFUL PENNY TWIRLING
» Penny's Lincoln Memorial side is facing down on the tip
» Penny is lying flat on the hanger's tip
» Hanger tip points upward toward your twirling finger
» Begin with a gentle swinging motion
» Gently build up swinging arc to around 30˚ from center
» At 30˚, increase the twirling force with a smooth clockwise motion to push the hanger into a fast, vertical loop

4. Divide students into pairs and review the Procedure for Part 1. Tell students to follow the instructions to calculate and record the magnitude and direction of the net force acting on each truck in the four examples provided. Review the correct answers for Figure 2 on the student sheet.

a. 10 N right ***b.*** 0 N ***c.*** 5 N right ***d.*** 5 N left

5. Next, review pertinent background information regarding Newton's Second Law of Motion and present the revised equation a = F/m. Instruct students to work with their partners to answer Analysis Questions 1 and 2 and review correct responses. Make sure students understand that the trucks in examples C and D have the same net force (5 N) even though their net forces are in opposite directions. As a result, according to a = F/m, they will also both have the same accelerations. Make sure they also understand that, since acceleration is directly proportional to the net force exerted, truck A will have the greatest acceleration.

Part 2 - Investigating Circular Motion with a Twirling Penny

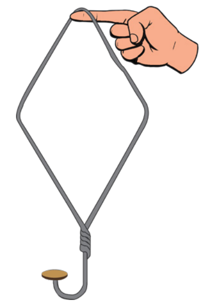
6. Explain that the physics of circular motion is a bit different than that of straight-line motion and tell students that they are going to investigate the physics of circular motion by twirling a penny from the tip of a coat hanger. Refer to Figure 3 on the activity sheet and demonstrate how to balance the penny flat on the tip of the hanger so that it is directly below (in a straight-line path down from) the opposite end of the hanger resting on their index finger.

7. Distribute the hangers, pennies, and safety glasses. Review the **Safety Considerations** and remind students that **everyone must wear safety glasses until ALL groups have finished twirling their hangers and groups must stay far enough apart to make sure no one is in the path of a twirling hanger**. Even if only one person is twirling a coat hanger, the entire class must keep their safety glasses on.

8. Tell students to follow the instructions in Part 2 of the activity sheet and circulate and assist groups as needed. Remind students to be patient and persistent as they try to get the penny to remain on the tip of the twirling coat hanger. If needed, provide the students with a few of the tips for successful penny twirling in Table 1.

9. Encourage each student to try the twirling penny challenge. Then, after at least one member in each pair has succeeded in keeping a penny on the twirling hanger, ask pairs to attempt the 3 additional Twirling Penny Challenges on the activity sheet. (NOTE: To save time and reduce student levels of frustration, do not require all groups to successfully complete each additional challenge.)

10. Have groups share the strategies they used to successfully twirl the penny as well as strategies they used to attempt each of the 3 Twirling Penny Challenges, then instruct students to work with their partners to answer Analysis Questions 3 and 4.



Procedure (continued)

11. Review correct responses to Analysis Questions 3 and 4. For Question 4, make sure students understand that Newton's First Law refers to objects moving in a straight line. In order for a moving object (such as a penny on a coat hanger) to overcome its tendency to maintain a straight line path of motion (i.e., its inertia) and instead move in a circle, an outside net force directed toward the center of the circle must be exerted. Then tell students that the outside net force that results in circular motion is called centripetal force.

12. Refer to the background information and conduct a whole class discussion/review of the concepts of centripetal force, centrifugal force, and support force and make sure students understand that there is no such force as a "centrifugal" force pulling an object outward. Instead, to maintain circular motion, centripetal force pushes or pulls an object toward the center of motion.

13. Instruct students to work with their partners to answer Analysis Questions 5 and 6. Have students share their responses and review correct responses.

Part 3 – Applying the Physics of Circular Motion to Road Design and Driver Safety

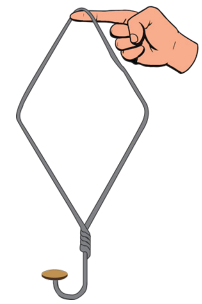
14. Refer to the background information and conduct a whole-class discussion of how the physics of circular motion applies to vehicles driving on curved roads, including the role of a moving vehicle's inertia (tendency to maintain movement in a straight line) and the force of friction between a vehicle's tires and the road surface.

15. Refer to Part 3 of the activity sheet and instruct students to work with their partner to answer Analysis Question 7. Have students share their responses and review the correct answer. Make sure students understand that, without a seat belt on a sharp curve, the centripetal force acting on the vehicle will not be transferred to the occupant. Instead, the occupant's inertia will keep the occupant moving in a straight line while the vehicle turns, which can result in severe injuries from occupant collisions with the vehicle's interior.

16. Show the "Twirling Penny" Conclusion video located at classroom.iihs.org/twirling-penny and conclude the lesson with a discussion of the relevant background information regarding banked turns. Instruct student pairs to work together to answer Analysis Question 8. Have students share their responses and review the correct answer. Finally, share specific information regarding the differences in size of the angles of banked turns on vehicle raceways such as the Indianapolis Motor Speedway and bicycle racetracks such as velodromes.

TEACHER LESSON PLAN

TWIRLING PENNY



Answers to Analysis Questions

1. Assume that the trucks in Figure 2 are all of the same mass and are all pointed toward the right. Follow steps a, b, and c to calculate the net force acting on each truck.

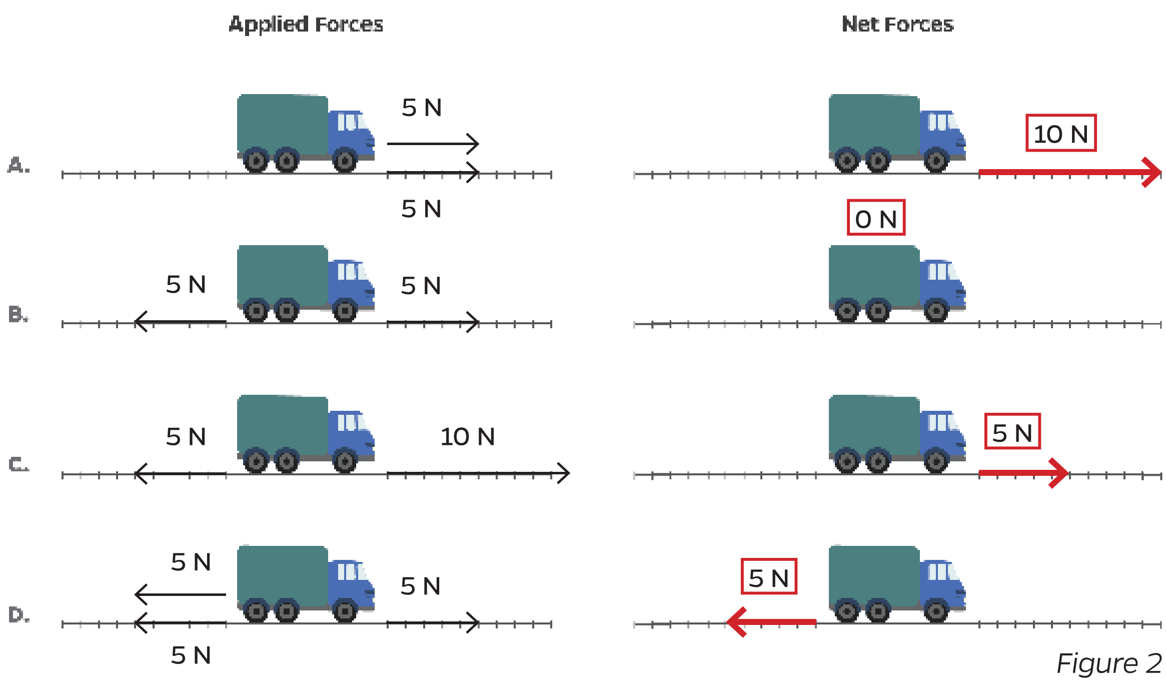


Figure 2

2. Which trucks are going to have the same acceleration?

C and D

3. Which truck is going to have the greatest acceleration?

A

4. If an object is at rest, is a net force required to accelerate an object in order to produce circular motion?

YES

5. If an object is already in circular motion, will that object stay in circular motion at a constant speed if no net force is continuously applied to it?

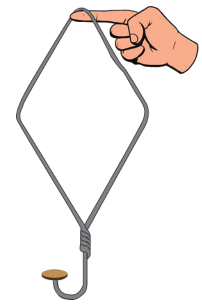
NO

6. What two forces are acting on the penny when it is <u>motionless</u> on the tip of the hanger?

The force of gravity and the support force of the hanger on your finger. When the penny is balanced on the tip of the coat hanger, the force of gravity pulls downward on the penny as the support force of the same magnitude (provided by the tip of the hanger on your finger) pushes upward on the penny in the opposite direction.

TEACHER LESSON PLAN

TWIRLING PENNY



Answers to Analysis Questions (Continued)

7. Using Newton's Second Law of Motion (a = F/m), explain how the penny stays on the tip of the twirling hanger when it is <u>in motion</u>.

According to Newton's second law of motion, an object that is accelerating must have a net force acting on it. By definition, an object is accelerating if its speed or direction is changing. By moving in a circle, the penny is constantly changing direction; therefore there must be a net force applied to the penny (by the tip of the hanger) to keep the penny moving in that circle. A net force that produces circular acceleration and thereby circular motion is often called a centripetal force.

8. Use the following 3 terms to explain what happens to an unbelted back-seat passenger when a car turns swiftly to the right on a flat road:

» centripetal force
» friction
» inertia

As the car rounds the curve to the right, the unbelted passenger may feel they are being thrust sideways (toward the left-side door by an outward pulling or "centrifugal" force.) There is actually no outward force pulling on them. What the unbelted passenger is really feeling is his/her own **inertia** *or tendency to travel forward in a straight line while the car is turning to the right. The force of* **friction** *between the vehicle tires and the road exerts a center-seeking (***centripetal force***) on the car to make it move in a circle (i.e., turn to the right). Since the passenger is not belted to the car, this same* **centripetal force** *does not act on the occupant and does not overcome the occupant's* **inertia***.*

9. Explain in your own words how banked turns on roads reduce vehicle accidents.

Since the road is at an angle rather than horizontal, the road's overall support force is NOT pointing straight up as it is on a flat road. Instead, one component of the overall support force points straight upward (vertical) while a second horizontal component points inward (toward the inside of the curve of the road). When a vehicle drives around a banked turn, the inward-pointing component of the road's support force provides additional centripetal force to complement the centripetal force provided by the friction between the tires and the road. This additional centripetal force helps keep the vehicle from skidding or sliding around the turn.

Extension

1. Have students view the "Twirling Tray" and/or the "Curve Ball" demonstration videos located at classroom.iihs.org/twirling-penny to review Newton's first law of motion, centripetal force and circular motion.

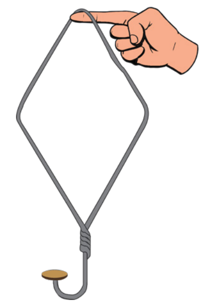
2. Have students visit the IIHS.org website to investigate the design and use of circular intersections called roundabouts to promote safe and efficient traffic flow. To find information on roundabouts on the IIHS.org site, tell students to either type "roundabout" in the Search website field or select "Roundabouts" from the Topics pulldown menu located at the top of the webpage.

STUDENT ACTIVITY

Name: ____________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

TWIRLING PENNY



MATERIALS NEEDED

Per pair of students

» 1-3 pennies

» 1 metal coat hanger

Per student

» 1 "Twirling Penny" Student Activity sheet

» 1 pair of safety glasses or goggles

Key Question(s)

» What forces keep a penny on a twirling hanger?

» How does Newton's Second Law of Motion help to explain how seatbelts protect occupants during rollover crashes or accidents occurring when vehicles drive around sharp turns?

» How do banked curves on highways help vehicles safely negotiate these turns?

Purpose

» To calculate the magnitude and direction of the net force acting on an object

» To identify the forces acting on an object in circular motion

» To use Newton's Second Law of Motion to explain circular motion

» To explain how the physics of circular motion affects occupants of vehicles driving around curves

» To describe how banked curves and seatbelt use make driving on curved roads safer

Figure 1

Did You Know?

Engineers design banked curves on some racetracks or highways to help vehicles maintain traction as they move through turns. On racetracks with high-speed turns, such as velodrome bicycle tracks (See Figure 1) or Indy raceways, the angle of the banked turns can be extreme. In this activity you will use pennies and a coat hanger to explore what forces affect a penny as it moves through a continuous high-speed turn.

Procedure

Part 1 - Calculating Net Force

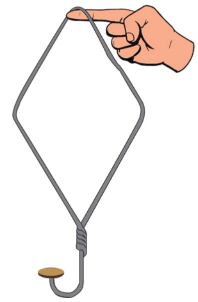
1. Assume that the trucks in Figure 2 are all of the same mass and are all pointed toward the right. Follow steps a, b, and c to calculate the net force acting on each truck.

a. If two or more forces are present on the left or right side of a truck, calculate the total of all of the forces on that side.

b. For each truck, subtract the larger total force (either on the left or the right side) from the smaller total force on the other side to determine both the magnitude of the net force acting on each truck as well as the direction of each net force (acting on the left or right).

c. In the "Net Force" column, use the marks on the lines next to each truck to draw arrows indicating both the direction of the net force (on the right or left side of each truck) and the magnitude of the net force in Newtons and write the total amount of the net force (such as "15N") above each arrow.

TWIRLING PENNY



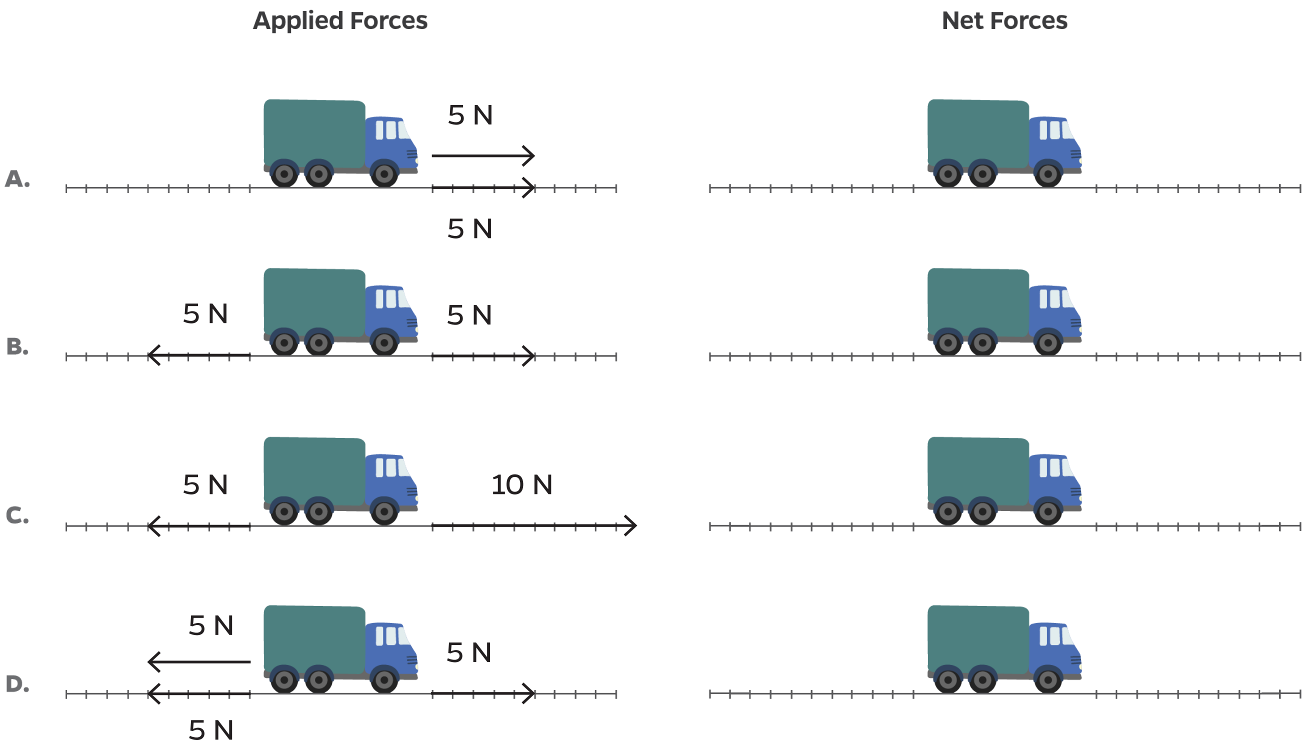


Figure 2

Analysis Questions

2. After your class discussion of Newton's Second Law and review of the equation a = F/m (where F = net force and a = acceleration), work with your partner to answer the following analysis questions regarding the trucks in Figure 2. HINT: Assume that the trucks all have the same mass.

a. Which trucks are going to have the same acceleration?

Circle all that apply: A. B. C. D.

b. Which truck is going to have the greatest acceleration?

Circle one: A. B. C. D.

TWIRLING PENNY

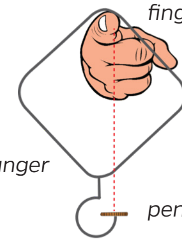


Figure 3

Part 2 – Investigating Circular Motion with a Twirling Penny

3. Follow your teacher's tips and the directions below to successfully twirl a penny on the tip of a coat hanger. To see Griff Jones twirl a penny, watch the activity's Introduction video at classroom.iihs.org/twirling-penny

***Safety Note:* Everyone must wear safety glasses until all groups have stopped twirling their hangers and groups must stay far enough apart to make sure no one is in the path of a twirling hanger.**

- ***a.*** Put on a pair of safety glasses.
- ***b.*** Hang the coat hanger on your index finger so that the tip of the hanger's hook is pointing upward towards your finger. If needed, adjust the bend of the hanger's hook so the tip is pointing straight upward towards your finger (See Figure 3).
- ***c.*** Carefully balance a penny on the tip of the hanger's hook.
- ***d.*** Practice gently swinging the hanger back and forth with successively larger swing heights without the penny dropping off the tip.
- ***e.*** Then, begin swinging the hanger back and forth with successively larger swing heights. Gradually increase the swing heights until you can twirl the hanger a full circle multiple times without the penny coming off of the hanger. Be patient! It takes practice to twirl the hanger in a smooth circular motion so the penny stays on the hanger.
- ***f.*** To stop the circular motion of the hanger and penny, take a giant step to the left or right (in the same direction as the penny is twirling) and stop the hanger on the upswing.
- ***g.*** After at least one group member has succeeded in keeping the penny on the twirling hanger several swings in a row, try completing these additional "Twirling Penny Challenges:"
  - ***i.*** Bring the twirling hanger to a stop without the penny falling off.
  - ***ii.*** Twirl the hanger as slowly as possible without the penny falling off.
  - ***iii.*** Twirl more than one penny on the tip of the hanger. (Griff's record is three pennies.)

Analysis Questions

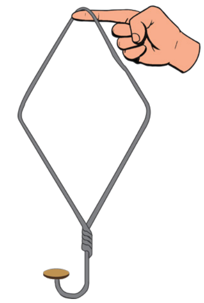
4. If an object is at rest, is a net force required to accelerate an object in order to produce circular motion?

Circle one: YES NO

5. If an object is already in circular motion, will that object stay in circular motion at a constant speed if no net force is continuously applied to it?

Circle one: YES NO

TWIRLING PENNY



Watch the activity's Conclusion video at classroom.iihs.org/twirling-penny After your class discussion of the concepts of "centrifugal" force, centripetal force, support force, and the force of gravity, work with your partner to answer the following questions:

6. What two forces are acting on the penny when it is <u>motionless</u> on the tip of the hanger?

______________________________ and ________________________________

7. Using Newton's Second Law of Motion (a = F/m), explain how the penny stays on the tip of the twirling hanger when it is <u>in motion</u>.

____

____

____

Part 3 – Applying the Physics of Circular Motion to Driver Safety and Road Design

After your class discussion of how the physics of circular motion applies to vehicles driving on curved roads, answer the following questions:

Analysis Questions

8. Use the following 3 terms to explain what happens to an unbelted back-seat passenger (see Figure 4) when a car turns swiftly to the right on a flat road:

- centripetal force
- friction
- inertia

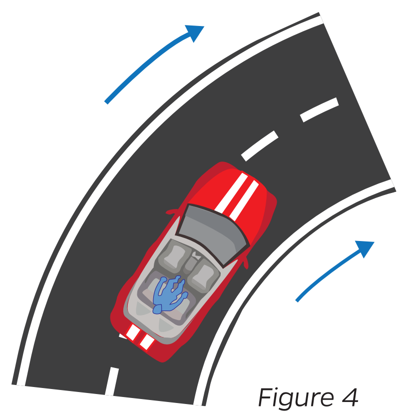


Figure 4

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9. Explain in your own words how banked turns on roads reduce vehicle accidents.

____

____

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____

TEACHER LESSON PLAN

CRASH SCIENCE IN THE CLASSROOM

THINK FAST, ACT FAST!

DEFINITIONS

central nervous system (CNS): the part of the nervous system consisting of the brain and spinal cord

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

peripheral nervous system (PNS): the part of the nervous system consisting of the nerves and ganglia outside the brain and spinal cord

reaction time: the elapsed time between the presentation of a sensory stimulus and the performance of the desired behavioral response

speed: distance traveled divided by the time required to travel that distance (Ex. meters per second or miles per hour)

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

Key Question(s)

» How fast is your reaction time?

» How far can a vehicle travel during your reaction time?

Grade levels: 5–12

Time required: 30-50 minutes

Objectives

Students will:

» calculate their reaction time using a measured distance.

» calculate the distance a moving vehicle travels during their reaction time.

» describe how their senses, nervous system, and muscles work together during their reaction time to produce a desired behavioral response (i.e., their foot hitting the brakes of a vehicle).

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

» HS-PS2-1

From Molecules to Organisms: Structures and Processes

» HS-LS1-2, MS-LS1-8, MS-LS1-3, 4-LS1-2

Background Information

Experimental psychologists, physiologists, and even baseball batting coaches use 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 performance of the desired behavioral response. There are three basic types of reaction time tests: 1. simple reaction time test with one stimulus and one response, e.g., pressing a button at the sound of a buzzer; 2. recognition reaction time tests with a recognized stimulus mixed in with unrecognized distractors, e.g., pressing a button when a familiar voice is heard; and 3. choice reaction time tests where the participant provides a response that corresponds to the stimulus, e.g., pressing the matching keyboard key for a particular letter appearing on a computer screen.

Although humans can and do react to stimuli perceived through all of their senses, most reaction time tests focus on our reactions to visual and auditory stimuli, although reaction times for tactile stimuli (such as an unanticipated touch) can also be measured fairly easily. Research indicates that, for human beings in general, the reaction time for auditory stimuli is faster than the reaction time for visual stimuli. However, due to a variety of physiological differences between human beings, there is no single accepted target "value" for simple reaction times to auditory or visual stimuli. Typical average reaction times for college-age individuals are between 140-160 milliseconds (0.14 -0.16 seconds) for sound stimuli and between 180 to 200 milliseconds (0.18-0.20 seconds) for visual stimuli.

THINK FAST, ACT FAST!

Background Information (continued)

Physiologically, a person's reaction time is determined by the actions of several body systems working together in response to a stimulus. This response occurs in three stages: 1. sensory input, 2. integration, and 3. motor output (see Figure 1). During the response process, the senses detect the stimulus (sensory input) and transmit it through the peripheral nervous system (PNS) to the central nervous system (CNS) of the spinal cord and brain. The brain analyzes and interprets the signal (integration) and then produces a motor output response signal. This signal is then transmitted back through the PNS to the muscular system to produce a muscular reaction (motor output).

As an example, suppose you were driving a car and a dog darted out in front of the car. First, your eyes would sense the stimulus (the moving dog) and sensory neurons would transmit this information from your eyes through your PNS to your CNS. Your brain would analyze and interpret the sensory signals regarding the stimulus and determine that you needed to hit the brakes to avoid hitting the dog. This motor output signal would then be transmitted back through your PNS to the muscles in your leg and foot causing you to step on the brakes.

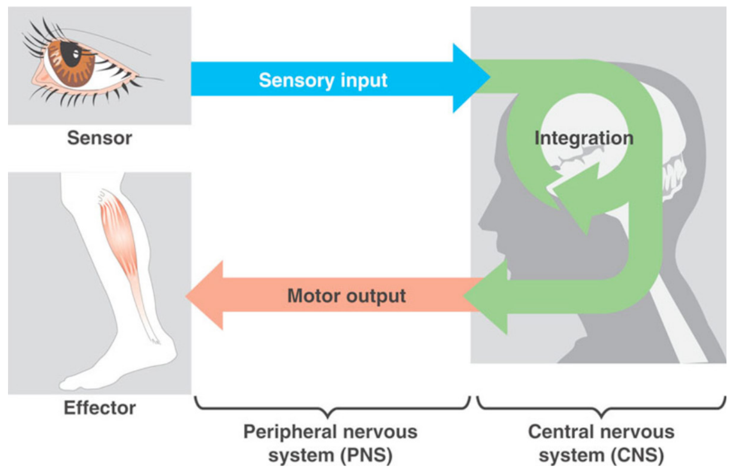


Figure 1. *Campbell N.A., Reece, J.B., BIOLOGY, 7th ed., Pearson Publishing, p.1013.*

Various factors can affect can affect an individual's reaction time (e.g., visual distractions, auditory distractions, too much sugar or caffeine in the diet, stress, lack of sleep, alcohol or drug consumption, physical fitness levels, hand-eye coordination levels, age, and brain injuries). Most teenagers have relatively short reaction times, but distractions while driving (e.g., eating, adjusting the stereo, listening to talking passengers, texting, or talking on the phone) usually increase their reaction times.

Distractions of any type are a common factor associated with vehicle crashes involving newly-licensed 16-year-old drivers. Research indicates that teenage drivers use cellphones and other emerging technologies while driving much more than adult drivers. Many states have implemented graduated licensing laws that place restrictions on newly licensed drivers designed to address the issue of teenagers driving while distracted (e.g., limiting the number of passengers a novice driver can carry). And, in some states, bans on using cellphones while driving have been added to those restrictions.

In this activity, students will calculate their reaction times using the measured distance a ruler drops vertically between their fingers before they react to catch it. To calculate their reaction time from the measured ruler-drop distance, students will use the following simple equation

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

t = reaction time (seconds)

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

THINK FAST, ACT FAST!

MATERIALS NEEDED

Per pair of students

» 1 metric ruler

Per student

» 1 "Think Fast, Act Fast" Student Activity Sheet

» 1 calculator with a square root function (√)

Per class

» 2 $1 bills

» 1 metric ruler for demonstration purposes

This equation is derived from a physics equation that determines how far an object freely falls vertically (neglecting air resistance) when it is accelerated only by the Earth's gravitational pull. The original equation is:

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

d = measured distance an object falls (the ruler)

t = the time the object falls
(the time the ruler falls through the students' fingers before it is caught)

g = the acceleration due to gravity (9.81 m/s^2 at the Earth's surface)

To save calculation time during the lesson, after re-arranging the equation to solve for t, the acceleration due to gravity (g) has been converted to cm/s^2 and other calculations that can be "pre-done" have already been completed for students. See Part 8 of the Procedure section for further information if needed.

In this activity, students will also calculate how far a moving vehicle would travel during their reaction time and discuss how reaction time is involved in safe driving practices. To simplify these calculations for students, we will assume that the velocity of the vehicle does not change during the time required to react to a visual stimulus and hit the brake. Therefore, to calculate how far a moving vehicle would travel during their reaction times, students will use the following physics equation for objects moving at a constant (unchanging) velocity:

$$d = v \times t$$

d = distance object travels (meters)

v = constant velocity (meters/second)

t = total time (seconds)

Advance Preparation

» Make copies of the student activity sheet and assemble sets of materials for each group.

» Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/think-fast-act-fast and decide if you want to incorporate them into the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/think-fast-act-fast

Procedure

1. Initiate the lesson by either showing the lesson's Introductory video or by conducting the dollar-bill reaction time test with student volunteers.

2. For the dollar-bill reaction time test, ask two student volunteers to come to the front of the classroom. Ask them to guess which one of them has the fastest reaction time. Tell them you have a simple test to determine who has the fastest reaction time. Pull two dollar bills from your pocket and announce that, if they can catch the bills they can keep them. Let them know that each volunteer will get a chance to try.

Procedure (continued)

3. Explain the procedure for the reaction time test:

a. The student trying to catch the dollar (the catcher) should rest his/her arm on the edge of a table or desk with their thumb and index finger open and 4.0 cm apart.

b. The person dropping the dollar bill (the dropper) should hold the bill vertically and long-ways between his/her thumb and index finger at one end of the bill and position the bill so that its mid-point is even with the catcher's open thumb and index finger (see Figure 2).

c. Tell the dropper to avoid giving the catcher any unintended hint of the bill's release. Also, make sure the dollar bill is held completely vertical to allow it to drop straight down between the catcher's fingers.

d. Have the dropper drop the dollar bill while the catcher tries to catch it. Typically, students' reaction times are not fast enough to catch the remaining half of the bill before it drops through their fingertips; but every once in a while, student are successful, so have TWO dollar bills on hand just in case!

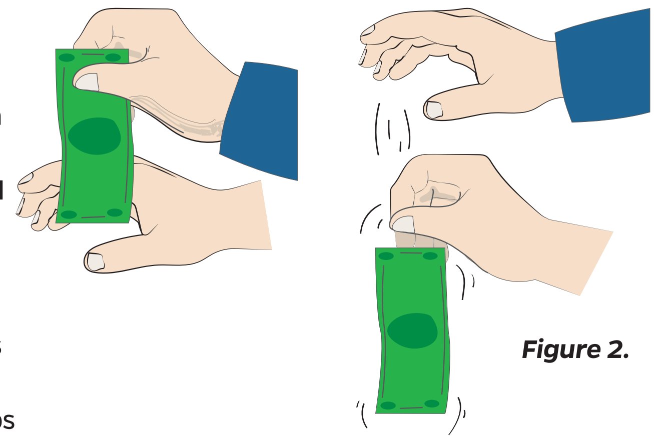


Figure 2.

4. Give each volunteer a chance to try to catch the bill dropped by the other volunteer. Then ask the class how they could change the reaction time test to improve the volunteers' chances of catching the bill. (Sample answers include: decreasing the 4.0 cm space between the catcher's thumb and index finger, giving the catcher a warning immediately before dropping the bill, dropping the bill from a greater height to allow more of the bill to drop through their fingers during their reaction time, or taping paper to the bill to lengthen it).

5. Using pertinent background information, provide the formal definition for the term "reaction time" and review the three types of reaction time tests. Distinguish between auditory and visual stimuli and ask students whether they think humans react more quickly to visual stimuli or auditory stimuli. Make sure students realize that most people react more quickly to auditory stimuli. Next, explain that in this activity, students will be conducting a simple reaction time test using a visual stimulus. Ask students to predict their reaction times for visual stimuli in seconds. You may want to give students a hint and tell them that most reaction times are less than one second.

6. After students have predicted their reaction times, explain that reaction times are typically measured in milliseconds (thousandths of a second) and make sure students understand that one millisecond is written numerically as 0.001 seconds.

7. Divide students into pairs and distribute copies of the "Think Fast, Act Fast" student activity sheets, rulers, and calculators. Refer to the activity sheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information.

THINK FAST, ACT FAST!

Procedure (continued)

8. Review the Procedure for Parts 1 and 2 of the activity and use a student volunteer to help you demonstrate the proper ruler "dropping" and "catching" procedure if needed. Review the simplified formula for calculating reaction time ($t = 0.0452\sqrt{d}$) and, using pertinent background information, explain that this simplified formula is derived from the formula used to determine how far an object freely falls vertically when it is accelerated only by the Earth's gravitational pull ($d = \frac{1}{2} gt^2$). Work through a sample reaction time calculation using a hypothetical distance measurement from a ruler drop test: Distance measured on ruler (d) = 12.2 cm. 0.0452 x the square root of 12.2 cm (which is 3.49 cm) = reaction time of 0.158 seconds.

9. Finally, make sure students know how to measure to the nearest millimeter on the ruler and make sure they know how to use the square root function on their calculators.

10. Circulate and assist groups as needed and make sure students are recording distances to the nearest millimeter and calculating reaction times to the nearest thousandth of a second.

11. After all groups have completed their calculations, check each group's measurements and calculations.

12. Next, ask students to answer Analysis Questions 1 and 2 individually and then work collaboratively with their partners to answer Analysis Questions 3 through 5. Conduct a whole-class discussion of their responses to these five questions and review pertinent background information regarding the physiological reaction time process and the factors affecting an individual's reaction time. Optional: Show the activity's Conclusion video.

13. Finally, ask students to use their own average reaction time result from the activity to individually answer Analysis Questions 6, 7, and 8. Conclude the lesson with a discussion of the impact delayed driver reaction times resulting from distractions might have on the distance a car travels before a driver is able to appropriately respond to an unexpected stimulus, such as an oncoming car or a child darting into the road.

Answers to Analysis Questions

1. **How did your reaction times vary across the 10 trials? AND**
2. **What trends, if any, do you see in your reaction times over the 10 trials?**

   Typically, "catchers" will get better with practice. So as the number of trials increases, their reaction times tend to decrease and improve.

3. **List at least 3 factors that might affect someone's reaction time.**

   Possible answers include: visual distractions, auditory distractions, too much sugar or caffeine in the diet, stress, lack of sleep, alcohol or drug consumption, physical fitness levels, hand-eye coordination levels, age, and brain injuries.

4. **Identify at least 3 examples of distractions that might increase your visual or auditory reaction time while driving.**

   Possible answers include: Talking on a phone, texting on a cell phone, socializing with passengers, operating a stereo or navigation system, eating, and listening to music.

TEACHER LESSON PLAN

THINK FAST, ACT FAST!

Answers to Analysis Questions (continued)

5. Write a maximum three-sentence description of how sensory organs, the nervous system, and muscles work together during the reaction time process.

During the response process, senses (like the eyes) detect a stimulus (sensory input) and transmit it through the peripheral nervous system (PNS) to the central nervous system (CNS) of the spinal cord and brain. The brain analyzes and interprets the signal (integration) and then produces a motor output response signal. This signal is then transmitted back through the PNS to the muscular system to produce a muscular reaction (motor output).

6. Calculate in <u>meters</u> how far your vehicle would travel during your average reaction time using the following velocity conversion: 105 km/hr = 29 m/s

Using a reaction time of 0.158 seconds as an example: distance = velocity × time

d = 29 m/s × 0.158s = 4.6 meters

7. Calculate in <u>feet</u> how far your vehicle would travel during your average reaction time using the following velocity conversion: 65 mph = 95 ft/s

Using a reaction time of 0.158 seconds as an example: distance = velocity × time

d = 95 ft./s × 0.158s = 15 feet

8. In general, how might a brief distraction (such as glancing at a cell phone to read a text message) combined with your reaction time affect the distance your vehicle would travel while driving?

Even brief distractions can have significant impacts on the distance a vehicle travels before a driver can react appropriately. According to NHTSA (the National Highway Traffic Safety Administration), sending or receiving a text while driving diverts a driver's eyes from the road for an average of 4.6 seconds. Using the speeds and reaction time values from Questions 6 and 7 above, if a vehicle is traveling at a speed of 65 miles per hour, the vehicle would travel 437 feet during the time of distraction (95 ft/s x 4.6 seconds) AS WELL AS the 15 feet it would travel during the driver's reaction time.

Extension

Have students conduct the "Distracted Driving Dangers"activity to determine how different types of distractions affect the time it takes to complete a "simulated driving" task and explore how driving while distracted can be minimized.

Name: ____________________ Class: __________ Date: ___________

STUDENT ACTIVITY

THINK FAST, ACT FAST!

MATERIALS NEEDED

Per pair of students

» 1 metric ruler

Per student

» 1 “Think Fast, Act Fast” Student Activity Sheet

» 1 calculator with a square root function (√)

Key Question(s)

» How fast is your reaction time?

» How far can a vehicle travel during your reaction time?

Purpose

» To calculate reaction time using a measured distance

» To calculate the distance a moving vehicle travels during your reaction time

» To describe how your senses, nervous system, and muscles work together during your reaction time to produce a desired behavioral response

Did You Know?

Experimental psychologists, physiologists, and even baseball batting coaches use human reaction time tests to gauge mental and physical performance. Reaction time is a measure of the time it takes you to physically react to a sensory stimulus once you detect it. In this activity you will use a ruler to conduct a simple reaction time test using a visual stimulus and determine your own reaction time.

Procedure

Part 1 - Conducting the Ruler-Drop Reaction Time Test

Each person in your pair needs to complete 10 trials of the ruler-drop reaction time test as the “catcher” while their partner is the “dropper.” Follow the ruler-drop test instructions below and record the distances for each of your own trials as the “catcher” in Column 1 of Table 1 on your own copy of the activity sheet.

Figure 1.

Ruler-Drop Reaction Time Test Instructions:

a. Catcher: Rest your arm on the edge of a table or desk and spread your thumb and index finger 4.0 cm apart.
b. Dropper: Position the zero centimeter mark (0.0 cm) of the ruler so that it is level with the top of the catcher’s open fingers. See Figure 1.
c. Dropper: Without any advance notice, release the ruler so that it drops vertically between the catcher’s open thumb and index finger.
d. Catcher: Try to catch the ruler as quickly as possible with your thumb and forefinger and keep holding the ruler vertically. DO NOT MOVE your fingers once you catch the ruler!
e. Dropper: Read the number (in centimeters) at the bottom of the catcher’s index finger on the ruler and measure to the nearest millimeter (hash mark) on the ruler. For example, if the bottom of the catcher’s finger is three hash marks above the 12 centimeter number, the distance measurement would be 12.3 cm.

THINK FAST, ACT FAST!

Procedure (continued)

Part 2 - Calculating Your Reaction Time

1. Use the formula below and the distance data from Column 1 of the Data Table to calculate your reaction times. Record your reaction time for each trial in seconds (to the nearest thousandth of a second) in Column 2 of the Data Table.

   Formula for calculating reaction time: **$t = 0.0452\sqrt{d}$**

   t = reaction time

   d = distance ruler dropped, in centimeters (cm)

2. Calculate and record your average reaction time for the 10 trials at the bottom of the Data Table.

Table 1. *Reaction Time Test Results*

DISTANCE RULER DROPPED = d (cm)	CALCULATED REACTION TIME $t= 0.0452\sqrt{d}$ (s)

Analysis Questions

Answer these two questions individually using your own reaction time test data:

1. How did your reaction times vary across the 10 trials?

2. What trends, if any, do you see in your reaction times over the 10 trials?

Answer these questions with your partner:

3. List at least 3 factors that might affect someone's reaction time.

4. Identify at least 3 examples of distractions that might increase your visual or auditory reaction time while driving.

Analysis Questions (continued)

5. An individual's reaction time is determined by the actions of several human body systems working together in response to a stimulus and this response occurs in three stages. Analyze Figure 2 below and write a maximum three-sentence description of how sensory organs (such as the eyes), the nervous system, and muscles work together during the reaction time process.

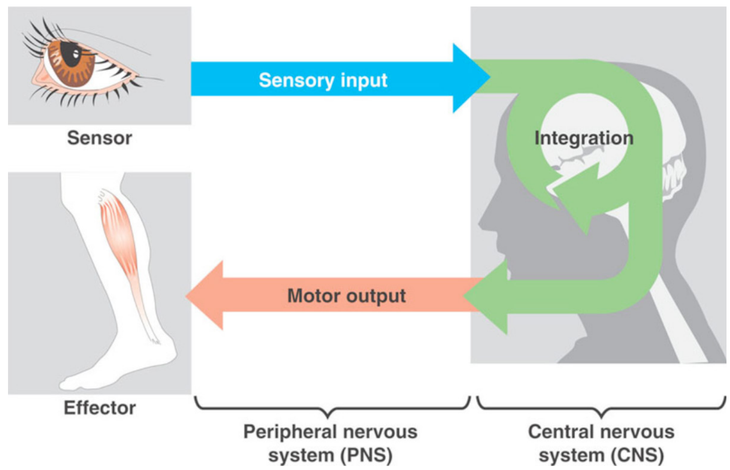


Figure 2. *Campbell N.A., Reece, J.B., BIOLOGY, 7th ed., Pearson Publishing, p.1013.*

Use your own personal average reaction time test result to answer these three questions:

Imagine you are driving straight ahead at a speed of 105 km/hour (65 miles per hour) and an incident forces you to quickly react and step on your brakes. Complete the following calculations to determine how far your vehicle would travel during your personal reaction time. (To simplify the calculation, we will assume that the velocity of your vehicle does not change during the time it takes you to react and hit the brakes). **Show your work in the spaces provided!**

The distance a vehicle will travel during a given reaction time can be found using the following equation:

distance = velocity × time

6. Calculate in meters how far your vehicle would travel during your average reaction time using the following velocity conversion: 105 km/hr = 29 m/s.

Analysis Questions (continued)

1. Calculate in <u>feet</u> how far your vehicle would travel during your average reaction time using the following velocity conversion: 65 mph = 95 ft/s.

2. In general, how might a brief distraction (such as glancing at a cell phone to read a text message) combined with your reaction time affect the distance your vehicle would travel while driving?

TEACHER LESSON PLAN

DISTRACTED DRIVING DANGERS

Key Question(s)

- How do different types of distractions affect the time required to complete a task?
- How can driving while distracted be minimized?

Grade levels: 8–12

Time required: one or two 50-minute class periods (depending on the number of trials completed for each distraction type)

Objectives

Students will:

- list six examples of voluntary driving distractions.
- predict which sensory distractions are the most distractive and least distractive.
- conduct and analyze results of a distracted driving simulation.
- use observations and data to rank driving distractions from most distractive to least distractive.
- develop a precise, one-sentence definition of distracted driving.
- use sample data to calculate how far a car travels while a driver is texting while driving.

*Next Generation Science Standards**

From Molecules to Organisms: Structures and Processes

- MS-LS1-8, 4-LS1-2

Engineering Design

- HS-ETS-1-2

Background Information

Review the background information in the “Think Fast, Act Fast” Teacher Lesson Plan. Distracted driving is a national safety concern. In 2009, 5,474 people were killed in crashes involving driver distraction, and an estimated 448,000 were injured (NHTSA, 2010). As immature and inexperienced drivers, teens are particularly vulnerable to distractions while driving. Teen drivers are three times more likely than other age groups to be involved in a fatal crash (IIHS, 2012). The most recent available data from the Centers for Disease Control and Prevention show motor vehicle collisions kill seven teens every day, making crashes the No. 1 cause of death for U.S. teens ages 13-19 (CDC, 2013). As secondary school teachers, many of us have seen students blindly bump into someone or something while simultaneously trying to text and walk.

While somewhat annoying and possibly harmful in a school hallway, texting and other distracting behaviors can become part of a lethal combination when teens begin driving. To address possible fatal effects of common distracted driving behaviors, this simple simulation activity helps students confront the dangers of distracted driving in the safety of their classroom.

DEFINITIONS

inference: an idea or conclusion that is based on observations and evidence. A greater number of and more detailed observations usually leads to more accurate inferences.

Graduated Driver Licensing (GDL): a system that gradually moves young beginning drivers to full driving privileges over time. GDL introduces young beginners to driving in a low-risk way under supervision, allowing them to become more mature and master their driving skills before receiving full licensure.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

TEACHER LESSON PLAN

DISTRACTED DRIVING DANGERS

MATERIALS NEEDED

Per group of four students

- 1 metric ruler

Per student

- "Distracted Driving Dangers - Student Activity" sheets (4)
- Touch Track #1 sheet (1)
- Touch Track #2 sheet (1)
- Charts 1 & 2 sheet (1)
- Charts 3 & 4 sheet (1)
- Stopwatch (1)
- Visual Distraction materials (e.g., playing cards or magazine photos)
- Auditory Distraction materials (e.g., textbooks, trade books, or novels)
- Manual Distraction materials (e.g., mixture of Chex-Mix and M&Ms or mixture of bolts, washers, and nuts)
- Cognitive Distraction materials (see Chart 3 for Mental-Math problems)
- All of the Above Distraction materials
  - 1 small calculator
  - Calculator-Math problems (see Chart 4)
- Paper bowls for Manual distractors (2)
- Zip-lock plastic bags for distractor materials (4) (e.g., Bag 1-playing cards, Bag 2-Chex-Mix mixture, Bag 3-Mental-Math Problems, and Bag 4-Calculator and Calculator-Math problems)

Supplemental (per class)

- Computer with web access
- Computer projector with speakers

Advance Preparation

- Make group copies of the "Distracted Driving Dangers" Student Activity sheet (1 per student), Touch Tracks #1, #2, Chart 1&2 sheet, and Math Problems 1&2 sheet.
- Gather smaller distractors and sort into small zip-lock bags.
  a. For Visual Distractors, if using playing cards, put 8-10 random cards into a zip-lock bag for each group. If using magazine photos, cut 8-10 photos per group. Laminating photos is suggested.
  b. For Manual Distractors, if using Chex-Mix and M&Ms, pour mixture into zip-lock bags.
  c. For Cognitive Distractors, cut out one set of Mental-Math problems and place in a zip-lock baggie.
  d. For "All of the Above" Distractors, cut out one set of Calculator-Math problems and place each set in a zip-lock bag along with a small calculator. Calculators should be small enough for students to hold with one hand.
- If using Chex-Mix and M&M's, discourage students from eating the mix since previous groups have handled it. If possible, putting aside some fresh mix to give students at the end of the activity is recommended.
- Preview this activity's Introduction and Conclusion videos at classroom.iihs.org/distracted-driving-dangers and decide if you want to incorporate them into the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/distracted-driving-dangers
- Preview and select one of the student-made videos from www.StopTextsStopWrecks.org
  CAUTION - VIEWER DISCRETION IS ADVISED: Select an age-appropriate video after considering your students' unique histories and potential for emotional triggers from distracted driving-related crash trauma.

DISTRACTED DRIVING DANGERS

Procedure

1. Engage students in the topic by showing the student-made public service announcement video you previewed from the "Stop Texts Stop Wrecks" website (see Advance Preparation on the previous page). Inform students that texting is only one example of a driving distraction.

2. Ask the class to describe distracting behaviors that drivers voluntarily engage in while driving (see the list below for examples). Ask a student volunteer to record their classmates' responses on the classroom's whiteboard or chart paper.

   Examples of voluntary driving distractions:

   » Texting
   » Taking selfie photos
   » Checking social media sites
   » Talking on a cell phone
   » Eating and drinking
   » Talking to passengers
   » Combing hair, applying make-up
   » Reading, including maps
   » Using a navigation system
   » Watching videos
   » Adjusting a radio, CD player, or MP3 player

3. Introduce the activity and state the first key question: How do different types of distractions affect the time required to complete a task? Explain that during the lesson students will investigate their ability to conduct a hands-on task while distracted. Optional: Show the activity's Introduction video located at classroom.iihs.org/distracted-driving-dangers

4. With the class list of distracted driving behaviors completed, inform students that traffic safety researchers classify driving distractions into four categories and challenge students to analyze the class list and try to determine the four categories. Then review the four types of distractions and explain that most distracted driving involves at least two or more of these distraction types (combining at least one sensory distraction – visual, auditory, or manual – with a cognitive distraction component).

   Four Categories Of Driving Distractions:

   a. Visual – looking at something other than the road
   b. Auditory – listening to something not related to driving
   c. Manual – manipulating something other than the wheel
   d. Cognitive – thinking about something other than driving

5. Distribute the "Distracted Driving Dangers" student activity sheet to each student. Ask students to answer Items 1 and 2 and record six examples of distracted driving behaviors from the class list and predict which combination of behaviors produces the greatest and the least amount of driving distractions (e.g., greatest = Visual + Cognitive; least = Auditory + Cognitive).

6. Inform students that since your school does not have an actual test track or driving simulator, they need another task that, like driving, also requires their full attention to perform properly. Explain that in this activity their task is to "drive" a Touch Track with their index finger (see Touch Track #1 sheet with numbers 1-10 randomly scattered on the page). To "drive" a Touch Track, students must find and touch each number on the paper track with their dominant hand's index finger in the correct sequence while being timed and checked for accuracy by their lab partners.

Procedure (continued)

7. Divide students into groups of 4 and distribute one Touch Track #1 and one stopwatch to each group. (NOTE: If you do not have enough students for groups of 4 students each, use the modifications described on the worksheets for groups of 3 students). Allow groups five minutes to practice "driving" on Touch Track #1, ensuring they time and record the times for their two practice runs to the nearest hundredth of a second (Item 3). (NOTE: Practicing with Touch Track #1 before conducting the actual investigation with Touch Track #2 allows students to familiarize themselves with the task of touching the numbers in the correct sequence as quickly as possible without giving them the chance to become familiar with the more difficult 25-number Touch Track layout used for the actual investigation.)

8. After the five-minute practice session, announce that it is time to "drive" a different Touch Track. Inform students you will increase the difficulty of the test by requiring them to "drive" on a longer track while one of their group members distracts them.

9. Review the roles for each group member (Chart 1) and the directions for distracting the "Driver" (Chart 2). Explain that students may alternate roles after each trial OR after a Driver completes all of the distractions. (For groups of three, combine the Checker and Timer roles.)

10. Inform the groups that all "Drivers" must first complete Touch Track #2 as quickly as possible without distractions to establish a baseline performance time for later comparison with their distracted driving times. Explain that they must record the times for their baseline and distracted "driving" performance to the hundredth of a second in Table 2. Although averaging "driving" times over multiple trials for each distraction yields more accurate data, if time is limited, have groups conduct only one trial per type of distraction. Another option is to limit the types of distractions investigated.

For example, after groups complete the baseline trial without distractions, groups could only complete one Visual Distraction trial and one All of the Above Distraction trial. (NOTE: To further increase the difficulty of Touch Track #2 and ensure that students do not memorize the layout of Touch Track #2, additional tracks with a different 1-25 layout and/or vertical orientation may be constructed. If small whiteboards and markers are available, students can create their own Touch Tracks as well. Using whiteboards to create the Touch Tracks allows students to easily change the location, color, or size of the 1-25 layout to increase the difficulty or further decrease the chance "drivers" will memorize the course.)

11. Circulate among the groups to ensure that students are performing their roles adequately, remembering to establish baseline performance times without distractions, and recording all performance times to the hundredths of a second on their data sheets. (NOTE: If trial times go over one minute, have students report their time in seconds, not minutes-seconds. As an example: 1 minute and 15 seconds would be recorded as 75 seconds).

12. After completing all trials, have group members work together to answer the three Analysis Questions and the Crash Question. Optional: Show the activity's Conclusion video located at classroom.iihs.org. Then conduct a whole-class discussion addressing these questions (see answers below).

13. Next, ask students to raise their hands if they have ever been in a moving car while the driver used a cell phone in a way that put people in danger and have some students describe their experiences. Compare your class data regarding the percentage of students who have felt endangered by drivers using a cell phone with results from a Pew Research Center survey. This survey found that 40% of American teens say they have been in a car when the driver used a cell phone in a way that put people in danger (Madden, M., & Lenhart, A, 2009).

Procedure (continued)

14. Conclude the lesson with brainstorming and a discussion of individual and group actions students and others can take to reduce distracted driving behaviors. Make sure students realize that ALL types of distractions endanger driver, passenger, and bystander safety.

15. Finally, if possible, conduct a whole-class exploration of the AAA "Tips for Preventing Distracted Driving" website (http://exchange.aaa.com/safety/distracted-driving/tips-for-preventing-distracted-driving/#.WQeGB461tmA) and the Insurance Institute for Highway Safety's website posts regarding distracted driving (http://www.iihs.org/iihs/iihs-website-search?q=distractions)

Answers to Analysis Questions

1. Review your data and rank the three types of sensory distractions from most distracting (longest completion time) to least distracting (shortest completion time). Compare your actual results with your earlier predictions.

Most students find the Auditory distraction the least distracting and the All the Above distraction, simulating texting with the calculator, the most distracting.

2. What are some possible explanations for the ways different types and combinations of distractions affect the driver's ability to complete the Touch Track?

The first three distractions (Visual, Auditory, and Manual) each focus on a single sensory distraction combined with a related cognitive task. For example, in the Visual Distraction your eyes have to look at a picture, then your nervous system has to send a signal to your brain to recall the name of the object and then send another nerve impulse to your mouth to say the name of the item pictured. The fourth distraction (Cognitive) isolates the mental task from a sensory distraction to simulate being "lost in thought" while driving. The fifth distraction (All of the Above) combines all three sensory distractions with a cognitive task which is clearly the most difficult type of distraction to overcome while "driving." The fifth distraction in this activity attempts to replicate the distracting impact of texting while driving.

3. Imagine you are an engineer trying to design an automated in-the-car system to detect distracted driving. As part of the engineering design process you must first clearly define the problem: distracted driving. Work with your team members to create a comprehensive yet brief (one-sentence) definition of distracted driving.

Student answers will vary but you could compare their definitions to those provided by two highway safety organizations. The National Highway Traffic Safety Administration (NHTSA) defines distracted driving as: "any activity that could divert a person's attention away from the primary task of driving." In 2011, the Governors Highway Safety Association stated: "Distracted driving is when a driver voluntarily diverts attention to something not related to driving that uses the driver's eyes, ears, or hands."

TEACHER
LESSON
PLAN

DISTRACTED DRIVING DANGERS

Answer to Crash Question

1. **You are driving a steady 89 km/hr (55 mph) on a highway and you receive a text from a friend. You decide to read the text and text back to your friend while driving. Subtract the time average of your "Without Distraction" trials from the time average of your "All of the Above" Distractions trials to determine the average amount of time sending and receiving a text could distract you and then use this time measurement and your velocity to determine the distance traveled while distracted.**

Sample data for completing Touch Track #2:

Average time for "All the Above" Distraction trials	*= 41.69 s*
- Average time "Without Distractions" trials	*= 30.15 s*
= Time difference due to distraction	*= 11.54 s*

89 km/h = 24.7 m/s (55 mph = 80.7 ft/s)

Assuming the car's velocity remains constant during the time distracted, the distance traveled is equal to the velocity multiplied by the distracted time, d = velocity × time.

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

d = velocity × time

d = 24.7 m/s × 11.54s = 285 meters (d = 80.7 ft/s × 11.54s = 1012 feet)

NOTE: Student results may vary widely. This simulation is intended to convey the real dangers that even simple distractions may bring to driving. Share with students, that according to NHTSA, sending or receiving a text at 55-mph diverts a driver's eyes from the road for an average of 4.6 seconds, the equivalent of driving the length of an entire football field, BLIND!

Extensions

1. Ask students to research their state's policy on issuing driver's licenses. During the 1990s, many states began enacting Graduated Drivers Licensing (GDL) laws for novice drivers. The programs and types of restrictions vary from state to state. Have students enter different values into the IIHS GDL Crash Reduction Calculator (go to classroom.iihs.org/teen-driving-issues/ then scroll down and click on **IIHS GDL Crash Reduction Calculator**) to investigate how varying states' existing GDL laws can change the crash rate of teen drivers.

2. Have students click on the pull-down TOPICS menu at iihs.org and select Advanced Driver Assistance and/or Distracted Driving to further investigate the following countermeasures for preventing distracted driving:

a. Using smartphone applications designed to prevent texting

b. Engineering autonomous vehicles that integrate the following advanced vehicle safety features

- » forward collision warning system
- » adaptive cruise control
- » heads-up displays
- » blind spot monitoring system
- » lane departure prevention
- » autonomous braking
- » drowsiness/fatigue warning

3. Ask students if they think laws banning cell phone use or texting while driving reduce crash risk. Explain that, so far, the laws have not significantly reduced crash risk. The more interesting question is why these laws do not seem to work. Discuss this conundrum of strong predictions not matching actual crash data. Have students read the Overview and Cellphone Laws sections at www.iihs.org/topics/distracted-driving and ask students to explain this disconnect between estimated crashes and real-world data, which indicate that crashes have been holding steady in recent years, even as cellphone use in general and driver use of phones in particular have proliferated.

STUDENT ACTIVITY

Name: ______________________________ Class: ______________ Date: ________________

CRASH SCIENCE IN THE CLASSROOM

DISTRACTED DRIVING DANGERS

MATERIALS NEEDED

For each group of 4 students

» "Distracted Driving Dangers - Student Activity" sheets (4)

» Touch Track #1 sheet (1)

» Touch Track #2 sheet (1)

» Charts 1 & 2 sheet (1)

» Charts 3 & 4 sheet (1)

» Stopwatch (1)

» Distractor Materials

  » Visual Distractors (playing cards or magazine photos)

  » Auditory Distractors (textbook, trade book, or novel)

  » Manual Distractors (Chex-mix and M&Ms or mixture of bolts, washers, and nuts)

  » Paper bowls for Manual distractors (2)

  » Cognitive Distractors (Chart 3 Mental-Math Problems)

  » All of the Above Distractors (Chart 4 Calculator-Math problems and 1 small calculator)

Key Question

» How do different types of distractions affect the time required to complete a task?

» How can driving while distracted be minimized?

Purpose

» To investigate the dangers of distracted driving behaviors in the safety of your classroom

Pre-Activity Discussion

Have you ever witnessed someone blindly bump into somebody or something while trying to text and walk? While somewhat annoying and possibly harmful in a school hallway, this and other distracting behaviors can become part of a lethal combination when driving. As inexperienced drivers, teens are particularly vulnerable to distractions while driving.

Procedure

1. List any 6 examples of voluntary driving distractions.

VOLUNTARY DRIVING DISTRACTIONS	

2. Predict which combination of behaviors produces the greatest and the least amount of driving distraction (For example: Greatest = Visual + Cognitive distraction)

Great amount = ____

Least amount = ____

3. Using a stopwatch, measure the time it takes you to complete two practice runs with Touch Track #1. Record your time to the nearest hundredth of a second in Table 1.

PRACTICE RUN	TIME TO COMPLETE TOUCH TRACK #1 (IN SECONDS)
1	
2	

Table 1. *Data table for Touch Track #1*

STUDENT ACTIVITY

DISTRACTED DRIVING DANGERS

Procedure (continued)

3. Review and agree on role assignments with your group members (see Chart 1 provided by your teacher). You may alternate roles after each trial OR after one "Driver" completes all of the distractions.
4. First, complete Touch Track #2 as quickly as possible without distractions to establish a baseline performance time. Later, you will compare this time with your distracted "driving" times. Record your times to the nearest hundredth of a second in Table 2.

DISTRACTION TYPE	TIME TO COMPLETE TOUCH TRACK #2 (IN SECONDS)*			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE TIME
WITHOUT DISTRACTIONS				
WITH DISTRACTIONS				
Visual				
Auditory				
Manual				
Cognitive				
All of the above				

**Report time in seconds NOT minute/second combinations.*
(For example: 1 minute and 15 seconds would be recorded as 75 seconds.)

Table 2. *Data table for Touch Track #2*

Analysis Questions

1. Review your data and rank the three types of sensory distractions from most distracting (longest completion time) to least distracting (shortest completion time). Compare your actual results with your earlier predictions in item 2.

____

____

2. What are some possible explanations for the ways different types and combinations of distractions affect the driver's ability to complete the Touch Track?

____

____

____

DISTRACTED DRIVING DANGERS

Analysis Questions (continued)

3. Imagine you are an engineer trying to design an automated in-the-car system to detect distracted driving. As part of the engineering design process you must first clearly define the problem: distracted driving. Work with your team members to create a comprehensive yet brief (one-sentence) definition of distracted driving.

Crash Question

1. You are driving a steady 89 km/hr (55 mph) on a highway and you receive a text from a friend. You decide to read the text and text back to your friend while driving. Subtract the time average of your "Without Distraction" trials from the time average of your "All of the Above" Distractions trials to determine the average amount of time sending and receiving a text could distract you and then use this time measurement and your velocity to calculate the distance traveled while distracted. Show your calculations in the box below.

Show your calculations here.

DISTRACTED DRIVING DANGERS

Charts 1 and 2

GROUP MEMBER ROLES*	RESPONSIBILITIES
Driver	Drives the Touch Track by touching all numbers in the correct sequence using the index finger on their dominant hand
Checker	Observes Driver to ensure he/she touches the numbers on the Touch Track in the correct sequence
Timer	Uses stopwatch to measure and record the time it takes the Driver to touch all numbers in the correct sequence
Distractor	Distracts the Driver by following the directions in Chart 2.

For groups of three, combine the Checker and Timer roles

Chart 1. *Group Member Roles*

TYPES OF DRIVING DIRECTIONS	DIRECTIONS FOR DISTRACTING THE DRIVER
Visual = looking at something other than the road	Inform the "Driver" that as they drive the Touch Track you will show them various items. They must look at the item and identify it by name. You will show them a different item every 3-5 seconds until they complete the Touch Track. (Possible items: playing cards or magazine photos).
Auditory = listening to something not related to driving	Inform the "Driver" that as they perform the Touch Track you will read them short sentences or parts of sentences from a book. They must repeat aloud exactly what you read to them.
Manual = manipulating something other than the wheel	Inform the "Driver" that as they perform the Touch Track they will remove uniquely shaped items from one bowl and place them in a second bowl. For example, you may ask them to remove the M&Ms from a bowl filled with a mixture of nuts, pretzels, and M&Ms.
Cognitive = thinking about something other than driving	Inform the "Driver" that as they perform the Touch Track you will ask them to mentally calculate a long addition problem (see Chart 3). They must give you their answer at the end of the problem.
All of the Above = combining Types 1-4	Inform the "Driver" that as they complete the Touch Track with one hand you will ask them to hold a small calculator in the other hand to input a long math problem into the calculator as you read it to them (see Chart 4) and then show their answer.

Chart 2. *Directions for distracting the "Driver"*

DISTRACTED DRIVING DANGERS

Charts 3 and 4

Chart 3. *Mental-Math Problems for Type #4 - Cognitive Distraction*

Directions: Inform the "Driver" that as they perform Touch Track #2 you will ask them to <u>mentally calculate</u> one of the long addition problems below. They must give you their answer at the end of the problem.

MENTAL-MATH PROBLEMS	ANSWERS
1 + 9 + 3 + 8 + 2 + 5 + 6 = ?	34
2 + 10 + 6 + 3 + 2 + 7 + 8 + 2 = ?	40
3 + 3 + 2 + 13 + 3 + 100 + 2 = ?	126
4 + 10 + 7 + 3 + 10 + 50 + 2 = ?	86
5 + 3 + 5 + 2 + 3 + 3 + 2 = ?	23
6 + 15 + 3 + 3 + 3 + 10 + 2 = ?	42
7 + 4 + 5 + 1 + 2 + 6 + 7 = ?	32
8 + 2 + 10 + 6 + 5 + 5 + 7 = ?	43
9 + 9 + 9 + 10 + 10 + 10 + 9 = ?	66

Chart 4. *Calculator-Math Problems for Type #5 - All of the Above Distraction*

Directions: Inform the "Driver" that as they complete Touch Track #2 with one hand you will ask them to hold a small calculator in their other hand and input one of the long math problems below into the <u>calculator</u> as you read the problem to them and then they must show you their answer.

CALCULATOR-MATH PROBLEMS	ANSWERS
1 × 9 + 3 + 8 ÷ 2 + 25 + 6 = ?	41
2 + 10 – 6 ÷ 3 × 2 + 8 + 8 × 2 = ?	40
3 × 3 + 2 + 13 ÷ 3 + 100 + 2 = ?	110
4 + 10 – 7 + 3 × 10 + 50 ÷ 2 = ?	75
5 × 3 + 5 ÷ 2 + 33 – 3 × 2 = ?	80
6 + 15 ÷ 3 + 3 × 9 + 10 ÷ 2 = ?	50
7 × 4 + 5 + 1 + 2 ÷ 6 × 7 = ?	42
8 ÷ 2 + 10 + 6 + 5 ÷ 5 × 7 = ?	35
9 × 9 + 9 + 10 ÷ 10 + 10 + 9 = ?	29

7

9

3

10

6

1

8

5

4

STUDENT ACTIVITY

2

CRASH SCIENCE IN THE CLASSROOM

DISTRACTED DRIVING DANGERS TOUCH TRACK #1

3 21 4 7

9

16 11

5

17 24

25

15

19 12

1

23 14

10

20

18 6

8 22

STUDENT ACTIVITY

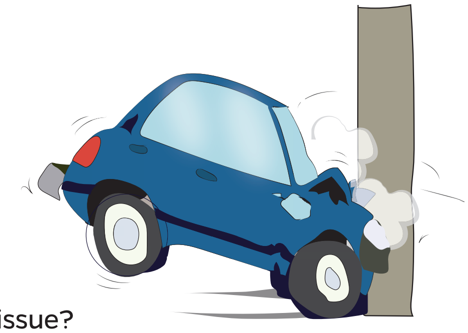
2 13

CRASH SCIENCE IN THE CLASSROOM

DISTRACTED DRIVING DANGERS TOUCH TRACK #2

TEACHER LESSON PLAN

STRESSING SILLY PUTTY



Key Question(s)

- How do crash forces apply stress to human tissue?
- How can stress-testing materials improve crash test dummy performance?

Grade levels: 6–12

Time required: two 50-minute class periods

Objectives

Students will:

- investigate the viscoelastic material behaviors of homemade slime/silly putty.
- construct a graph of the slime's Borax concentration vs. average creep time.
- describe the effect of increasing the slime's Borax concentration on creep time.
- identify three ways crash forces apply stress to human tissue.
- describe how investigating a viscoelastic material's response to stress might improve a crash test dummy's performance.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

- HS-PS2-6, MS-PS2-2, 5-PS2-1

Matter and Its Interactions

- 5-PS1-3, 5-PS1-4

Engineering Design

- HS-ETS1-2

Background Information

The human body is composed of different combinations/amounts of four primary types of tissue: epithelial, muscle, nervous, and connective. The strength of any tissue depends on many factors, including its elasticity; and, depending on these factors, different tissues behave differently when exposed to different types, rates, and durations of stress.

Stress is defined as the average force exerted over a defined area. Stress produces strain. Strain is a measure of the percentage change in an object's shape when it is stressed. In other words, strain describes how much the size and/or shape of a stressed material changes.

Every material, whether it's concrete or human tissue, has a critical stress limit. Stay below that limit and there is no damage or failure. Go beyond a material's critical stress limit and there can be significant damage and/or failure (breakage). Trauma (stress) to a human body part like a bone, heart, brain, or liver resulting from a vehicle crash can lead to its failure just like stress to the concrete in a bridge support resulting from a vehicle crashing into it can cause the entire structure to fail and collapse. Bioengineers study how living biological materials respond to different types of traumatic stress, such as the stresses experienced in a vehicle crash.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS in the classroom homepage.*

DEFINITIONS

creep: The response of a viscoelastic material such as Silly Putty® when a constant stress force is applied.

critical stress limit: the maximum amount of stress a material can withstand before failure (breaking)

strain: a measure of how an object reacts to stress (e.g., how much its shape or size changes when stretched)

strain rate: how fast a material is stretched. Viscoelastic materials are strain rate-dependent.

For example, if you quickly stretch Silly Putty® (with a fast strain rate), then it breaks immediately; yet if you stretch it slowly (with a slow strain rate), it is more elastic and does not break.

stress: the average force exerted over a defined area.

viscoelastic: materials like Silly Putty® that exhibit the characteristics of both a solid and a liquid

STRESSING SILLY PUTTY

Background Information (continued)

In order to better design vehicle safety features, bioengineers must understand the critical stress limits of different human body parts and the critical stress limits of the different tissues making up these body parts.

Many "soft" living tissues and organs are viscoelastic which means they exhibit some of the properties of both solids and liquids. Solids and liquids behave differently when exposed to stress, which can make studying the effects of the stress forces of vehicle crashes on viscoelastic human body parts difficult. Since homemade silly putty is also a viscoelastic material, it can be used to simulate the effects of different stress forces on viscoelastic human tissue.

Consider this question: Is slime/silly putty a solid or a liquid? The answer is: it depends. A solid is a material that has structural rigidity and is resistant to a change in shape. In other words, solids maintain their shapes and do not "flow" easily. A liquid, on the other hand, is a material that easily changes shape and flows to take the shape of its container. Depending on the way stress forces are applied to it, silly putty can behave like a solid or a liquid. For example, if you put a ball of silly putty in a container at room temperature, over time it spreads out to take the shape of its container, like a liquid. However, if you quickly stretch a ball of silly putty, it snaps and breaks into two pieces, like a solid. This type of dual behavior for a material is called viscoelastic material behavior.

Many living and non-living materials exhibit viscoelastic material behavior. They are categorized into two major groups: synthetic (man-made) polymers and natural (biological) polymers. The term polymer is derived from the Greek roots "poly" which means "many" and "mer" which means "parts." On a molecular level, a polymer is a large macromolecule composed of many subunits of the same compound joined together in a chain. Common examples of synthetic polymers include plastics (such as PVC, vinyl, and Styrofoam®), white glue, silicone, and Silly Putty®. Common examples of natural polymers include latex rubber and cellulose fiber from plants, silk produced by spiders, silkworms, and other insects, the wool, hair and fur of mammals, and even all of the DNA and RNA in all living organisms.

The behavior of viscoelastic materials when experiencing stress depends on three major factors: 1. the **amount** of stress force applied, 2. **how fast** a stress force is applied, and 3. **how long** a stress force is applied. Two important terms used when studying the effects of stress on viscoelastic materials are "strain rate" and "creep." Strain rate refers to how fast a viscoelastic material is stretched. For example, if you slowly stretch silly putty (slow strain rate), the material seems to stretch forever, is very pliable, and behaves more like a highly viscous liquid. If you quickly stretch silly putty (fast strain rate), then it breaks immediately. It seems stiff, and behaves more like a solid with little elasticity. This same material has two very different responses to a stress depending on how fast the stress force is applied.

Creep describes how viscoelastic materials change their shape and/or size in response to a constant stress force. An example of creep is when a bungee cord (a polymer) is used to hang a bike from a ceiling. The weight of the bike applies a constant stress force over time, so the bungee cord lengthens (creeps) over time. However, as long as the polymer chain is not broken, once the stress force (weight of the bike) is removed, the bungee cord will shrink back to its original length.

In this activity, students will study strain rate and creep using homemade silly putty. By observing the viscoelastic behavior of silly putty, students can simulate the different ways human many tissues and organs respond to different stress forces. It is recommended that students perform Part 1 (Making and Playing with Silly Putty) on Day 1, discuss the definitions and concepts at the end of Day 1 (or beginning of Day 2), and then complete Part 2 (Measuring Silly Putty Creep) on Day 2.

TEACHER LESSON PLAN

STRESSING SILLY PUTTY

MATERIALS NEEDED

DAY 1

For each group of 3-4 students

- 2 64-ounce (1.8L) plastic containers (such as food containers without lids) for mixing
- 3 small plastic spoons
- 4 teaspoons of Borax in a paper or plastic cup
- Approximately 10 ounces (300 ml) of water in a 12-ounce plastic cup
- 3 2-ounce (60 ml) condiment cups of white glue
- 1 100ml graduated cylinder
- 3 quart-size zipping plastic bags
- 1 permanent marker to label plastic bags
- Soap for cleaning containers and hands
- **OPTIONAL:** Newspapers to work areas or desks

Per student

- 1 “Stressing Silly Putty” Student Activity Sheet
- 1 pair of safety glasses

To share with the entire class

- 1 sample of homemade or store-bought silly putty
- 1 box of Borax® (76-ounces). Borax is the brand name for sodium borate and is available at grocery stores in the detergent section. (See Figure 1).
- 2 to 3 sets of measuring spoons. Have students share the class sets of measuring spoons to measure 1 teaspoon of Borax into one of their plastic spoons and ask them to use this as a reference for other measurements.
- “Stress & Strain” video segment from https://classroom.iihs.org/stressing-silly-putty

MATERIALS NEEDED

DAY 2

For each group of 3-4 students

- Plastic bags of silly putty batches 1, 2, and 3
- One metric ruler
- One stopwatch

Per student

- 1 “Stressing Silly Putty” Student Activity Sheet

Advance Preparation

DAY 1

- Make copies of the student activity sheet and assemble sets of materials for each group. To save time, pre-measure and dispense the four teaspoons of Borax powder, 10 ounces of water, and three 2-ounce containers of white glue for each group.
- Mix up a sample of Batch 1 of homemade silly putty (or purchase a small container of real Silly Putty®) so you can demonstrate the proper technique for applying each of the three types of stress (tensile, shearing, and compression).
- If newspaper is available, cover lab stations with newspapers for easier clean-up.
- Cue up the video segment “Stress & Strain” at classroom.iihs.org/stressing-silly-putty
- Watch the activity’s Introduction and Conclusion videos at classroom.iihs.org/stressing-silly-putty and decide if you want to incorporate them in the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/stressing-silly-putty

DAY 2

- No advance preparation required.

Safety Considerations

Sodium borate (Borax®) is slightly toxic by inhalation and ingestion. Make sure students wear safety glasses and wash their hands thoroughly after handling.

Figure 1. *Borax®*

STRESSING SILLY PUTTY

Procedure - Day 1

1. Introduce the activity by asking students to define the terms "stress" and "strain" in their own words. Students will most likely define these two concepts in terms of emotional or mental tension/worry. Explain that, in this activity, students will be investigating these terms from a more scientific perspective. Next, use background information and the definitions provided to scientifically define the terms "stress" and "strain."
2. Show students the "Stress & Strain" segment from Understanding Car Crashes – When Physics Meets Biology. After the segment, review the equation for stress and the three types of stress:
   a. Equation: Stress = Force ÷ Area
   b. Three types of stress:
      » Tensile or Tensional – stretching
      » Shearing – twisting by opposing forces
      » Compression – uniform pressing
3. Distribute a "Stressing Silly Putty" Student Activity Sheet to each student and review the Key Questions, the Purpose of the Activity, and the Did You Know? information. Optional: Show the activity's Introduction video located at classroom.iihs.org. Review the Procedure for Parts 1 and 2 — Making Homemade Silly Putty and Observing the Properties of Homemade Silly Putty.
4. Divide students into groups and distribute all Day 1 supplies, including safety glasses. Remind students to put on their safety glasses before they begin mixing the ingredients! Also, remind students to closely follow the mixing instructions outlined in the Procedure.
5. Conduct a demonstration of the following techniques BEFORE allowing students to complete Parts 1 and 2:
   a. Show students how to use a consistent technique for measuring out the teaspoons of Borax. Remind them to use one of the class sets of measuring spoons to measure 1 teaspoon of Borax into one of their plastic spoons. They can then use that spoonful as a guide for their other Borax measurements. Demonstrate how to create a level teaspoon by scraping off the excess using the flat edge of a ruler.
   b. Use a sample of homemade or store-bought silly putty to demonstrate how to apply the three different types of stress:
      » Tensile or tensional stress– stretching the silly putty
      » Shearing stress – twisting the silly putty
      » Compression stress – pressing the silly putty between your hands
6. While students are completing Part 1 and making their homemade silly putty, circulate among the groups to ensure that they are following the solution mixing directions closely. It is very important to ensure that the glue and water solution is mixed thoroughly, with no obvious areas of excess water. (Not mixing it thoroughly prolongs the final mixing time of the Borax solution with the glue solution.)
7. Before moving on to Part 2, remind groups to use permanent markers to write their team name on each bag and label each bag's Borax concentrations (low, medium, or high). Also remind them to squeeze as much air as possible out of bags 2 and 3 before setting them aside for Day 2.
8. Once all groups have completed Part 1, made their three batches of silly putty, cleaned up their prep areas, and set batches 2 and 3 aside, allow students 5-10 minutes of open exploration time with Batch 1 of their silly putty before they begin observing its properties and answering the three observation questions as a group.
9. Have groups share their observations and conduct a whole-class discussion of their results for the 3 investigations conducted in Part 2 (strain rate, shape changes, and creep).

STRESSING SILLY PUTTY

Answer Key for Part 2

A. Investigating Strain Rate

Directions: Stretch the silly putty at different rates by grabbing a blob of putty with two hands and pulling it apart in opposite directions at different speeds. Try pulling it apart very slowly and then try again with a quick pull. This is called a strain rate test. The strain rate defines how fast the material is stretched.

Describe your observations and indicate whether the silly putty behaves more like a solid or more like a liquid for each strain rate.

» ***Slow strain rate:*** *If you slowly stretch the silly putty, it is very pliable and seems to stretch forever; it behaves more like a thick liquid.*

» ***Fast Strain rate:*** *If you quickly stretch the silly putty, it breaks immediately, seems stiff, and behaves more like a solid with little elasticity*

B. Investigating Shape Changes

Directions: Roll a small piece of silly putty into a ball (about the size of a large marble or a malted milk ball) and let the ball sit on a table for 1 minute.

Describe your observations and indicate whether the silly putty behaves more like a solid or more like a liquid while rolling it into a ball and then after it has been sitting on the table for 1 minute.

» ***While rolling it into a ball:*** *You can hold the silly putty without a container and use your hands to mold it into different shapes, like a soft solid.*

» ***After sitting for 1 minute:*** *Over time, the ball of silly putty on the tabletop does not maintain its original shape and starts to spread out, like a thick liquid.*

C. Investigating Creep

Directions: Roll the silly putty into a cylinder shape and hold one end of it vertically above the table top. This stretching by a constant force (in this case, the constant force is the pull of gravity) is called **creep**.

Describe your observations while you hold the cylinder of silly putty above the table and indicate whether it behaves more like a solid or more like a liquid.
While holding a cylinder of silly putty by one end, the silly putty slowly stretches and elongates from its own weight. It behaves like either a soft solid or a thick liquid.

10. Conclude DAY 1 with a review and discussion of pertinent background information regarding viscoelastic materials and their properties. Collect all groups' three labeled bags of silly putty (make sure they are tightly sealed) and collect all activity sheets. Store the silly putty bags in a secure, dry, room-temperature location overnight.

STRESSING SILLY PUTTY

Procedure - Day 2

1. Review the three types of stress discussed on Day 1 (tensile, shearing, and compression) and explain that today's lesson will focus on investigating how each of their three different batches of silly putty responds to one of these types of stress (tensile stress) which often affects the tissues and organs of occupants in a vehicle crash.
2. Using pertinent background information, remind students that many "soft" human tissues and organs are composed of different types of viscoelastic materials whose responses to different stress forces are similar to the responses of silly putty made with different concentrations of Borax solution. Explain that, in order to accurately measure the impacts of the stress forces experienced by occupants in a vehicle crash, bioengineers build crash test dummies made of synthetic materials with properties as similar to human tissues and organs as possible. In addition, make sure students realize that bioengineers also need to be able to measure the critical stress limits of human body parts in order to better design vehicle safety features.
3. Explain that in this activity students will investigate each batch of silly putty's response to tensile stress by measuring the time it takes a cylinder-shaped lump of putty (whose bottom is held 20 cm above the table) to stretch downward (stretching on its own due to the force of gravity) and touch the table. Remind students that they observed this type of creep (the stretching produced by a constant stress force) on Day 1.
4. If necessary, review the definitions of independent (manipulated) and dependent (responding) variables and the procedure for creating a line graph and drawing a best-fit line.
5. Re-distribute each group's three bags of silly putty and their Student Activity Sheets and give each group a stopwatch and a metric ruler.
6. Review the Procedure for **Part 3 – Measuring Homemade Silly Putty Creep** and the roles for each group member (Chart 1).

ROLE	DESCRIPTION
1	Putty Manager: Forms the cylinder (4 cm diameter) and holds the silly putty at the same height above the table (bottom of cylinder starting height of 20 cm above the table) for each trial
2	Measurer: Holds the ruler and checks the diameter of each cylinder and monitors the height of the silly putty above the table for each trial
3	Timer: Operates the stopwatch
4	Recorder: Records data (If working in groups of three, assign this role to everyone in the group.)

7. Tell students that it is very important that the diameter and shape of the silly putty be consistent for each trial. To ensure this consistency across trials, instruct students to make their cylinders the SAME DIAMETER each time. An ideal diameter for this activity is 4 cm. This can be checked by simply holding the cylinder vertically above the ruler between the 0 and 4 cm marks. If the silly putty is not formed into a uniform diameter cross-section cylinder and held in the same way for every trial, the results will have a lot of variability and error. Encourage students to hold the putty cylinders as stationary as possible until the silly putty stretches the full 20 cm to touch the table.
8. Circulate among the groups to ensure that students are performing their roles, using a consistent and correct procedure for each trial, and are correctly recording data in their data tables.

9. After all groups have completed their "creep" tests and recorded all data in their data tables, have students clean up their work areas and put all of their supplies away. Review the Procedure for **Part 4 – Analyzing Creep Test Results and Drawing Conclusions**. Instruct students to work with their group members to answer the questions and complete the tasks in Part 4. Optional: Show the activity's Conclusion video located at classroom.iihs.org.
10. Conclude the lesson with a whole-class discussion addressing student responses to the analysis questions and have students share and compare their completed graphs and best fit lines. (Answers to questions and a sample line graph are included below).

Answer Key to Part 4

1. **Looking at your creep test data, do you see a large or a small variation in the time it took each batch of silly putty to fall to the table during the three trials? If you have a large variation in the creep times for a particular batch, what factors could have caused this?**

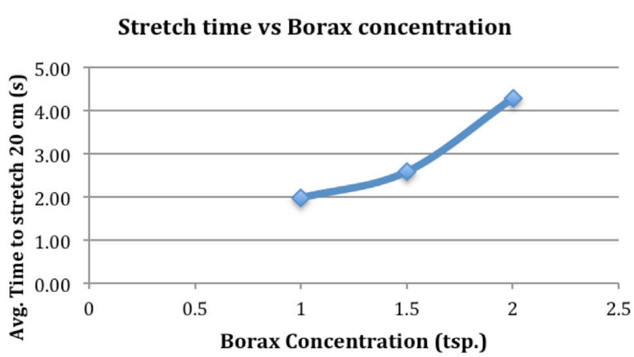
   Variations in creep time for three trials using one batch should be small. If groups have a large variation in creep time for a particular batch, it is most likely the result of human experimental error. Error may have been introduced if the silly putty was not shaped into a uniform cross-section cylinder each time or if the cylinder did not have the same diameter each time. Additional sources of error include not holding the cylinder at the same height above the table for each trial or not holding the cylinder stationary while waiting for the sample to creep 20 cm. Finally, reaction time delays or other errors associated with the starting and stopping of the stopwatch during each trial sometimes occur.

2. **Use the data from your Data Table to construct a line graph comparing Borax concentration and creep time results. Borax concentration levels in teaspoons should be on the x-axis and average creep time in seconds should be on the y-axis. After plotting your data points, draw a best-fit line indicating the relationship between these two variables.**

   Title – Average Creep Time vs. Borax Concentration Levels

   Independent variable (x axis) – Borax concentration level (teaspoons)

   Dependent variable (y axis) –Average Creep time (seconds)



3. **Analyze the graph and describe the relationship between the variables in one sentence.**

   As the concentration of Borax increased, the average creep time of the silly putty increased.

   OR

   Average creep time of the silly putty increased as Borax concentration levels increased.

STRESSING SILLY PUTTY

1. **As a review, name and describe three ways crash forces apply stress to human tissue.**

   Crash forces can apply stress in the following three ways:

   » *Tensile or tensional stress– stretching tissue*

   » *Shearing stress – twisting tissue*

   » *Compression stress – pressing the tissue between at least two surfaces*

2. **The human body is composed of both viscoelastic materials and a variety of other materials, including solids, such as bones, and liquids, such as blood. In your own words, explain how conducting stress tests on a variety of man-made materials (including viscoelastic materials, solids, and liquids) can help bioengineers design better crash test dummies.**

   Bioengineers can conduct tensile, shearing, and compression stress tests on a variety of man-made materials to determine which synthetic materials behave the most like human tissues and organs. Once they have found the man-made materials that behave the most like human tissues and organs and have critical stress limits that closely match those of their human body counterparts, they can use these materials to construct components of crash test dummies that mimic the behaviors/responses of key areas of the human body that are most at risk of injury in crashes (e.g., the skull, neck, ribs/sternum, pelvis, and legs).

   If time permits, provide the following additional information: *Crash test dummies are constructed using several different types of materials including aluminum, steel, and many types of viscoelastic plastics). The dummies are loaded with sensors that record a variety of measurements in and on the dummy's body during a crash test, including stress forces and the amount of resulting strain (distortion of body parts). The ability of crash test dummies to mimic the human body's response to crash forces and the dummy's ability to accurately measure the impacts of these crash forces on different parts of the body is called biofidelity. Crash test dummies with higher biofidelity are better at accurately predicting the risk of injury in crashes.*

Extensions

For chemistry students or other students interested in knowing WHY/HOW homemade silly putty composed of different concentrations of Borax behaves differently in the creep test (Part 4), discuss the following information:

White glue is an example of an elastic polymer made up of very long chains of molecules (polyvinyl acetate). These chains slowly slide past one another enabling the glue to be squeezed out of the bottle or slowly poured in a long stream. When Borax solution is added to the glue, it makes it "stiffer." Why?

The very long polymer strands in glue, on their own, don't stick to each other which allows them to flow freely. However, when Borax solution is added, the borate ions of the Borax solution form cross-links between the molecules of the glue. These cross links connect the individual long polymer strands in the glue together along their sides, making it harder for the polymer chains to flow, stretch, and move. The more Borax added, the more cross links created, and the stiffer the silly putty.

Find additional teaching resources for exploring stress and strain in the context of engineering at www.TeachEngineering.org. TeachEngineering is a searchable, web-based digital library collection of standards-based engineering curricula for K-12 educators designed to make applied science and math come alive through engineering design. The TeachEngineering collection provides educators with free access to a growing curricular resource of activities, lessons, units, sprinkles and maker challenges.

TeachEngineering STEM curriculum for k-12

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

STRESSING SILLY PUTTY

Key Question

- How do crash forces apply stress to human tissue?
- How can stress-testing materials improve crash test dummy performance?

Purpose

- To investigate how different types of homemade slime/silly putty (simulated human tissue) respond to different types of stress forces

Did You Know?

Every material, whether it's concrete or a human tissue or organ, has a critical stress limit. Stay below the limit and there is no damage or failure. Go beyond a material's critical stress limit and there can be significant damage and/or failure (breakage). Trauma (stress) to human body parts including bones, tendons, ligaments, and organs like the heart, brain, or liver from a vehicle crash can lead to its failure just like stress to the concrete in a bridge support resulting from a vehicle crashing into it can cause the entire structure to fail and collapse.

Bioengineers study how human body parts, including bones, tissues, and organs, respond to different types of traumatic stress, such as the stresses experienced in a vehicle crash. In order to design more effective vehicle safety features and better protect the human body from the harmful effects of stress forces resulting from vehicle crashes, bioengineers must understand the critical stress limits of different human body parts. Since living human beings are not used in crash tests, crash test dummies made from synthetic materials must be used instead. When stressed, many man-made materials react in ways that are very similar to human body parts. A man-made material that behaves the same way many soft human tissues and organs behave when stressed is Silly Putty®. In this activity, you will investigate how different types of homemade slime/silly putty react to different stress forces to better understand how bioengineers design more realistic crash test dummies.

Procedure - Day 1

Part 1 — Making Homemade Silly Putty

1. If newspaper is provided, cover your work area with newspaper first. Lay out all of your group's Day 1 supplies and use two small pieces of scrap paper to make labels to place in front of each container. Label one container "Container 1-Borax Solution" and the other "Container 2-Glue Solution."
2. Make sure everyone is wearing their safety glasses and follow the instructions below to make three different batches of silly putty with different concentrations of Borax (low, medium, and high). Refer closely to Tables 1 and 2 and measure out all ingredients as precisely as possible when making the Borax and glue solutions.
3. In Container 1, make Batch 1 – Low Borax concentration solution by mixing 30 ml of water with ½ teaspoon of Borax. Stir well for 30-60 seconds. HINT: Use the class set of measuring spoons to measure 1 teaspoon of Borax into your plastic spoon. Then use this as a reference for your other measurements.

MATERIALS NEEDED

DAY 1

For each group of 3-4 students

- 2 64-ounce (1.8L) plastic containers (such as storage containers without lids) for mixing
- 3 small plastic spoons
- 4 teaspoons of Borax powder in a small paper or plastic cup
- Approximately 10 ounces (300 ml) of water in a 12-ounce plastic cup
- 3 2-ounce (60 ml) condiment cups of white glue
- 1 100ml graduated cylinder
- 2 quart-size zipping plastic bags
- 1 permanent marker to label plastic bags
- Soap for cleaning
- **OPTIONAL:** Newspapers to work areas or desks

Per student

- 1 "Stressing Silly Putty" Student Activity Sheet
- 1 pair of safety glasses

STUDENT ACTIVITY

STRESSING SILLY PUTTY

MATERIALS NEEDED

DAY 2

For each group of 3-4 students

- Plastic bags of homemade silly putty batches 1, 2, and 3
- 1 metric ruler
- 1 stopwatch
- **OPTIONAL:** One sheet of graph paper

Per student

- 1 "Stressing Silly Putty" Student Activity Sheet

CONTAINER #1 - BORAX SOLUTION			
BATCH NUMBER	BORAX CONCENTRATION	BORAX AMOUNT	WATER AMOUNT
1	*Low*	*1/2 tsp*	*30ml*
2	*Medium*	*1 tsp*	*30ml*
3	*High*	*2 tsp*	*30ml*

CONTAINER #2 - GLUE SOLUTION	
GLUE AMOUNT (FILL 2OZ CLEAR CUP)	WATER AMOUNT
2ounces (60ml)	*60ml*
2ounces	*60ml*
2 ounces	*60ml*

Procedure - Day 1 (continued)

Tables 1 & 2 - Container #1 and Container #2 Solutions

1. In Container 2, make one batch of glue solution by first pouring in the 2 ounces of white glue from one of the condiment cups and then using the graduated cylinder to measure out 60 ml of water. Slowly pour the water into the container with the glue and use one plastic spoon to stir the glue and water together for 60 seconds until you have a uniform consistency and color. **It is important that this solution is uniform, with no areas of excess water, or it prolongs the mixing time in Step 5.**
2. After mixing the glue and water thoroughly, continue stirring the glue mixture and slowly pour the Borax solution from Container 1 into the glue solution in Container 2. Be sure that all of the Borax mixture is transferred into Container 2.
3. When the solution starts to thicken, mix it with your hands instead of the spoon. Continue to mix until a uniform solution is achieved and NO water is present.
4. Store this first batch of silly putty in a zip-lock plastic bag and use the permanent marker to write your team name and Low concentration on the bag. Squeeze all of the air out of the plastic bag before sealing it.
5. Thoroughly clean your hands and both containers with soap and water and discard the spoon.
6. Use the same procedure described in steps 3 through 8 above to make two more batches of silly putty, using 1 teaspoon of Borax (Medium concentration) for Batch 2 and 2 teaspoons of Borax (High concentration) for Batch 3. Make sure all three plastic bags of silly putty are labeled with the Borax concentration level and your team name and that the aire has been squeezed out of each bag.
7. Once all three batches of silly putty have been made, clean up your work area and set aside the silly putty bags containing batches 2 and 3 for use on Day 2. You only need to keep batch 1 for Part 2!

STUDENT ACTIVITY

STRESSING SILLY PUTTY

Procedure - Day 1 (continued)

Part 2 — Observing the Properties of Homemade Silly Putty

1. Before making any formal observations of specific properties of your silly putty, make sure each member of your group is able to spend a few minutes handling and playing with the silly putty to get a sense of how it feels and behaves. Your teacher will tell you when to move on to step 2 and work with your group members
2. Complete the following three "tests" to learn more about the specific properties of your silly putty and record your observations and responses in the spaces below each item.

A. Investigating Strain Rate

Directions: Stretch the silly putty at different rates by grabbing a blob of putty with two hands and pulling it apart in opposite directions at different speeds. Try pulling it apart very slowly and then try again with a quick pull. This is called a strain rate test. The strain rate defines how fast the material is stretched.

Describe your observations and indicate whether the silly putty behaves more like a solid or more like a liquid for each strain rate.

Slow strain rate:

Fast Strain rate:

B. Investigating Shape Changes

Directions: Roll a small piece of silly putty into a ball (about the size of a large marble or a malted milk ball) and let the ball sit on a table for 1 minute.

Describe your observations and indicate whether the silly putty behaves more like a solid or more like a liquid while rolling it into a ball and then after it has been sitting on the table for 1 minute.

While rolling it into a ball:

After sitting for 1 minute:

C. Investigating Creep

Directions: Roll the silly putty into a cylinder shape and hold one end of it vertically above the table top. This stretching by a constant force (in this case, the constant force is the pull of gravity) is called creep.

Describe your observations while you hold the cylinder of silly putty above the table and indicate whether it behaves more like a solid or more like a liquid.

STUDENT ACTIVITY

STRESSING SILLY PUTTY

Procedure - Day 2

Part 3 — Measuring Homemade Silly Putty Creep

1. Make sure your group has their 3 bags of silly putty and Student Activity Sheets from Day 1 as well as a ruler and a stopwatch.

2. Review the following group member roles and determine who is performing each role.

ROLE	DESCRIPTION
1	Putty Manager: Forms the cylinder (4 cm diameter) and holds the silly putty at the same height above the table (bottom of cylinder starting height of 20 cm above the table) for each trial
2	Measurer: Holds the ruler and checks the diameter of each cylinder and monitors the height of the silly putty above the table for each trial
3	Timer: Operates the stopwatch
4	Recorder: Records data (If working in groups of three, assign this role to everyone in the group.)

Note: It is very important that the diameter and shape of the putty be consistent for each trial and that each putty cylinder is held at exactly the same height above the table throughout each trial.

3. Follow this procedure for EACH trial:

a. The Putty Manager should form the silly putty into a 4 cm diameter uniform cylinder and have the Measurer check the diameter using the ruler.

b. The Measurer should then hold the ruler vertically so that the "0 cm" mark touches the top of the table.

c. The Putty Manager should hold the top and bottom ends of the silly putty cylinder vertically with two fingers of one handing holding the top and two fingers of the other hand holding the bottom so that the bottom of the silly putty cylinder is positioned exactly 20 cm above the table.

d. While still holding the top of the cylinder with 2 fingers, the Putty Manager should remove his/her other two fingers from the bottom of the putty while the Timer immediately starts the stopwatch. The Putty Manager needs to keep the hand holding the silly putty stationary and at the same height until the silly putty touches the table and the Timer should stop the stopwatch as soon as the bottom of the putty cylinder touches the tabletop.

e. The Recorder should record this time (creep time) on the Data Table.

4. Repeat this Procedure (a. through e.) with the same silly putty batch two more times and record the creep times for all three trials in the Data Table.

5. Write a descriptive title for your data table and identify the independent and dependent variables in the spaces provided. Be sure to include the units of measurement for each variable.

6. Follow the creep test procedure outlined above for the other two batches of silly putty and record all creep times in the Data Table.

STRESSING SILLY PUTTY

Table 3 - Title:

MY INDEPENDENT VARIABLE IS	MY DEPENDENT VARIABLE IS:			
	TRIAL #1	TRIAL #2	TRIAL #3	AVG. OF TRIALS

Part 4 — Analyzing Creep Test Results and Drawing Conclusions

Work with your group members to answer the following questions and complete the following tasks:

1. Looking at your creep test data, do you see a large or a small variation in the time it took each batch of silly putty to fall to the table during the three trials? If you have a large variation in the creep times for a particular batch, what factors could have caused this?

2. Use the data from your Data Table to construct a line graph comparing Borax concentration and creep time results. Borax concentration levels in teaspoons should be on the x-axis and average creep time in seconds should be on the y-axis. After plotting your data points, draw a best-fit line indicating the relationship between these two variables.

STUDENT ACTIVITY

CRASH SCIENCE IN THE CLASSROOM

STRESSING SILLY PUTTY

Title: ____

3. Analyze the graph and describe the relationship between the variables in one sentence.

____

____

4. As a review, name and describe three ways crash forces apply stress to human tissue.

____

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5. The human body is composed of both viscoelastic materials and a variety of other materials, including solids, such as bones, and liquids, such as blood. In your own words, explain how conducting stress tests on a variety of man-made materials (including viscoelastic materials, solids, and liquids) can help bioengineers design better crash test dummies.

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TEACHER LESSON PLAN

STRESSING OVER PENCIL PRESSURE

Key Question(s)

» How can magicians lay on a bed of sharp nails unharmed? Is it magic or science?

» Why is an understanding of force, pressure, and stress important when designing strong, safe vehicles?

Grade levels: 8–12

Time required: 50 minutes

Objectives

Students will:

» measure the diameter of the two different ends of a mechanical pencil.

» calculate the radius, surface area and resulting pressure from different ends of a mechanical pencil.

» explain the relationship between force and pressure.

» given the same applied force, describe the relationship between surface area and pressure.

» explain how engineers differentiate between pressure and stress.

» describe how the concepts of force, pressure, and stress are relevant when designing strong and safe vehicles.

*Next Generation Science Standards**

Engineering Design

» HS-ETS1-2

Background Information

Force vs. Pressure – The concepts of force and pressure are closely related but they are not the same thing. Force is a push or pull that can accelerate a mass and is measured in Newtons (N). Examples of forces include your finger exerting a force to push a coffee mug across a table or your finger exerting a force to pull a coffee mug across a table. Pressure is a measure of the amount of force applied over a given surface area and is measured in Newtons per square meter (also known as Pascals (Pa). The equation for pressure is: P = F ÷ A or P = F/A where

» P = Pressure (N/m^2 or Pa)

» F = The force applied to the surface (N)

» A = The area of the surface (m^2)

Increasing the surface area over which a given force is applied reduces the overall pressure on a material while decreasing the surface area over which a given force is applied increases the overall pressure on a material. Consider the different results that occur when a person stands on a trampoline vs. when a person lays down on a trampoline.

DEFINITIONS

force: a push or pull that can cause a mass to accelerate, measured in Newtons (N)

pressure: the amount of force applied over a given surface area; P = F/A.

stress: the average internal force applied per unit of cross-sectional area of a material;
σ = stress = F/A

stress test: applying pressure to stress a material until it fails

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

TEACHER LESSON PLAN

STRESSING OVER PENCIL PRESSURE

MATERIALS NEEDED

Per pair of students

- One mechanical pencil with lead and an eraser (with the lead diameter written on the pencil)
- One metric ruler with millimeters marked

Per Student

- One "Stressing over Pencil Pressure" Student Activity Sheet
- One calculator
- **OPTIONAL**: One sheet of notebook paper

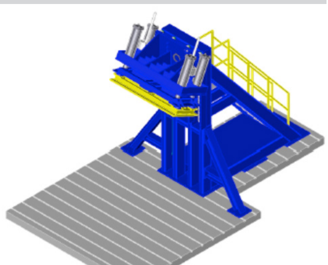

Figure 1.
Roof Crush Test System

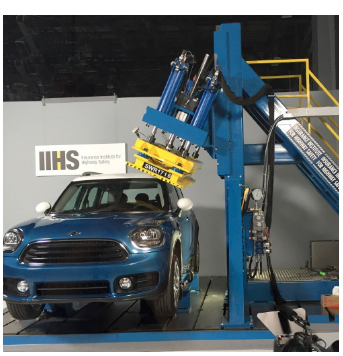

Figure 2.
IIHS Roof Strength Test

Background Information (continued)

A person standing on a trampoline concentrates his/her entire weight (force) over a small surface area and sinks down deeper into the trampoline compared to a person lying down on a trampoline who distributes his/her entire weight over a larger surface area, and thus does not sink down as far. In both instances, the force applied (weight of person) is the same, but the pressure on the trampoline is different.

Pressure vs. Stress – The concepts of pressure and stress are also closely related. Both measure the amount of force applied over a given surface area and both have the same formula (P=F/A) and SI units (Pascals, PA). However, pressure and stress are applied in different locations on a given material. Pressure refers to the external force applied over a given surface area of a material. Applying pressure on the outside of a material causes stress inside the material. Thus, stress refers to the internal force applied over a cross-sectional area within a material. Using the trampoline example, the person on the trampoline is applying pressure to the external surface of the trampoline. This creates stress within the fabric of the trampoline. The greater the external pressure exerted on a material, the greater the internal stress.

How do engineers test the strength of materials?

One of the ultimate goals of mechanical and civil engineers is to design safe structures that are strong enough to withstand a wide variety of external forces such as wind, earthquakes, or collision (impact) forces. Whether designing bridges or vehicles, engineers help to ensure the safety of structures by analyzing the strength of their component parts (e.g., a bridge support pillar or the bumper of a car). One method used to test the strength of structural components is a stress test. In stress tests, pressure is applied to the outside of a component to create stress inside the component until the component reaches its stress limit and fails (i.e., breaks, fractures, crumbles, or deforms excessively).

How does the IIHS test the strength of a vehicle's roof?

The IIHS conducts stress tests on vehicle roofs to rate their strength. Strong roofs maintain their shape and do not cave inward when they collide with the ground or another vehicle during a rollover. Stronger roofs crush less, reducing the risk that people will be injured by contact with the roof or ejection from a rolling vehicle through windows, windshields or doors that break or open when roofs collapse. In the IIHS Roof Strength Test, the strength of a vehicle's roof is tested by applying pressure created by a large 1.8 m x 0.76 m (6 ft. x 2.5 ft.) metal plate pushing against one side of the roof at a slow, constant speed (see Figures 1-2). A good rating requires the roof to withstand a force of at least four times the vehicle's weight before the roof is crushed inward 12.7 cm (5 inches).

TEACHER LESSON PLAN

CRASH SCIENCE IN THE CLASSROOM

STRESSING OVER PENCIL PRESSURE

Advance Preparation

- Make copies of the student activity sheet and assemble sets of materials for each group.
- Cue up the bed-of-nails portion of the video segment “Force and Pressure” at https://classroom.iihs.org/stressing-over-pencil-pressure
- Watch the activity’s Introduction and Conclusion videos at classroom.iihs.org/stressing-over-pencil-pressure and decide if you want to incorporate them into the lesson.
- For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/stressing-over-pencil-pressure

Safety Considerations

- When conducting the activity, students should briefly and gently press the pencil between their palms or the index fingers of their left and right hands (see Figures 1 and 2 on the student activity sheet). And, students should only test themselves; they cannot use their pencils to test other students.

Procedure

1. Initiate the activity by asking the first Key Question: “How do magicians lay on a bed of nails unharmed? Is it magic or science?” Ask students how they think someone can lay on a bed of nails containing hundreds of sharp nails without having the nails puncture their skin. Inform students that in this activity they will use mechanical pencils to conduct tests similar to a bed-of-nails demonstration on a smaller scale.
2. Divide students into pairs and distribute copies of the “Stressing Over Pencil Pressure” student activity sheets and calculators to each student and distribute the mechanical pencils and metric rulers to each pair of students. Refer to the activity sheet and review the Key Questions, the Purpose of the activity, and the Did You Know? information. Optional: Show the activity’s Introduction video located at classroom.iihs.org.
3. Review the Procedure for Parts 1 and 2 of the activity, refer to Figures 1 and 2 on the activity sheet, and demonstrate how to safely press the pencil between your palms or between your left and right index fingers. Review the following Safety Considerations:
   a. Students should gently and briefly press the pencil between their palms or fingers for 3 seconds. During this time, they should try to apply an equal force to each end of the the pencil with each hand by holding their hands or fingers steady so the pencil remains stationary (and does not move to the left or to the right).
   b. Students should only press the pencil between their own palms or index fingers. They should not use their pencils to conduct tests on others.
4. Have students complete Parts 1 and 2 and record their observations and inferences. Then have students share their observations. Review or make a class list of the useful adjectives students used when making their observations in Part 1 (such as sharp, pointed, intense, spiky, soft, blunt, dulled, rounded).
5. Next, ask for a show of hands of students who thought the forces applied at each end of the pencil were the same and those who thought the forces applied at each end were different. After students have had a chance to explain the reasoning behind their responses in Part 2, explain that each end of the pencil applied the same amount of force to their palms or fingers. Most students will be surprised by this fact! Explain that, when the pencil was pressed between their two palms or fingers and kept stationary, one hand was applying a force to the right, and the other hand was applying a force to the left. However, we know the pencil was not moving, so it did not accelerate in any direction.

Procedure (continued)

Therefore, according to Newton's Second Law of Motion, there was no net force acting on the pencil (in other words, the forces were balanced). Ask the students how can two forces combine to give zero total force. The only way two forces can cancel is if the two forces are equal in magnitude (strength) and opposite in direction. So now we know the strength of the forces pushing on each end of the pencil were the same. What about the forces acting on each hand? By Newton's Third Law, these forces are action/reaction forces.
Whatever force one hand exerts on the pencil, the pencil exerts back on that hand with the same strength. So since the two forces pushing on each end of the pencil were the same strength, we now know the forces acting back on each hand also had to have the same magnitude. Ultimately, the force applied to one hand or finger by the eraser end is the same strength as the force applied by the pencil lead end.

6. Pose this next question to the class: If the forces applied at each end of the pencil were the same, why did the two ends of the pencil feel so different when held between your palms or fingers? Based on their sense of touch used in the pencil stress test, most students will claim that the "sharp, pointy" lead hurts or "presses down" more than the "soft, blunt" eraser. Using the background information provided regarding force and pressure, lead students to the realization that the differences they perceived were due to differences in the pressure applied by each end of the pencil and make sure students understand that pressure is a measure of the amount of force exerted over a given surface area. The lead has less surface area than the eraser; thus, even though equal forces are applied at each end of the pencil, the lead exerts more pressure on your skin than the eraser.

7. Explain that the next phase of the activity will focus on using pencil measurements to calculate the radius and cross-sectional surface area of the lead and the eraser as well as the amount of pressure exerted by these two ends of the pencil. Review the Procedure for Parts 3 and 4 of the activity and the equations for calculating radius, surface area, and pressure. Remind students to show their calculations in the margins of the student activity sheet or on a separate sheet of notebook paper.

8. Circulate and assist groups as needed. After all groups have completed their calculations, check each group's measurements and calculations. See sample data below.

   - Part 3-Diameter measurements:
     - Eraser diameter = 6 mm
     - Lead diameter = 0.5 mm
   - Part 4-Radius calculations in millimeters:
     - Eraser radius = 3 mm
     - Lead radius = 0.25 mm
   - Part 4-Radius calculations in meters:
     - Eraser radius = 0.003 m
     - Lead radius = 0.00025 m
   - Part 4-Cross-sectional surface area calculations:
     - Eraser area = 0.000028 m^2 = 2.8 x 10^{-5} m^2
     - Lead area = 0.00000020 m^2 = 2.0 x 10^{-7} m^2
   - Part 4. Pressure calculations:
     - Eraser pressure = 18,000 Pa = 1.8 x 10^4 Pa
     - Lead pressure = 2,500,000 Pa = 2.5 x 10^6 Pa

9. Review the Procedure for Part 5 of the activity and instruct each pair of students to develop two general conclusions to share. Optional: Show the activity's Conclusion video. Conduct a whole-class discussion of the paragraphs provided and have pairs share their conclusions. Students should be able to draw the following two general conclusions:

STRESSING OVER PENCIL PRESSURE*

Procedure (continued)

  a. Pressure and stress are calculated using the same equation, F÷A. But when calculating pressure, engineers or scientists are concerned with the outside force applied to the surface of a material. When calculating stress, they focus on the internal force applied over the cross-sectional area of the material.
  b. Engineers use stress tests to determine the strength of individual structural components by applying pressure to the outside of the component to create stress inside the component until it reaches its critical stress limit and fails (i.e., breaks, fractures, crumbles, or deforms excessively).

10. Next, ask students to work collaboratively with their partner to answer the Analysis Questions and conduct a whole-class discussion of their responses. If necessary, review the definitions of force, pressure, and stress and make sure students understand that, for a given amount of force, the smaller the surface area the greater the pressure (and stress) produced. If needed, draw comparisons to common everyday experiences involving the relationships between pressure, stress, and surface area using any or all of the following additional questions:

  a. "What would hurt more: someone stepping on your foot with high heels or tennis shoes? Why?" (Answer: High heels exert more pressure, thus they would hurt more and potentially result in more stress to your skin and other tissues).
  b. "Why would high heels produce more pressure" (Answer: They have a smaller surface area than tennis shoes).
  c. "Why is it better to lay flat on thin ice rather than standing on thin ice?" (Answer: Laying flat reduces the pressure exerted on the sheet of ice by increasing the surface area across which the force, i.e., the weight of your body, is exerted. With lower external pressure there is less risk that the ice will reach its critical stress limit and "fail" by cracking or breaking.)

11. Revisit Key Question 1 asked at the beginning of the lesson: How can magicians lay on a bed of sharp nails unharmed? Is it magic or science? Show the bed-of-nails portion of the video segment "Force & Pressure" from Understanding Car Crashes – When Physics Meets Biology and ask students to answer the question. (Answer: Since your weight is spread across a large surface area rather than being concentrated in one spot, the resulting pressure exerted on any individual nail is not enough to break the skin.)

12. Inform students that thousands of people are killed each year in rollovers and review the following information: One of the safety features used to protect occupants in a rollover is the roof. A second rollover safety feature is electronic stability control. Electronic stability control is a computerized technology that improves a vehicle's stability by detecting and reducing the loss of traction. While electronic stability control is designed to prevent rollovers, vehicle roofs must be strong enough to protect occupants if a rollover actually occurs. Strong vehicle roof structures are critical in order to protect occupants in a rollover.

13. Then use the background information provided to explain how the IIHS conducts Roof Strength Tests and develops ratings. Make sure students understand that the Roof Strength Test is an example of a real-world test that measures force, pressure, and stress to determine the overall strength of a structure. Conclude the lesson by encouraging students to visit www.iihs.org and search "roof strength test" to watch an actual test and explore the Roof Strength Test ratings of different vehicles.

STRESSING OVER PENCIL PRESSURE*

Answers to Analysis Questions

1. **In your own words, what is the difference between force and pressure?**

   Force is a push or pull that can accelerate an object. The amount of force applied over a given area is called pressure.

2. **Compare your pressure calculations for the pencil eraser and the pencil lead in the pencil pressure test. Which end exerted greater pressure?**

   The pencil lead exerted greater pressure. Generally, you can expect students' calculated pencil lead pressures to be 70-150 times greater than their eraser pressure. For the sample data provided, the pencil lead pressure was 139 times greater than the eraser's pressure.

3. **Using your calculations of cross-sectional surface area and pressure exerted by the pencil eraser and the pencil lead during the pencil pressure test, describe the general relationship between surface area and pressure.**

   If a force is applied over a greater surface area, the resulting pressure on a material will be lower. Decreasing surface area increases the amount of pressure exerted.

4. **How do engineers differentiate between pressure and stress?**

   Pressure results from outside forces applied to the outside surface of a material. Pressure on the outside of a material creates stress inside the material.

5. **How does an understanding of force, pressure, and stress help engineers design stronger and safer vehicles?**

   To develop stronger vehicles, engineers conduct stress tests on structural components to ensure that each structure can withstand the pressure and stress created when a variety of forces are applied.

Extension

Find additional teaching resources for exploring stress and strain in the context of engineering at www.TeachEngineering.org. TeachEngineering is a searchable, web-based digital library collection of standards-based engineering curricula for K-12 educators designed to make applied science and math come alive through engineering design. The TeachEngineering collection provides educators with free access to a growing curricular resource of activities, lessons, units, sprinkles and maker challenges.

* This activity was adapted from TeachEngineering's "Feel the Stress."

TeachEngineering
STEM curriculum for k-12

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

STRESSING OVER PENCIL PRESSURE

MATERIALS NEEDED

DAY 1

Per pair of students

» One mechanical pencil with lead and an eraser (with the lead diameter written on the pencil)
» One metric ruler with millimeters marked

Per student

» One "Stressing over Pencil Pressure" Student Activity Sheet
» One calculator
» **OPTIONAL:** One sheet of notebook paper

Key Question

» How can magicians lay on a bed of sharp nails unharmed? Is it magic or science?
» How are force, pressure, and stress relevant in engineering strong and safe vehicles?

Did You Know?

The physics concepts of force, pressure, and stress are all related but all different. Automotive engineers must understand the differences between these three concepts as well as their relationships to each other in order to design strong and safe structural components for vehicles, such as roofs and body frames. In this activity you will use mechanical pencils to conduct tests similar to a bed-of-nails demonstration on a smaller scale to investigate the relationships between these concepts.

Purpose

» To explain the relationship between force and pressure
» To describe the relationship between surface area and pressure
» To explain how engineers differentiate between pressure and stress
» To describe how the concepts of force, pressure, and stress are relevant when designing strong and safe vehicles

Procedure

Part 1 - Making Observations about Pencil Pressure

Push the pencil lead out so that it is sticking out 3 mm from the tip of the pencil. Take turns conducting the pencil pressure test on your own hands and work with your partner to describe your observations.

a. Pencil Pressure Test Instructions: Gently press each end of the mechanical pencil (pencil lead end and eraser end) between the centers of your palms or between the index fingers of your left and right hands (see Figures 1 and 2) and hold the pencil in place for 3 seconds. During this time, you should hold your hands or fingers steady so the pencil remains stationary (and does not move to the left or to the right).

Safety Warnings: Briefly and gently press the pencil between your palms or fingers and do not use your pencils to conduct tests on others.

Figure 1

Figure 2

Procedure (continued)

Part 1 - Making Observations about Pencil Pressure

1. Describe how the two different ends feel WITHOUT using the words force, pressure, or stress.

» Pencil lead end observations:

____

» Eraser end observations

____

Part 2 - Making Inferences about Pencil Pressure

After partners have conducted the pencil pressure test, work together to answer the following question:

2. As you gently pressed your palms together, do you think each end of the pencil applied the same amount of force to each of your palms/fingers or different amounts of force to each palm/finger? Explain why you think the forces were equal or different.

____

____

____

Part 3 – Recording Pencil Measurements

3. Using a metric ruler with millimeter (mm) markings, measure the diameter (the distance across a circle through its center point) of the pencil's eraser. Record it below.

» Eraser diameter = ____________________ **(mm)**

4. Record the diameter of the pencil lead in the space below. On most mechanical pencils, the diameter is written at the end of the pencil near the eraser (see Figure 3).

» Lead diameter = ____________________ **(mm)**

Figure 3

Part 4 - Calculating Radius, Surface Area, and Pressure

Your pencil pressure observations can be explained mathematically using the measurements from Part 3 to make a few calculations. Work with your partner to complete the calculations for radius, area, and pressure. NOTE: For all calculations, show your work in the margins of this activity sheet or on a separate sheet of notebook paper. Record your final calculations below

STRESSING OVER PENCIL PRESSURE

Procedure (continued)

Part 4 - Calculating Radius, Surface Area, and Pressure

5. First, calculate the radius of the eraser and the radius of the pencil lead.
Radius = Diameter ÷ 2

- Eraser radius = ________________ **(mm)**
- Lead radius = __________________ **(mm)**

6. Next, convert the radius of the pencil eraser and the radius of the pencil lead from millimeters (mm) to meters (m). Remember that 1 m = 1000 mm, so divide the radius in mm by 1000. For example: 5 mm ÷ 1000 = 0.005 m.

- Eraser radius = ________________ **(m)**
- Lead radius = __________________ **(m)**

7. Since both the pencil lead and the eraser are circular, use each radius calculated in question 6 to calculate the cross-sectional surface area of the eraser and the cross-sectional surface area of the lead using the formula for the area of a circle. NOTE: For ease of calculation in this activity, we are assuming that the shape of the eraser remained circular even after it was pressed against your skin. Area (A) = $\pi \times r^2$

A = cross-sectional surface area of a circle (m^2) = $\pi = 3.14$

- r = the radius of either the eraser or the lead (m) = __________________ **(m)**
- Eraser cross-sectional surface area = ________________ **(m^2)**
- Lead cross-sectional surface area = __________________ **(m^2)**

8. To simplify the calculations required, assume that a force (F) of 0.5 Newtons was applied by each end of the pencil during everyone's pencil pressure tests. Use this force value and the cross-sectional surface areas calculated in item 7 to calculate the amount of pressure exerted on your palms or fingers by the eraser end and the pencil lead end in the pencil pressure test.

P = F ÷ A
P = Pressure (N/m^2) or Pascals (Pa)
F = Force applied to the surface (N)
A = cross-sectional surface area (m^2)

- Eraser pressure = _____________________ **(Pa)**
- Lead pressure = _______________________ **(Pa)**

Read the following paragraphs and discuss them with your partner. Then be ready to share two general conclusions you can make about pressure and stress and their engineering applications.

STRESSING OVER PENCIL PRESSURE

Procedure (continued)

Part 5 – Exploring Pressure and Stress

Is pressure the same as stress? Not really, but their amounts can be the same if the same force is applied to a material. Pressure and stress are closely related. Mathematically, they both are equal to force divided by area (F/A). But one of the biggest differences between the two is where the force is applied on a material. With pressure, the force is applied on the outside surface of the material. With stress, the force is applied inside or within the material. Pressure on the outside of a material can cause stress inside a material.

How do engineers use stress to test the strength of an object? One of the ultimate goals of mechanical and civil engineers is to design safe structures that are strong enough to withstand a wide variety of external forces such as wind, earthquakes, or collision (impact) forces. Whether designing bridges or vehicles, engineers help to ensure the safety of structures by analyzing the strength of their component parts (e.g., a bridge support pillar or the bumper of a car). One method used to test the strength of structural components is a stress test. In stress tests, pressure is applied to the outside of a component to create stress inside the component until the component reaches its stress limit and fails (i.e., breaks, fractures, crumbles, or deforms excessively).

Analysis Questions

1. Describe how the two different ends feel WITHOUT using the words force, pressure, or stress.

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2. Compare your pressure calculations for the pencil eraser and the pencil lead in the pencil pressure test. Which end exerted greater pressure?

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3. Compare your pressure calculations for the pencil eraser and the pencil lead in the pencil pressure test. Which end exerted greater pressure?

---

4. How do engineers differentiate between pressure and stress?

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5. How does an understanding of force, pressure, and stress help engineers design stronger and safer vehicles?

TEACHER LESSON PLAN

CRASH SCIENCE IN THE CLASSROOM

PAPER CAR CRASH!

CULMINATING ACTIVITY

DEFINITIONS

crashworthiness: how well a vehicle protects its occupants in a crash. A crashworthy vehicle design reduces the risk of death and injury

impulse (J): the product of a force and the time interval during which the force acts, $F\Delta t$

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

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS in the classroom homepage.*

Key Question(s)

- Is it possible to build a car frame and body from paper and glue that is strong enough to protect a raw egg during a head-on collision?
- What engineering and design features determine a vehicle's crashworthiness?

Grade levels: 5–12
Time required: Varies with ability.
Recommended time: At least one week to design and build a car. Provide approximately 100 minutes of class time (two 50-minute periods) for design brainstorming, vehicle building, vehicle testing, and design revision. The remaining building time should be completed outside of class

Objectives

Students will:

- design and test a paper car that protects a raw egg as it crashes into a concrete barrier.
- describe a collision in terms of momentum changes, impulses, impact forces, and impact times.
- identify at least three engineering or design features that determine a vehicle's crashworthiness.

*Next Generation Science Standards**

Forces and Interactions

- HS-PS2-1, HS-PS2-3, 5-PS2-1

Engineering Design

- HS-ETS1-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, 3-5-ETS1-1, 3-5-ETS1-2

Recommended Prior Knowledge and/or IIHS in the Classroom Activities

At a minimum, prior to this lesson students should already be familiar with the concepts of inertia, momentum, impulse, impact time, impact force, potential energy, and kinetic energy. The following IIHS in the Classroom lessons directly address these topics and ideally all 4 of these lessons should be completed prior to this culminating activity: "Penny for Your Thoughts on Inertia," "Momentum Bashing," "Egg Crash- Designing a Collision Safety Device," and "Conservation: It's the Law!"

IIHS in the Classroom Culminating Activity Options

Both this "Paper Car Crash" Culminating Activity and the "Project Pedestrian" Culminating Activity are intended to be used as capstone engineering design projects that allows students to apply the crash science and physics concepts addressed in the IIHS in the Classroom program. Both of these multi-day design challenges strive to integrate science, technology, engineering, and mathematics (STEM) and encourage both critical and creative thinking and problem solving. The "Paper Car Crash" Culminating Activity uses less expensive materials and is more "low-tech" and less-complex and rigorous. The "Project Pedestrian" Culminating Activity is more "high-tech" and requires specialized data gathering sensors. It is also more complex and rigorous from an engineering perspective because it requires students to complete all 7 steps of the Engineering Design Process (See Project Pedestrian Background Information).

TEACHER LESSON PLAN

PAPER CAR CRASH!

Background Information

Crashworthiness is a term used to describe how well a vehicle protects its occupants in a crash. Vehicle structure and occupant restraints (e.g., safety belts and airbags) are the primary vehicle design features influencing crashworthiness. The Insurance Institute for Highway Safety (IIHS) evaluates the crashworthiness of vehicles using five tests: 1. moderate overlap front crash, 2. small overlap front crash, 3. side crash, 4. roof crush test, and 5. head/seat restraint strength tests. The IIHS rates vehicles as good, acceptable, marginal or poor based on their performance on all five tests combined. A "good" crashworthy design significantly reduces the risk of death and injury. During this project, students will design and build a crashworthy paper car to protect a raw egg occupant from "injury" or "death" during a collision with a brick wall.

To design a winning crashworthy paper car, students must apply two physics concepts used in the real-world engineering of vehicle safety features: momentum and impulse. Momentum (p) is the mass of an object multiplied by its velocity ($p = m \times v$). It is a measure of how difficult it is to stop a moving object. It is also a vector quantity (with both magnitude and direction) and its direction is the same direction as the object's velocity. In a collision, momentum is determined by a vehicle's mass and velocity at the time of the collision. When moving, more massive vehicles have more momentum just as vehicles traveling faster have more momentum. When a vehicle crashes and comes to a stop, the vehicle's momentum is reduced to zero. Increasing the odds of surviving a collision lies in managing this change in momentum. An impulse (J) is required to change an object's momentum and is the product of the average force (F) exerted on an object and the time interval during which it acts (Δt). In short-hand notation, the magnitude of an impulse can be written as $J = F_{avg} \Delta t$.

To change momentum ($m\Delta v$) and stop a moving vehicle, an impulse can be applied to the vehicle in a variety of force and time combinations. However, extreme combinations can have dramatically different impacts on both the vehicle and it occupants. Here is a simplified example: an out-of-control truck runs off a country road into a field and it is slowly brought to a stop as it plows through the haystack producing only minor damage to the truck and its occupants (see Figure 1). In this situation, by plowing through the haystack, the change in momentum occurs over a long time thereby producing a smaller average impact force on the truck.

Now, replay the scenario but have the out-of-control truck run off the road and hit a wall (see Figure 2). In this case, the change in momentum occurs over a short time as the wall barely moves upon impact. The shorter impact time produces a larger average impact force which can result in extensive damage to the vehicle and significant injury to its occupants. Looking more closely at this momentum-impulse relationship, we can see that both vehicles would experience the same total impulse but with different combinations of time of impact and force of impact even though the product of force and time would be the same in each case.

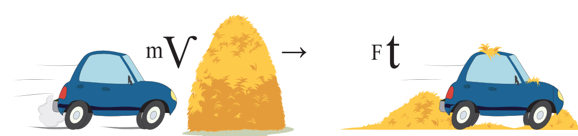

Figure 1. *Stop the truck with a <u>small impact force</u> applied over a <u>long time</u> (i.e. truck hits a haystack and gradually slows to a stop with very little damage)*

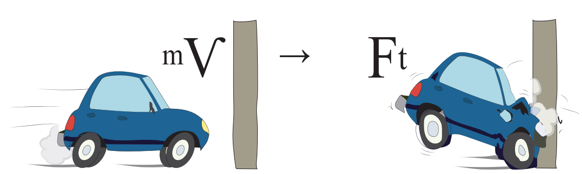

Figure 2. *Stop the truck with a <u>large impact force</u> applied over a <u>short time</u> (i.e. truck hits a brick wall with major damage)*

During this culminating activity, students will discover that an occupant has a much greater chance of surviving a collision if the impulse results from gradually reducing momentum and spreading the impact force over a longer period of time. Similarly, they should discover that the odds of serious injury (a cracked egg) or death (a broken egg) significantly increase if the impulse results from a large impact force applied over a short period of time.

TEACHER LESSON PLAN

PAPER CAR CRASH!

MATERIALS NEEDED

Grouping Format: Students may work alone or with a partner

Teacher provides per student or pair of students

- » Two sheets of 8½” x 11” standard-weight paper
- » Four wheels*
- » Two axles, 5 cm each*
- » One plastic drinking straw (for axle housing only)
- » Access to a metric balance
- » One large, Grade A raw egg
  NOTE: Wash hands thoroughly with soap and water after handling raw eggs, especially if they break!
- » One to two copies of the “Paper Car Crash” student activity sheet
- » One metric ruler with millimeters

Students provide for building cars outside of class

- » Glue (low-temp glue sticks and guns recommended)
- » Scissors
- » Centimeter ruler
- » Colored pencils, crayons, and markers for vehicle decoration and for writing car name and student/team name on car (no stickers or paint)

Teacher provides (for entire class and competition):

- » Two sections of vinyl gutter, 3 m (10 feet) each, Genova RAINGO® Gutters RW 100
- » One gutter connector*, Genova RAINGO® Gutter Slip Joints, RW 105*
- » One 6 or 8-foot ladder
- » One lab stool or small (3-4-foot high) step ladder
- » One concrete block or brick wall
- » One pan balance with at least 200 grams of masses or one digital balance
- » 60 grams of stacking gram masses (to simulate the mass of a raw Grade A large egg for test runs of paper cars the day before the actual competition)
- » Newspaper and paper towels to protect the floor and clean up any broken eggs
- » One stopwatch
- » One meter stick or metric tape measure
- » Web access to video segments “Reducing Racing Injuries” and “Reducing Crash Injuries” at classroom.iihs.org/paper-car-crash

Optional classroom supplies:

- » One pair of large bolt cutters (only needed if brass axles from PITSCO are used)
- » Photogate timer
- » One 3x5 card per car if using a photogate timer
- » One roll of masking tape if using a photogate timer
- » One calculator per student or pair
- » Glue guns and glue sticks, low temperature

**see ordering information*

Safety Considerations

- » Hot glue guns can burn skin and clothes. Teacher supervision may be needed with some students. Low-temperature glue guns are recommended for younger students.
- » Scissors can cut skin. Caution students to direct sharp edges or points away from themselves and others.
- » Make sure students wash their hands thoroughly with soap and water after handling raw eggs, especially if they crack or break.

TEACHER LESSON PLAN

PAPER CAR CRASH!

Ordering Information for Car and Track Supplies*

NOTE 1: Wheels and axles may be ordered individually from PITSCO and the vinyl gutter track and slip joint can be purchased locally OR a Crash Track Kit containing wheels and axles for 50 cars, the two pieces of vinyl gutter track, and slip joint can be purchased from Ward's Science.

NOTE 2: The PITSCO crash car supplies are recommended for use with older students (Grades 8-12) while the Ward's Crash Kit is recommended for use with younger students (Grades 5-7).

- Wheels and Axles – PITSCO Science (pitsco.com),
  - Lx Wheel, W30846, 100 pack, price approximately $9.00
  - Axles 1/8" solid rod for axles, 12" length, W54576, approximate cost $1.50 each
- Vinyl gutters - RAINGO® Gutters and slip joints available from most large home improvement centers. Manufactured by Genova Products, 7034 East Court Street, Davison, Michigan 48423, retail costs approximately $8.00 each for 10-foot section, approximately $4.00 each for slip joint to connect sections together.
- Crash Track Kit - Ward's Science (http://wardsci.com), Egg Race and Crash Track Kit, Item #360127, provides track, wheels, and plastic axles, approximate costs $83.00.

Advance Preparation

1. If possible, order enough materials to allow every student to build a car. If resources are limited, allow teams of two students to build a car.
   - If using PITSCO car supplies, the 12" long 1/8" diameter solid axle rods need to be cut into 5 cm lengths using large bolt cutters. If using the Ward's Crash Test Kit, the hard plastic axles can be cut into 5 cm lengths using scissors.
   - Assemble glue guns and glue sticks if you plan to allow students to work on their cars during class time.
   - Before the day of the crash competition, acquire two 10-foot sections of vinyl gutter, one slip joint connector, one lab stool or small step ladder, a concrete brick, and a 6- or 8-foot ladder and assemble the crash track as illustrated in Figure 4.
   - Cue up the video segment "Reducing Race Injuries" from Understanding Car Crashes – When Physics Meets Biology DVD at classroom.iihs.org/paper-car-crash
2. Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/paper-car-crash and decide if you want to incorporate them into the lesson.
3. For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/paper-car-crash
4. (Optional) Cue up videos of previous "Paper Car Crash!" classroom competitions to show students after introducing the challenge.
   - To find "Paper Car Crash" videos, click on the Teacher tab at classroom.iihs.org/paper-car-crash and scroll down to Lesson Step 6.
   - While allowing students to see car designs created by other classes may slightly decrease their design creativity, seeing other student-designed cars in action typically increases both student excitement and motivation and helps build students' confidence in their own ability to successfully create a competitive car.

TEACHER LESSON PLAN

PAPER CAR CRASH!

Procedure

1. Initiate the activity by asking students to compare and contrast the extent and "harmfulness" of injuries one is likely to receive when tripping and falling on a concrete sidewalk versus tripping and falling on soft sand. Review pertinent background information regarding momentum and impulse and make sure students realize that, in both cases, the initial momentum and resulting impulse of a person's "collision" with the sidewalk or sand is the same, but, since the soft sand "gives" during the collision, the force of impact is spread out over a longer period of time, resulting in fewer or less severe injuries.
2. Next, show the "Reducing Race Injuries" segment from Understanding Car Crashes – When Physics Meets Biology. Ask students how they think some people are able to survive major collisions in passenger vehicles.
3. Explain that vehicle engineers apply the concepts of momentum and impulse when designing both the structure of vehicles and internal features used to restrain and protect vehicle occupants during a crash (such as seat belts and air bags). Introduce the concept of crashworthiness and review pertinent background information regarding the five tests used by the IIHS to determine crashworthiness. Tell students that, as a culminating activity for their study of the science and engineering of car crashes, they are going to participate in a competition that allows them to apply the crash-related laws and concepts of physics.
4. Distribute copies of the "Paper Car Crash" student activity sheet to each student and review the Purpose of the activity (and the two criteria for determining the most crashworthy paper car). Explain that, during this activity, students will be challenged to design and build crashworthy paper cars to protect a raw egg "occupant" from "injury" or "death" during a head-on collision with a brick wall. Optional: Show the activity's Introduction video and previous "Paper Car Crash!" classroom competitions videos (see Advance Preparation above).
5. Let students know if you are having them work individually or in pairs and have students divide into pairs or assign pairs if necessary. Ask students to read the Design Considerations paragraph and then review the three questions to help stimulate the design process:
   a. Should your vehicle be rigid and strong (like a 1950s muscle car) or is it better if it collapses (like an Indy racing car)?
   b. Should the occupant (egg) be able to move freely in the vehicle or should it be strapped to the vehicle?
   c. How can your vehicle be designed to easily remove and inspect the egg after a crash?
6. Next, walk students through the Design Product/Presentation, Design Timeline, and the Rules & Specifications sections of the activity sheet. If necessary, modify the Design Timeline to meet your own class curriculum pacing needs or class ability level. Inform students that their cars are due the day before the Crash Day Competition to allow them to conduct preliminary runs and determine each vehicle's final velocity or average velocity (see Step 11 - Methods 1 or 2 for determining final or average velocity).

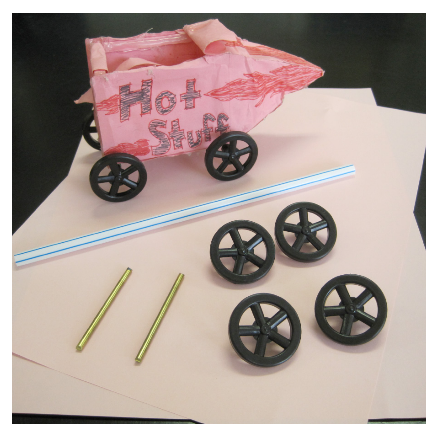

Figure 3. *Paper car building supplies provided to students and a sample of a completed car.*

PAPER CAR CRASH!

Procedure (continued)

7. Distribute the building materials you are providing (2 sheets of paper, 4 wheels, 2 axles, and 1 plastic straw) (Figure 3) and remind students that cars wider than 6.5 cm will not fit on the Crash Track. Inform them you have pre-cut the axles to 5 cm each to ensure that the combined width of two wheels and an axle does not exceed 6.5 cm. Also remind them that the straw can ONLY be cut into pieces and glued to the bottom of their paper vehicle to serve as a "housing" for sliding their axles through to attach the wheels/axles to the car.

8. Distribute the building materials you are providing (2 sheets of paper, 4 wheels, 2 axles, and 1 plastic straw) (Figure 3) and remind students that cars wider than 6.5 cm will not fit on the Crash Track. Inform them you have pre-cut the axles to 5 cm each to ensure that the combined width of two wheels and an axle does not exceed 6.5 cm. Also remind them that the straw can ONLY be cut into pieces and glued to the bottom of their paper vehicle to serve as a "housing" for sliding their axles through to attach the wheels/axles to the car.

9. Befovre students begin brainstorming their paper car designs, explain how automotive engineers must manage the enormous amount of kinetic energy in high-speed crashes by designing front ends that crumple on impact to absorb this energy before it reaches the occupants. Unfortunately, this safety feature only works if the occupants are wearing their seat belts, which are fastened to the vehicle's safety cage (the framework of reinforced struts on the sides, front, rear, and top of the occupants' seating area). Securing occupants to the safety cage ensures that both the safety cage and the occupant slow down at the same rate. Struggling with these conflicting constraints -- constructing a front end weak enough to crumple while making the safety cage strong enough to protect the egg -- helps students realize the vital role of seat belts. Their egg survives only if the crumple zone and the safety cage work well together and the egg is "wearing" its seat belt.

Figure 4. *Crash track set-up*

10. If time allows on Day 1, conduct a whole-class or small-group brainstorming session. Provide approximately 100 minutes of class time (two 50-minute periods) for design brainstorming, vehicle building, vehicle testing, and design revision. Give students at least one week of combined in-class and out-of class time to design and build their cars.

11. Construct the crash track by connecting two 3-meter (10-foot) vinyl rain gutters using a gutter slip joint creating a six-meter track (20-foot) (see Figure 4). One end of the track should be elevated on the second-from-the-top step of a six-foot stepladder. The middle of the track should be supported at the slip joint with a lab stool or small step ladder. Additional sets of gutters and slip joints can be used to create multiple tracks for side-by-side racing if desired.

12. **On the day before** the Crash Competition, have students use a pan balance or digital balance to find the mass of their cars. Then have each student or pair of students introduce and explain the design features of their vehicle and inspect all cars to ensure they meet the required building specifications (i.e., mass, length, width, no tape or paint, etc.). Make sure each car has been labeled with: the vehicle name, builder name(s), vehicle length in centimeters, and vehicle mass in grams

13. Once cars pass inspection, have students conduct preliminary runs of their cars on the crash track to determine each vehicle's final velocity or average velocity (depending on photogate availability and students' ability-levels, see Methods 1 and 2 below).

PAPER CAR CRASH!

Procedure (continued)

For the preliminary runs, no raw eggs should be used and no barrier should be placed at the end of the track so cars can roll freely and gradually stop. To simulate the approximate mass of a Grade A large egg, students should place 60 grams of plastic gram stacker masses in their cars, allowing them to measure each vehicle's momentum without the risk (and mess) of a broken egg.

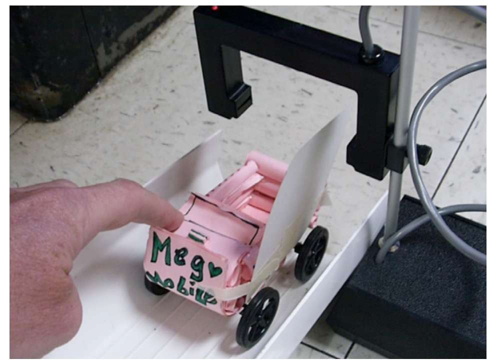

Figure 5. *Checking card height in timer*

- **Method 1 – Calculating final velocity using a photogate at the end of the ramp**
  Place the photogate at the end of the track, plug it in, and turn it on. Have students use masking tape to tape a 7.62 x 12.7 cm (3 x 5 inch) index card long side up on the side of their cars so the cards are tall enough to pass through the photogate (see Figure 5). Each car should be placed at the top of the track and released. As the card passes through the photogate, the photogate will record the time it takes the width of the card to pass through the photogate. Instruct students to divide the width of the card (7.62 cm) by the time recorded on the photogate to determine the car's final velocity in centimeters/second. Then have students convert this value to meters/second for future calculations of momentum.
- **Method 2 – Calculating average velocity using a stopwatch and meter sticks**
  Use a meter stick or metric measuring tape to measure the total length of the track in meters to the nearest centimeter. Next, have students use a stopwatch to measure the total time it takes for each car to travel the total length of the track. Instruct students to calculate the average velocity of their cars by dividing the total length of the track (in meters) by the total time it took for their cars to travel the total length of the track (in seconds). (Average velocity = total distance traveled by car in meters ÷ time to travel total distance traveled in seconds.)

14. **On Crash Competition Day**, place a concrete block against the lower end of the track to simulate a head-on collision. Distribute raw eggs and have students place their eggs in their cars. If you are conducting the Crash Competition in one 50-minute class period, you can save time by conducting only three rounds of competition. For Round 1, place the starting end of the track on the top step of the ladder so the top of the track is 200 cm above the floor. After each car's run, have students remove their eggs and inspect them for damage. Remind students that cracks of any size indicate an occupant injury and these vehicles will be eliminated. Allow all cars that successfully protect their eggs in Round 1 to advance to Round 2.

ROUND NUMBER	STARTING HEIGHT OF TRACK ABOVE FLOOR (CM)
1	200
2	220
3	240

Figure 6

15. For Round 2, raise the starting end of track by pulling the ladder forward a few feet closer to the brick at the end of the ramp so that the top of the track is now 220 cm above the floor. (This puts the track at a greater angle relative to the floor, thereby raising the starting end). Complete runs of all cars surviving Round 1, remove and inspect all eggs, and allow any cars that successfully protected their eggs in Round 2 to advance to Round 3. For Round 3, pull the ladder forward again until the top of the track is 240 cm above the floor (see Figure 6).

Procedure (continued)

16. If a tiebreaker is needed at the end of Round 3, have students calculate each remaining car's momentum (mass x velocity) using the data gathered during the previous day's preliminary runs. The car with the greatest momentum and uncracked/unbroken egg wins.

17. When all students have completed the competition, ask students to identify the design features they observed in the more and less crashworthy paper cars. Optional: Show the activity's Conclusion videos. Students should notice that designs allowing eggs to slow down gradually within the safety cage have higher survival rates (such as a collapsing folded paper accordion that functions like an airbag or a cab forward-shaped front end that allows the egg to move forward into a narrowing cone). Typically, students are quick to identify design flaws in cars with egg "fatalities" and discover that cars with stiff front ends do not crumple enough on impact, thus resulting in a higher impact force on the egg.

18. Remind students that the IIHS evaluates a vehicle's crashworthiness with the help of five tests: moderate overlap front crash, small overlap front crash, side crash, roof crush test, and head/seat restraint strength test. And explain that the IIHS rates vehicles as good, acceptable, marginal or poor based on the vehicle's performance on all five tests combined. Encourage students to visit the IIHS website (www.iihs.org) to discover the crashworthiness ratings of vehicles they often ride in or drive.

19. To conclude the lesson, show the "Reducing Crash Injuries" segment from classroom.iihs.org/paper-car-crash and use the background information provided to remind students of the relationship between impulse and changing an object's momentum. Make sure students understand that occupants have a much greater chance of surviving a collision if the impulse results from gradually reducing momentum and spreading the impact force over a longer period of time.

20. Options for Older Students: If time permits, ask students to describe how raising the track's height increased their car's crashing speed and relate this increase in speed based on increased height to the concepts of gravitational potential energy and kinetic energy addressed in the "Conservation: It's the Law" and "Ball of Energy" activities. Ask students to explain how changes in potential and kinetic energy relate to research documenting the fact that exceeding speed limits results in more fatal crashes. Make sure students understand that, with a greater starting height, the paper cars begin with greater potential energy which then increases the amount of kinetic energy the cars have when they reach the concrete block at the end of the track. Review the formula for kinetic energy ($KE = \frac{1}{2} mv^2$) and remind students that, since kinetic energy is proportional to the square of a vehicle's velocity, if velocity is doubled, the amount of kinetic energy in a collision is quadrupled.

21. Additional Assessment Options: If an additional assessment is desired, two optional "lab report-style" assessments are provided below (Option 1 is recommended for younger students since it is shorter and involves fewer calculations. This option cannot be used if a photogate is used.).

Crash Report Criteria for Option 1 (15 Points)

» Submit a report addressing Items 1-4.

» Report should be double-spaced, 12-point font, Times New Roman.

TEACHER LESSON PLAN

PAPER CAR CRASH!

Option 1 *- Project Assessment Categories (50 Total Points)*

CATEGORY	POINTS	DESCRIPTION
Quality of construction	20	Construction of car shows evidence of time and effort invested in the building process.
Performance of car	10	Car swiftly carries the egg the entire length of the track during test runs. Car does not drag due to excess friction between car parts.
Car specifications	5	Car meets required specifications of length, width, and mass.
Crash report	15	Report thoroughly and accurately communicates data and calculations. (See specific report criteria below.)
Total	**50**	
Extra credit (optional)	+1	Cars that keep the egg from cracking receive 1 point of extra credit per successful completion of each round of competition.

1. **Purpose (2-3 paragraphs, 4 points)**
   a. Describe the project's challenge and rules. What factors determine the winner?
   b. Describe how you applied your understanding of momentum and impulse to design a safer car.
   c. Define and discuss impact force and impact time. What is their relationship to each other? How are they related to impulse and the change in momentum?
   d. How do crumple zones and airbags affect impact time and impact forces to keep you safe during a collision?

2. **Photograph or Diagram (2 points)**
   a. Include a photograph or large hand-drawn picture of your vehicle.
   b. Label key design features.

3. **Data Table (3 points)**

» Construct a 2-column data table that includes the following, including units:

   a. distance traveled by car (cm)
   b. time of run (seconds)
   c. width of car (cm)
   d. length of car (cm)
   e. mass of car without egg (grams)
   f. mass of car with egg (grams)

4. **Calculations (6 points)**

» Show all equations and calculations used to obtain the quantities listed below:

   a. Convert distance traveled by your car from centimeters to meters.
   b. Convert mass of your car with the egg from grams to kilograms.
   c. Calculate average velocity (m/s):
      Average velocity =
      total distance traveled by car in meters ÷ total time from stopwatch of distance traveled in seconds
   d. Calculate the car's average momentum upon impact (kg x m/s):
      Momentum = (total mass of car with egg) x (average velocity)

PAPER CAR CRASH!

Option 2 *- Project Assessment Categories (70 Total Points)*

CATEGORY	POINTS	DESCRIPTION
Creativity of design	6	Overall design or particular features of car design are unique.
Quality of construction	10	Construction of car shows evidence of time and effort invested in the building process.
Performance of car	7	Car swiftly carries the egg the entire length of the track during test runs. Car does not drag due to excess friction between car parts.
Car specifications	7	Car meets required specifications of length, width, and mass.
Crash Report	40	Report thoroughly and accurately communicates data and calculations. (See specific report criteria below.)
Total	**70**	
Extra credit (optional)	+1	Cars that keep the egg from cracking receive 1 point extra credit per successful completion of each round of competition.

Crash Report Criteria for Option 2 (40 Points)

» Submit a report fully addressing Items 1-9.

» Report should be double-spaced, 12-point font, Times New Roman

1. **Purpose (2-3 sentences, 3 points)**

Provide a brief statement describing the project's challenge and rules. What factors determine the winner?

2. **Materials (2 points)**

List materials and quantities used to construct your vehicle.

3. **Methods (2 paragraphs, 5 points)**

Describe your building process. Summarize the problems you encountered during the building process and how you solved them.

4. **Photograph or Diagram (1 page, 2 points)**

a. Include a photograph or large hand-drawn picture of your vehicle.

b. Label key design features (e.g., crumple zones, safety cage).

5. **Data Table (4 points)**

Construct a data table that provides the following (include measurement units)

a. distance traveled by vehicle (cm)

b. total time of run (measured with stopwatch in seconds)

c. width of vehicle (cm)

d. length of vehicle (cm)

e. mass of vehicle without egg occupant (g)

f. mass of vehicle with egg occupant (g)

g. width of photogate flag (cm), (if photogate used)

h. time for photogate flag to pass through photogate timer at end of run (s), (if photogate used)

PAPER CAR CRASH!

Crash Report Criteria for Option 2 (continued)

6. **Calculations (8 points)**

Show all equations and calculations used to obtain the quantities listed below:

- If a photogate was used, use the final velocity to calculate momentum. Otherwise, use the average velocity, but realize this will only provide an estimate of the vehicle's final momentum.

a. Convert distance traveled by your car from centimeters to meters.

b. Convert mass of your car with the egg from grams to kilograms.

c. Final velocity using a photogate:

Convert width of photogate flag from centimeters to meters.

Final velocity (m/s) = width of photogate flag (in meters) ÷ photogate time (in seconds)

d. Average velocity using a stopwatch (no photogate):

Average velocity (m/s) =
total distance traveled by car in meters ÷ total time from stopwatch of distance traveled in seconds

e. Calculate the vehicle's momentum before impact using this equation:

Momentum (kg x m/s) = (total mass of vehicle with egg in kg) x (final or average velocity in m/s

7. **Performance Assessment (2-3 paragraphs, 8 points)**

a. Citing your own measured and calculated data, describe the performance of your vehicle and whether or not it met your expectations.

b. Compare your vehicle's performance to another vehicle in the class.

- What were the strengths and weaknesses of each design?
- Cite data and calculations to support your conclusion.

c. There is always room for improvement in a design. How would you modify your car to improve its performance?

8. **Conclusion (3-4 paragraphs, 8 points)**

a. Identify at least three engineering or design features that determined your vehicle's crashworthiness.

b. Define and discuss impact force and impact time. What is their relationship to each other? How are they related to impulse and changing an object's momentum?

c. How do crumple zones and airbags affect impact time and impact forces to improve a vehicle's crashworthiness?

STUDENT ACTIVITY

Name: ______________________ Class: __________ Date: ___________

CRASH SCIENCE IN THE CLASSROOM

PAPER CAR CRASH!

MATERIALS

Provided by teacher for each student or pair of students

- Two sheets (8½ in. x 11 in.) copy paper
- Four wheels
- Two axles
- One plastic drinking straw (only to be cut and used for axle housings as explained by your teacher)
- Access to a metric balance
- One large, Grade A raw egg (NOTE: Wash hands thoroughly with soap and water after handling raw eggs, especially if they crack or break!)
- One to two copies of the "Paper Car Crash" Student Activity Sheet

Materials you will need to build your car outside of class:

- Glue (low-temp glue sticks and glue guns recommended)
- Scissors
- Centimeter ruler
- Colored pencils, crayons, and markers for vehicle decoration (no stickers or paint)

Key Question

- Is it possible to build a car frame and body from paper and glue that is strong enough to protect a raw egg during a head-on collision?
- What engineering and design features determine a vehicle's crashworthiness?

Purpose

The objective of the Paper Car Crash Contest is to apply your science and engineering knowledge and skills to design and build the most crashworthy car that includes a minimum of three safety design features. The winning car's crashworthiness will be based on two criteria:

1. The car with the greatest momentum at the time of collision, and,
2. A car in which the occupant (raw egg) is neither injured (cracked shell) nor killed (broken shell) as a result of the collision.

Grouping Format

You may work alone or with a partner.

Safety Warning

Hot glue and glue guns can burn. Please use caution if using hot glue guns. Low-temp glue guns are recommended and also work very well.

Design Considerations

Successful science and engineering inquiry requires a variety of skills to identify problems/needs, create initial design plans, and test, change, and improve designs. Habits of mind and other traits such as logical reasoning, patience, insight, energy, creativity, persistence, and openness to new ideas must be combined with a sound knowledge base in order to succeed. To assist with your design process, consider the following questions:

- Should your vehicle be rigid and strong (like a 1950s muscle car) or is it better if it collapses (like an Indy racing car)?
- Should the occupant (egg) be able to move freely in the vehicle or should it be strapped tightly to the vehicle?
- How can your vehicle be designed to easily remove and inspect the egg after a crash?

Design Product/Presentation

Your challenge is to design and build a car with the greatest momentum (i.e., fast and massive) using only two sheets of copy paper and unlimited amounts of glue for the car's frame and body. Your paper car must be able to carry a raw egg down an inclined track ramp and protect it during a crash with a concrete block. Your teacher will provide the wheels, axles, and axle housing for construction of your car. Read the Rules & Specifications listed below before beginning your design process and remember that in order to win, you must have BOTH a car with the greatest momentum AND an egg occupant that survives the crash unharmed.

PAPER CAR CRASH!

Design Product/Presentation (continued)

On the day before the car crash contest, you must introduce your design to the class and identify at least 3 safety design features you incorporated into your car's design.

Design Timeline

You have 1-2 weeks to design and build your car (your teacher will specify the exact due date). Approximately 100 minutes of class time (two 50-minute periods) will be provided for design brainstorming, vehicle building, vehicle testing, and design revision. The rest of your work should be completed on your own time.

Rules & Specifications

1. Maximum car width: less than equal to 6.5 centimeters (including axles and wheels)
2. Maximum car length: less than or equal to 16.5 centimeters
3. Minimum car mass without the egg: greater than or equal to 40 grams
4. Glue, paper, wheels, axles, and the straw-axle housing are the only construction materials allowed. The entire frame of the car must be made of paper and glue.
5. Your vehicle will be disqualified if it exceeds length and width dimensions, does not meet minimum mass requirements, or contains stickers, paint, tape, cardboard or any other non-licensed materials that contribute to the structural integrity of the vehicle.
6. Vehicle designs must allow for easy access to and removal of the egg (occupant) for inspection after the crash.
7. Vehicle designs should be able to withstand 2-3 trials/collisions without parts replacement or repairs.
8. There can be no physical contact between the vehicle and the designer once the vehicle has been released onto the track.
9. All vehicles must visibly display the following information on their frames:
   a. vehicle name
   b. builder's name
   c. vehicle length in centimeters
   d. vehicle mass in grams

Assessment Options

In addition to completing the design, construction, and crash-testing process for your car, your teacher may also assess your project by one of the following two options:

Option 1 *- Project Assessment Categories (50 Total Points)*

CATEGORY	POINTS	DESCRIPTION
Quality of construction	20	Construction of car shows evidence of time and effort invested in the building process.
Performance of car	10	Car swiftly carries the egg the entire length of the track during test runs. Car does not drag due to excess friction between car parts.
Car specifications	5	Car meets required specifications of length, width, and mass.
Crash report	15	Report thoroughly and accurately communicates data and calculations. (See specific report criteria below.)
Total	**50**	
Extra credit (optional)	+1	Cars that keep the egg from cracking receive 1 point of extra credit per successful completion of each round of competition.

STUDENT ACTIVITY

PAPER CAR CRASH!

Crash Report Criteria for Option 1 (15 Points)

» Submit a report addressing Items 1-4.

» Report should be double-spaced, 12-point font, Times New Roman.

1. **Purpose (2-3 paragraphs, 4 points)**
   a. Describe the project's challenge and rules. What factors determine the winner?
   b. Describe how you applied your understanding of momentum and impulse to design a safer car.
   c. Define and discuss impact force and impact time. What is their relationship to each other? How are they related to impulse and the change in momentum?
   d. How do crumple zones and airbags affect impact time and impact forces to keep you safe during a collision?

2. **Photograph or Diagram (2 points)**
   a. Include a photograph or large hand-drawn picture of your vehicle.
   b. Label key design features.

3. **Data Table (3 points)**
   Construct a 2-column data table that includes the following, including units:
   a. distance traveled by car (cm)
   b. time of run (seconds)
   c. width of car (cm)
   d. length of car (cm)
   e. mass of car without egg (grams)
   f. mass of car with egg (grams)

4. **Calculations (6 points)**
   Show all equations and calculations used to obtain the quantities listed below:
   a. Convert distance traveled by your car from centimeters to meters.
   b. Convert mass of your car with the egg from grams to kilograms.
   c. Calculate average velocity (m/s):
      Average velocity =
      total distance traveled by car in meters ÷ total time from stopwatch of distance traveled in seconds
   d. Calculate the car's average momentum upon impact (kg x m/s):
      Momentum = (total mass of car with egg) x (average velocity)

PAPER CAR CRASH!

Option 2 *- Project Assessment Categories (70 Total Points)*

CATEGORY	POINTS	DESCRIPTION
Creativity of design	6	Overall design or particular features of car design are unique.
Quality of construction	10	Construction of car shows evidence of time and effort invested in the building process.
Performance of car	7	Car swiftly carries the egg the entire length of the track during test runs. Car does not drag due to excess friction between car parts.
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Crash Report	40	Report thoroughly and accurately communicates data and calculations. (See specific report criteria below.)
Total	**70**	
Extra credit (optional)	+1	Cars that keep the egg from cracking receive 1 point extra credit per successful completion of each round of competition.

Crash Report Criteria for Option 2 (40 Points)

» Submit a report fully addressing Items 1-9.

» Report should be double-spaced, 12-point font, Times New Roman

1. **Purpose (2-3 sentences, 3 points)**

Provide a brief statement describing the project's challenge and rules. What factors determine the winner?

2. **Materials (2 points)**

List materials and quantities used to construct your vehicle.

3. **Methods (2 paragraphs, 5 points)**

Describe your building process. Summarize the problems you encountered during the building process and how you solved them.

4. **Photograph or Diagram (1 page, 2 points)**

a. Include a photograph or large hand-drawn picture of your vehicle.
b. Label key design features (e.g., crumple zones, safety cage).

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Construct a data table that provides the following (include measurement units)

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c. width of vehicle (cm)
d. length of vehicle (cm)
e. mass of vehicle without egg occupant (g)
f. mass of vehicle with egg occupant (g)
g. width of photogate flag (cm), (if photogate used)
h. time for photogate flag to pass through photogate timer at end of run (s), (if photogate used)

Crash Report Criteria for Option 2 (continued)

6. Calculations (8 points)

Show all equations and calculations used to obtain the quantities listed below:

» If a photogate was used, use the final velocity to calculate momentum. Otherwise, use the average velocity, but realize this will only provide an estimate of the vehicle's final momentum.

a. Convert distance traveled by your car from centimeters to meters.

b. Convert mass of your car with the egg from grams to kilograms.

c. Final velocity using a photogate:

Convert width of photogate flag from centimeters to meters.

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d. Average velocity using a stopwatch (no photogate):

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Momentum (kg x m/s) = (total mass of vehicle with egg in kg) x (final or average velocity in m/s

7. Performance Assessment (2-3 paragraphs, 8 points)

a. Citing your own measured and calculated data, describe the performance of your vehicle and whether or not it met your expectations.

b. Compare your vehicle's performance to another vehicle in the class.

  » What were the strengths and weaknesses of each design?

  » Cite data and calculations to support your conclusion.

c. There is always room for improvement in a design. How would you modify your car to improve its performance?

8. Conclusion (3-4 paragraphs, 8 points)

a. Identify at least three engineering or design features that determined your vehicle's crashworthiness.

b. Define and discuss impact force and impact time. What is their relationship to each other? How are they related to impulse and changing an object's momentum?

c. How do crumple zones and airbags affect impact time and impact forces to improve a vehicle's crashworthiness?

TEACHER LESSON PLAN

PROJECT PEDESTRIAN

CULMINATING ACTIVITY

Key Question(s)

- How can the front ends of vehicles be designed to minimize pedestrian injuries in a crash?

Grade levels: 9–12

Time required: Three 50-minute class periods (depending on your students' prior familiarity with using acceleration sensors and other technology included in this STEM engineering activity.)

Objectives

Students will:

- use a variety of simple materials to design protective bumpers for small toy cars.
- Conduct simulated vehicle-pedestrian collisions with their toy cars to measure the impact of these collisions on a pedestrian in meters per second squared (a unit of acceleration).
- analyze crash pulse graphs from their simulated collisions to determine which types of materials and bumper designs provide the best protection to pedestrians in a collision.
- describe a vehicle-pedestrian collision in terms of changing momentum, impulse, impact force, and impact time.
- analyze a vehicle-pedestrian collision fatality data table to determine the age groups at greatest risk of death in vehicle-pedestrian collisions at intersections.
- apply knowledge regarding vehicle-pedestrian collisions to make inferences about the potential effectiveness of automatic emergency braking (AEB) systems in different vehicle-pedestrian scenarios.

*Next Generation Science Standards**

Motion and Stability: Forces and Interactions

- MS-PS2-2, HS-PS2-3

Engineering Design

- HS-ETS1-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3

Recommended Prior Knowledge and/or IIHS in the Classroom Activities

At a minimum, prior to this lesson students should already be familiar with the concepts of inertia, momentum, impulse, impact time, impact force, potential energy, and kinetic energy. The following IIHS in the Classroom lessons directly address these topics and ideally all 4 of these lessons should be completed prior to this culminating activity: "Penny for Your Thoughts on Inertia," "Momentum Bashing," "Egg Crash-Designing a Collision Safety Device," and "Conservation: It's the Law!"

DEFINITIONS

Acceleration: the rate at which velocity changes. Calculated by dividing the change in an object's velocity by the time interval of that change.

Automatic emergency braking (AEB) systems: AEB systems help prevent crashes or reduce their severity by automatically applying the brakes for the driver. The systems use on-vehicle sensors such as radar, cameras, or lasers to detect an imminent crash, warn the driver, and apply the brakes if the driver does not take sufficient action quickly enough.

Crash pulse: A vehicle crash pulse, sometimes called a deceleration curve, is a graph illustrating the change in acceleration of a vehicle over the total time of a crash.

**For complete NGSS Performance Expectations, please download the Full Standards Alignment PDF from the IIHS -HLDI in the classroom homepage.*

DEFINITIONS (CONTINUED)

g unit: used as a unit of stress measurement for objects undergoing acceleration; calculated as the ratio of an object's acceleration or deceleration relative to the baseline of acceleration due to gravity at sea level (9.81 m/s^2).

IIHS in the Classroom Culminating Activity Options

Both this "Project Pedestrian" Culminating Activity and the "Paper Car Crash" Culminating Activity are intended to be used as capstone engineering design projects that allows students to apply the crash science and physics concepts addressed in the IIHS in the Classroom program. Both of these multi-day design challenges strive to integrate science, technology, engineering, and mathematics (STEM) and encourage both critical and creative thinking and problem solving. The "Paper Car Crash" Culminating Activity uses less expensive materials and is more "low-tech" and less-complex and rigorous. The "Project Pedestrian" Culminating Activity is more "high-tech" and requires specialized data gathering sensors. It is also more complex and rigorous from an engineering perspective because it requires students to complete all 7 steps of the Engineering Design Process (See Background Information).

Background Information

Acceleration

The concept of acceleration is one of the toughest concepts to understand when studying motion. Yet our bodies are acutely aware of the effects of acceleration. Acceleration occurs when a force is applied to an object that is greater than the object's inertia and any frictional forces present. If the force is strong enough to change our velocity (by either changing our speed, our direction or both) then we feel a forward, backward, or sideways lurch.

If Newton's Second Law of Motion (F=ma) is rearranged in terms of acceleration it becomes $a = F/m$. So, if the mass of an object remains constant but the applied net force increases, the acceleration also increases proportionally. Another way to measure acceleration is by measuring how quickly an object's velocity changes. The equation for calculating acceleration then becomes $a = \Delta v \div \Delta t$ where Δv is the change in velocity over the time interval Δt.

Since acceleration is a measure of how much velocity of an object (measured in meters/second) changes over time (measured in seconds) it is expressed using the standard unit is m/s^2. In physics, the term "acceleration" applies to any change in the velocity of an object, including increasing speed, decreasing speed (also called deceleration), or changing direction. However, *for ease of student understanding during this activity, the term "acceleration" will be used when speed increases and the term "deceleration" will be used when speed decreases*.

Acceleration Measured in g units

Although not an "official" unit of acceleration in the metric system, measures of acceleration and deceleration are often reported in g units. Measurement of **g** units is typically achieved using an accelerometer. Technically, a **g** is the ratio of an object's acceleration or deceleration relative to the baseline of acceleration due to gravity near Earth's surface (9.81 m/s^2). A person normally perceives his/her weight from a combination of the downward acceleration of 1 **g** on their mass resulting from the Earth's gravitational force along with the upward support force exerted by the ground or floor. For additional information on support force see the "Twirling Penny Activity."

Crash researchers often use the **g** unit as a stress measurement for bodies undergoing horizontal acceleration or deceleration. If a person speeds up at a rate twice the normal 1 **g** or 9.81 m/s^2, that person would experience 2 **g**, which is (2)x(9.81 m/s^2), or about 19.6 m/s^2. Thus, this person would feel twice as "heavy" as normal. Depending on how a person is oriented when he/she is accelerated or decelerated, he/she can feel multiple **g**'s from front-to-back, back-to-front, side-to-side or head-to-toe. When rapidly accelerating or decelerating, fighter pilots can experience up to 9 **g** s during extreme maneuvers.

Human Tolerance of Acceleration

Human tolerance of acceleration/deceleration depends on multiple factors, including: a. the magnitude of the acceleration or deceleration, b. the direction in which the acceleration acts, c. the length of time a person is accelerated, d. the rate at which a person is accelerated, e. the region of the body being accelerated, and f. characteristics of the person (including age, overall health and fitness, and gender). The Wayne State Tolerance Curve (WSTC) was developed to better understand human tolerances of head injuries occurring in vehicle crashes (See Figure 1). The WSTC displays the relationship between linear head acceleration (measured in **g**'s) and the duration of acceleration (measured in milliseconds). For example, in a vehicle crash if a head is accelerated forward at 100gs for 5 milliseconds (5/1000ths of a second), that rate of acceleration is not life threatening. But, if a head is accelerated forward at 100gs for 10 milliseconds or longer, the resulting injuries could be life threatening. Although the human head can withstand extremely high accelerations for a very short duration, any combination of acceleration and duration above the smooth curve on the WSTC (i.e., in the red-shaded area) is beyond the human tolerance level and could be life-threatening.

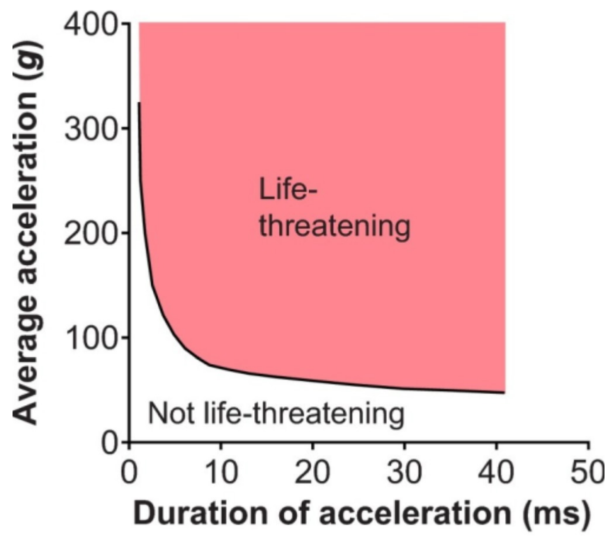


Figure 1 - Wayne State Tolerance Curve

Engineering Design Process

An egineering design process is simply a multi-step process used by engineers to stimulate creative and critical thinking and assist in the successful development of new products or systems. Although there are several different types of engineering design models, in this activity, a 7-step cycle will be used (See Figure 2). The seven components of this particular engineering design process include: 1. ASK, (identify the need and constraints) , 2. RESEARCH the problem, 3. IMAGINE (develop possible solutions), 4. PLAN (select a promising solution), 5. CREATE (build a prototype), 6. TEST AND EVALUATE the prototype and 7. IMPROVE (redesign the prototype as needed). This process is represented as a continuous loop to indicate that the process (or parts of the process) may have to be repeated multiple times before a successful product is created. In addition, depending on the specific need/problem and known constraints (such as amount of time or types of materials available) the steps may be completed in a different order. Additional information regarding challenge-based learning and the engineering design process visit NSTA.org and TeachEngineering.org.

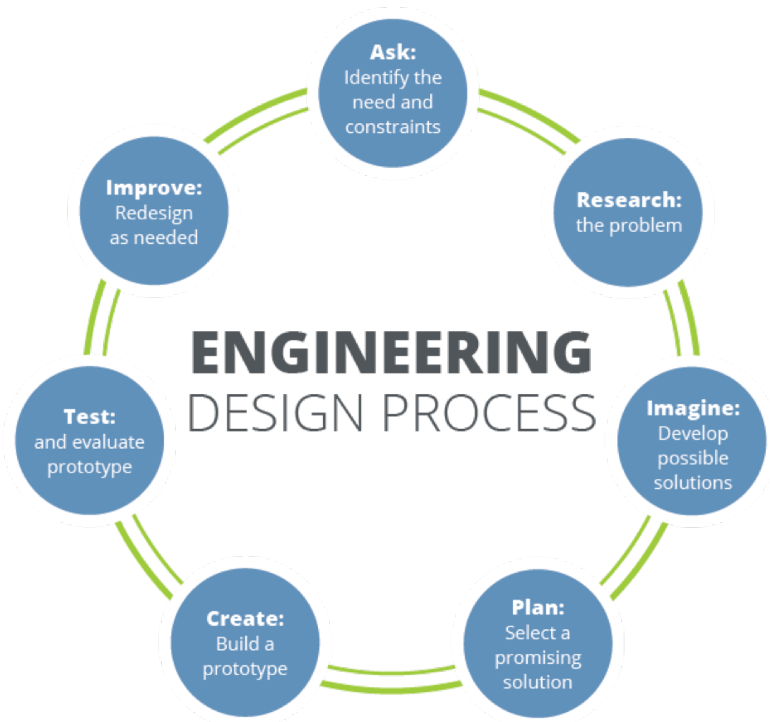


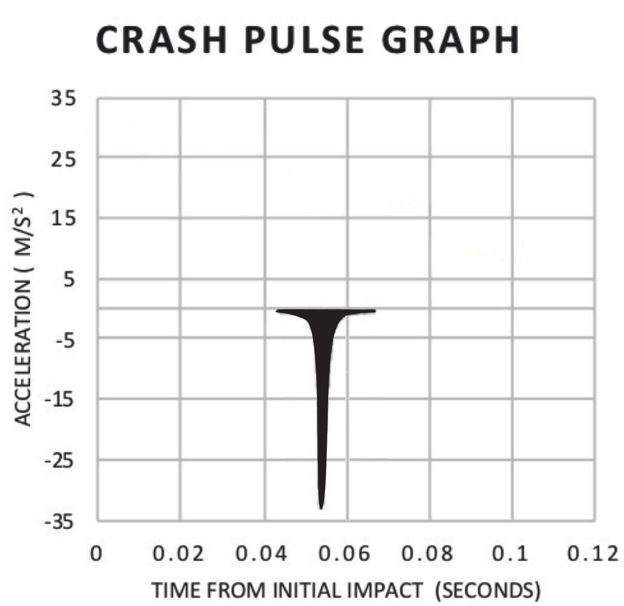
Figure 2 – Seven-step Engineering Design Cycle

Crash Pulse Graphs

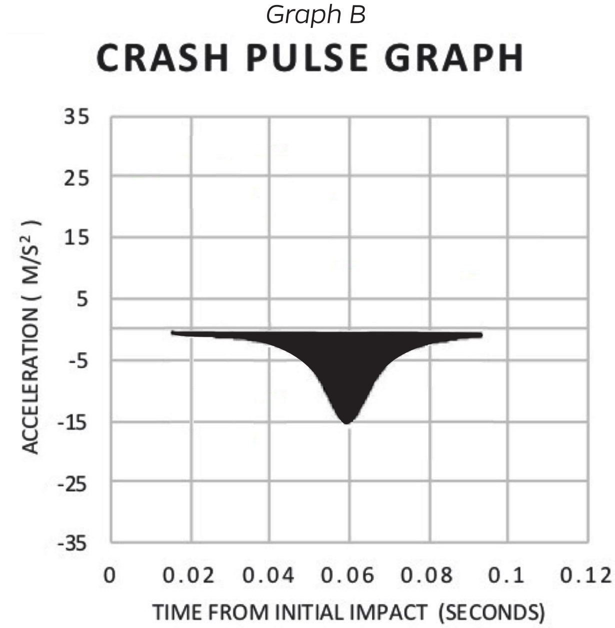
During a frontal crash test, a vehicle's front end suffers a series of bends, breaks, and twists, which reduce its speed (decelerate the vehicle) until the vehicle stops. This series of decelerations is officially measured using the metric system unit of meters per second squared or m/s^2, but can also be expressed in gs. (See "Definitions" section above for additional detail). When the series of decelerations in a crash is measured by an accelerometer and plotted against the time duration of the crash (which occurs in a fraction of a second), the resulting graph is called a crash pulse graph. In other words, a vehicle crash pulse graph is the time history of the change in a vehicle's acceleration during a crash.

The series of decelerations in a crash first affect the vehicle's exterior structures, then the vehicle's interior components, and finally the vehicle's occupants. Numerous factors can affect the shape of a crash pulse graph, including vehicle shape, vehicle structure, vehicle composition, vehicle mass, time of impact, and the amount of the vehicle involved in the crash. The more severe and abrupt a vehicle's deceleration is (Graph A), the more severe the possible injuries to both vehicle occupants or pedestrians involved in the collision will be. If the deceleration of a vehicle in a crash occurs more gradually (Graph B), the potential for injury or death of vehicle occupants or pedestrians involved in a collision is greatly reduced. Thus, when designing vehicles for crashworthiness, one of the major goals of engineers is identifying vehicle shapes, structures, and composition materials that help vehicles decelerate more gradually during a collision.

Graph A



Graph B



Vehicle-pedestrian Crash Statistics

Over the last decade, the IIHS reports that pedestrian deaths in vehicle-pedestrian crashes in the U.S. have increased 53% since reaching their lowest point in 2009. Vehicle-pedestrian crashes have become both deadlier and more frequent. In the United States, a total of 6,283 pedestrians were killed in vehicle crashes in 2018, accounting for 17% of all crash fatalities; and approximately 75,000 pedestrians were injured in motor vehicle crashes on public roadways in 2018. Among pedestrian crashes of all severities, the most common scenario involves pedestrians crossing in front of a passenger vehicle that is traveling straight ahead. These crashes typically occur on roads with speed limits below 40 mph and about half of these crashes occur at intersections.

Vehicle-pedestrian Crash Research

To reduce injuries and deaths from vehicle-pedestrian crashes, researchers focus on three main areas: 1. traffic engineering, 2. crash avoidance features of vehicles, and 3. vehicle design features. Examples of traffic engineering improvements include more sidewalks, pedestrian overpasses, medians, and lower speed limits in areas frequented by pedestrians. Crash avoidance features on vehicles, such as pedestrian detection and autobrake systems that detect moving pedestrians and apply the brakes are another important countermeasure. Vehicle design features, especially front end designs of bumpers and hoods that help “cushion” a pedestrian in a crash, can also reduce the severity of pedestrian injuries.

In vehicle-pedestrian collisions, most struck pedestrians are hit by the front of a vehicle. The severity of the resulting injury depends on a number of factors, including the speed of the vehicle and the height of the pedestrian relative to the height of the bumper and front end of the vehicle. For pedestrians struck by cars, the initial contact occurs lower on the body, often at the waist or below. When pedestrians are struck by taller vehicles such as SUVs or pickup trucks, the initial contact occurs higher up on the body (often above the waist), posing a greater risk of injury to the head and internal organs. As a result, lower limb traumas from collisions with cars are the most common pedestrian injuries while head injuries from collisions with larger vehicles are responsible for most pedestrian fatalities.

Highway safety regulators in many other countries are engaged in vehicle testing programs specifically aimed at protecting pedestrians. Four potential vehicle design features showing great promise for reducing pedestrian injuries and death in collisions include: 1. increasing the distance between the underside of the vehicle hood and the top of the engine, 2. pop-up hoods that automatically lift up a few inches upon impact in a collision, 3. external airbags around hoods and windshields in the areas where pedestrians most often hit their heads in a collision, and 4. bumpers with more “give” in a collision (the focus of this activity).

Day 1 - Measuring Baseline Crash Pulses of Unmodified Cars

MATERIALS NEEDED

For each group of 2-3 students:

» 1 Hot Wheels® toy car or similar toy car
» 4 sections of Hot Wheels® track
» 3 Hot Wheels® track connectors
» 2 game dice or 4 pennies
» 4-6 textbooks or similar-sized track supports
» 1 2.5-cm thick, 10 cm x 20 cm (4 x 8 inch) foam pad or similar soft padded object to cushion the sensor after each simulated crash
» 1-2 pairs of scissors
» 1 metric ruler, 30 cm length
» 1 foam packing peanut
» 1 paper "Pedestrian Crash Test Dummy" outline (See Advance Preparation)
» 15 cm of transparent tape
» 50 cm of masking tape
» 1 wireless acceleration sensor with accompanying analysis software or app (e.g., PocketLab Voyager, Vernier GoDirect, PASCO 3-Axis, see ordering information below*)
» 1 Bluetooth® 4.0 capable computing device (e.g., smartphone, tablet, laptop computer) to communicate with the sensor

Per student:

» 1 "Project Pedestrian" Student Activity Sheet
» 1 calculator
» 1 pair of safety glasses

OPTIONAL MATERIALS

Per class:

» Audio file of NPR broadcast "Why Pedestrian Deaths Are at a 30-Year High" (Running time 3:33, air date 3/28/19) (Can download MP3 file from "Project Pedestrian" Teacher area.)
» Wireless connection to online document storage site (e.g., Google Docs, iCloud, Dropbox)
» Computer with web access
» Computer projector with speakers

Per group:

» 1 camera-enabled device (e.g., smartphone or tablet with camera) to take photos of bumper designs

Ordering information for wireless acceleration sensors

NOTE 1: The following sensors are compatible with iOS, Android, Chrome OS, Windows 10, and Mac OS.

Note 2: Each company provides free software or an app to analyze their sensor's recorded data. Before using any of the sensors, you must download the sensors' software or app to a Bluetooth® 4.0 capable computing device (e.g., tablet, laptop computer, smartphone).

» GoDirect® Acceleration sensor – by Vernier, item # GDX-ACC (Vernier.com), $99 each
» PocketLab Voyager® sensor – by PocketLab (thepocketlab.com), $148 each
» Wireless 3-Axis Accelerometer/Altimeter – by PASCO, item # PS-3223 (pasco.com), $85 each

Day 2 – Measuring Crash Pulses of Cars with Modified Bumpers

NOTE: In addition to all of the materials used in Day 1, the bumper design materials listed below also need to be provided.

MATERIALS NEEDED

For each group of 2-3 students:

» 2 cotton balls
» 2 cotton squares
» 2 pipe cleaners
» 3 plastic drinking straws *(of varying widths if possible)*
» 2 pieces of dish sponge (2.5 cm x 2.5 cm x 1.5 cm)
» 1 quarter-sized lump of soft clay or Play-doh®
» 3 foam packing peanuts *(of varying shapes and sizes if possible)*
» 1 10 cm x 10 cm square of plastic bubble wrap

OPTIONAL MATERIALS

Per class:

» Wireless connection to online document storage site (e.g., Google Docs, iCloud, Dropbox)
» Computer with web access and printer
» Computer projector with speakers

Advance Preparation

» Make copies of the "Project Pedestrian" Student activity sheets for Day 1, Day 2, and Day 3 (1 set per student) and the "Pedestrian Crash Test Dummy Outline" sheet (see next page) and cut out one rectangular dummy outline per group.

» If a computer with speakers is available, download the "Why Pedestrian Deaths Are At A 30-Year High" National Public Radio (NPR) broadcast (running time 3 ½ minutes) from the "Project Pedestrian" Teacher Area.

» Watch the activity's Introduction and Conclusion videos at classroom.iihs.org/project-pedestrian and decide if they should remain in the lesson.

» For additional lesson advice, watch the Teacher Tips video for this activity located under the Teacher tab at classroom.iihs.org/project-pedestrian

» Assemble sets of Day 1 and Day 2 materials for each group.

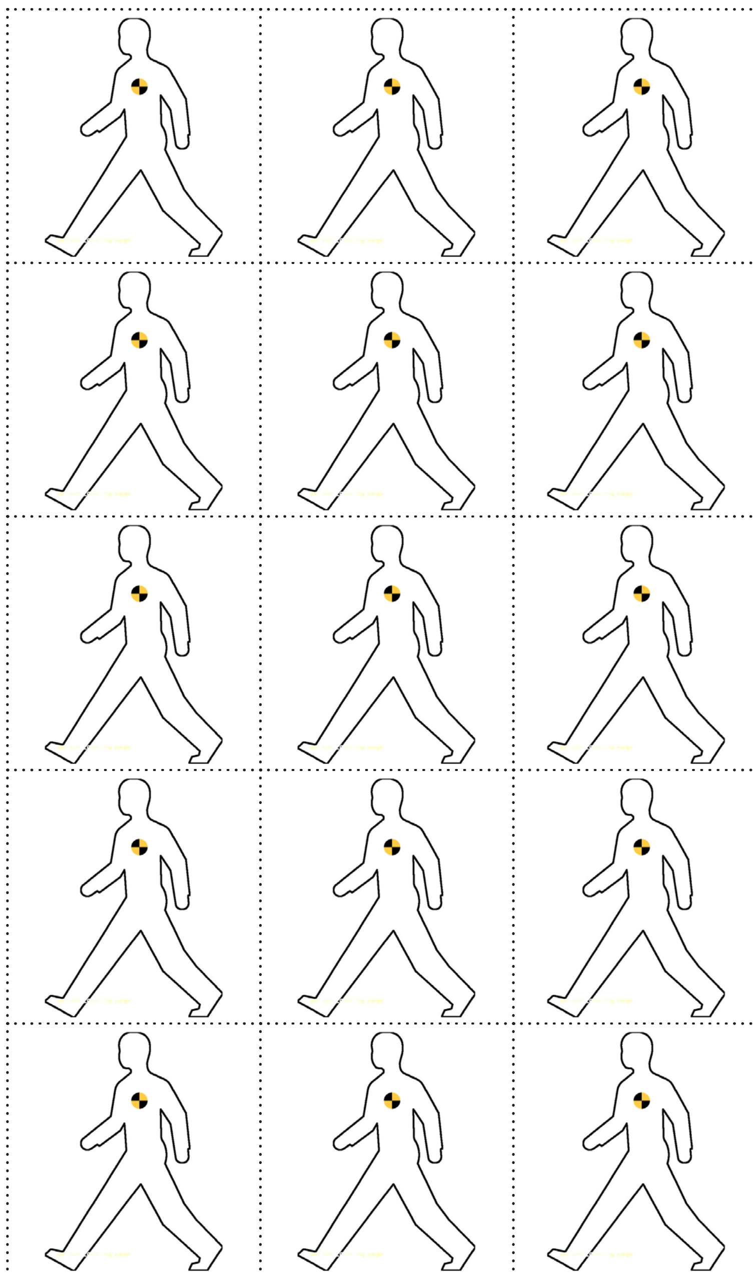
» Download the wireless acceleration sensor's analysis software or app (provided free on the sensor company's website, see Ordering information for wireless acceleration sensors) to each Bluetooth® 4.0 capable computing device (e.g., tablet, laptop computer, smartphone).

» (Optional) Prepare the sensors for the students
  › To save class time, or if working with students who are unfamiliar with using sensors, prepare the sensors (1 per group) before class by following the "Sensor Preparation" steps on the Project Pedestrian Student Activity sheet and pair each sensor with a Bluetooth® 4.0 capable computing device (e.g., tablet, laptop computer, smartphone) that has the sensor's analysis software or app downloaded on it.

» For Day 3, cue up the video segment "**Performance of pedestrian crash prevention varies among midsize cars**" (running time 2:33) located in this lesson's video gallery or on the IIHS website (iihs.org) at https://www.iihs.org/news/detail/performance-of-pedestrian-crash-prevention-varies-among-midsize-cars.
CAUTION - VIEWER DISCRETION IS ADVISED: The video contains dramatic footage of a vehicle striking a child-size crash dummy and may not be suitable for younger students.

Pedestrian Crash Test Dummy Outline

Advance Preparation - Cut along dotted lines to produce one outline per group.



PROJECT PEDESTRIAN

Procedure

Day 1 - Measuring Baseline Crash Pulses of Unmodified Cars

1. If a computer with speakers is available, play the National Public Radio (NPR) broadcast “Why Pedestrian Deaths Are At A 30-Year High” (Download from the Project Pedestrian Teacher Area, running time 3 ½ minutes). Otherwise, skip to Step 2.
2. Initiate the activity by asking students the three questions below regarding pedestrian safety and review correct answers.
   a. Question 1 - The next time you cross a street in the U.S. are you more or less safe than pedestrians were 10 years ago? (Answer: You are less safe. The number of pedestrian deaths in the U.S. has increased since reaching its lowest point of 4,109 deaths in 2009.)
   b. Question 2 - Are pedestrians more likely to be struck by vehicles in urban (cities), suburban, or rural areas? (Answer: Most pedestrian crashes occur in urban areas where pedestrian activity is concentrated. In 2016, 76% of all pedestrian deaths in the U.S. occurred in urban areas.)
   c. Question 3 - What areas of a vehicle (front, side, or rear) and parts of a vehicle most often strike a pedestrian? (Answer: Most pedestrians are hit by the front of a vehicle and most initial contacts are with the bumper and/or the front edge of the hood.
3. Introduce the activity and pose the Key Question: How can the front ends of vehicles be designed to minimize pedestrian injuries in a crash?
4. Inform students that, as part of the engineering design process, automotive scientists and engineers often build models to simulate collisions and test the potential effectiveness of different vehicle safety designs and added safety features. Explain that during this activity, students will be working in groups of 2-3 to design protective bumpers for small toy cars and conduct simulated vehicle-pedestrian collisions with these cars to determine which types of materials and bumper designs provide the best protection to pedestrians in a collision.
5. Show the “Project Pedestrian” Introduction video located at classroom.iihs.org/project-pedestrian. Distribute a “Project Pedestrian – Day 1” Student Activity Sheet to each student and review the Purpose of the Activity and the Did You Know? Information.
6. Divide students into groups and distribute all Day 1 supplies, including safety glasses and calculators.
7. Review the Procedure for **Part A - Pedestrian Crash Test Track Assembly**. Refer to Figure 1 on the Student Activity sheet to show students a sample of a complete Pedestrian Crash Test Track set up.
8. Instruct groups to set up their tracks in a smooth flat area and assist groups as needed. (NOTE: Long flat tables or tile floors work well.)
9. Once all test tracks have been assembled, instruct students to test their tracks for straight alignment by rolling a toy car along the entire length of the track. Tell students to straighten and re-tape their tracks until the car rolls freely along the entire length of the track when released.

Procedure (continued)

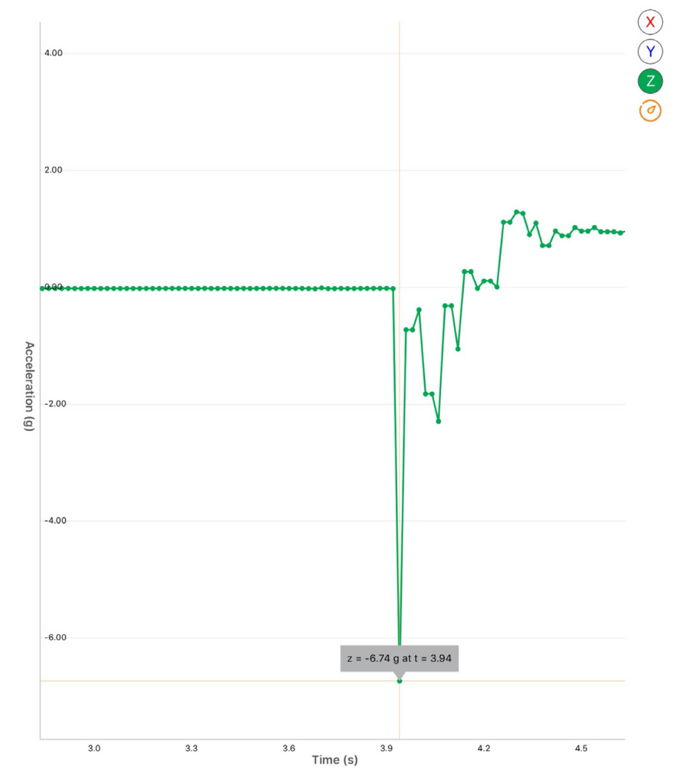
10. Next, walk students through the procedure for preparing the sensor (see Project Pedestrian Student Activity Sheet, **Part B - Preparing the sensor**)

- ***a.*** To raise the bottom of the sensor above the raised edges of the track, show students how to tape the dice together to make a small platform for the sensor. If dice are not available, a stack of four pennies taped together may be used to make the small platform (See Figures 2 and 3). Remind them to use the clear tape to tape the Styrofoam® packing peanut and the paper Pedestrian Crash Test Dummy outline to the sensor (See Figures 5 and 6).
- ***b.*** Circulate among the groups to ensure that they are following the sensor preparation directions closely. It is very important to ensure that they adjust the sensor's sampling rate (i.e., how many data points are measured in one second) to at least 50 points per second.
- ***c.*** Remind groups to select the measurement units of g's for acceleration and test that the sensor is recording in the Z-axis (forward/backward movement) by tapping the front of the sensor with their finger while watching the sensor's application or software display for a downward "spike" (negative range) on the graph.
- ***d.*** Make sure students understand that, the downward "spike" (negative range) on the graph indicates the sensor is moving backwards (i.e., the toy car strikes the sensor's front knocking it in the direction toward the back of the sensor). If upward "spikes" (positive range) are preferred, turn the sensor around 180˚ and allow the car to strike the back of the sensor.
- ***e.*** Inform students that engineers and scientists call the graph of the "spike" produced by the collision a crash pulse graph. Use background information and the definitions provided to define the term "crash pulse." Explain that in this activity, their challenge is to reduce the height of the crash pulse spike recorded by the sensor during the crash between the toy car and the Pedestrian Crash Test Dummy. The taller the spike, the greater the impact on the Pedestrian Crash Test Dummy (measured in g's) and the greater the probability of injury.

11. Before moving on to Part C, remind groups of the importance of accurately measuring and recording the height of their track's starting line (see Figure 1 and Table 1) and the sensor's crash site location (34 cm from the far end of the track, see Figures 1 and 7).

12. Next, review the procedure for **Part C - Measuring Baseline Crash Pulses of Unmodified Cars** and review the instructions for completing Data Table 1 (See Sample Completed Data Table in Figure 1). Circulate and assist groups as needed during the crash tests without modified front-ends.

Figure 1: Sample Data Table 1
Data Table 1. Baseline Crash Pulses of Unmodified Cars

TRIAL #	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL #5
1	-4.77	
2	-5.28	
3	-5.24	
4	-7.34	
5	-6.74*	
6	-4.48	
7	-6.69	
8	-4.80	
9	-6.07	
10	-6.32	
AVG.	-5.77	

**see sample graph, green line is Z-axis*

13. Once groups have completed Data Table 1, ask student to disassemble the tracks, turn off the sensors and recording devices, and store the supplies. To better ensure that students accurately replicate their track setup for Day 2, remind students to double check the measurements for their track's starting line height and sensor's crash site location (i.e., 34 cm from the end of the track). If cameras are available on group members' smartphones or tablet devices, ask them to take pictures of their track set ups before they disassemble them to further facilitate Day 2's reassembly.

14. Conclude Day 1 by asking students to share and compare their results. Remind students of the activity's key question: How can vehicle front ends be designed to minimize pedestrian injuries in a crash? Make sure students understand that impacts in which vehicles decelerate more slowly (i.e., crashes with lower negative acceleration measurements on their sensors) would likely result in less severe injuries to pedestrians. Inform groups that their challenge for Day 2 will be to engineer new front ends for their cars that help them decelerate more slowly and reduce acceleration measurements when their car impacts the Pedestrian Crash Test Dummy sensor.

15. Collect groups' completed Day 1 Project Pedestrian Student Activity sheets.

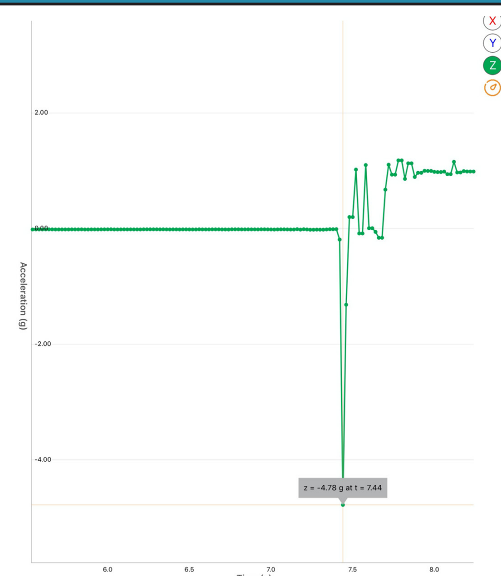
Procedure

Day 2 - Measuring Crash Pulses of Cars with Modified Bumpers

1. Divide students into their Day 1 groups and redistribute all Project Pedestrian Crash Test Track building supplies and the “Project Pedestrian – Day 1” and “Project Pedestrian – Day 2” activity sheets. Refer to the activity sheet and review the Key Question and explain that today’s lesson will focus on investigating how to reduce injuries during a crash by modifying the front end of a car with materials that reduce the impact of the crash on a struck pedestrian (as measured in g’s).
2. Instruct groups to reassemble their Project Pedestrian Crash Test Tracks using their assembly measurements from Day 1. If students recorded pictures from Day 1, remind them to refer to the pictures to help facilitate a more accurate reassembly of the crash track.
3. Distribute the wireless sensors and Bluetooth® 4.0 capable computing devices (e.g., smartphones, tablets, laptop computers). Ask groups to turn on and pair their sensors and computing devices.
4. Once all groups have completed assembling their tracks and pairing their devices, refer to the Day 2 section of the student activity sheet and review the Engineering Challenge Rationale, Engineering Design Challenge, and Design Parameters and review the Day 1 and 2 Safety Notes.
5. Distribute the Day 2 modified bumper building materials.
6. Next, review the Procedure for **Part D - Brainstorm, Design, and Build Modified Bumpers** and instruct groups to work collaboratively with their partners and brainstorm a bumper designed to reduce the crash decelerations recorded on the Pedestrian Crash Test Dummy’s sensor in simulated collisions.
7. Allow groups 15-20 minutes to brainstorm, draw, describe, and build their designs and instruct them to complete items 1-4 on Part D of the activity sheet.
8. Review the Procedure for **Part E - Test, Gather Data, and Analyze Modified Bumper Performance** and instruct groups to conduct at least five trials using their car with modified bumper. Circulate among groups to ensure that students are using a consistent and correct procedure for each trial and are correctly recording results in Data Table 2 (See Sample Completed Data Table in Figure 2 below).
9. After students have completed their simulations and filled in Data Table 2, instruct groups to analyze their data as well as observations made of their modified bumper’s performance during the simulations to complete item 9 on Part E of the activity sheet.
10. Review the Procedure for **Part F - Redesigning Modified Bumper Based on Observations and Data** and instruct groups to modify and test their designs and record results in Data Table 3 (See Sample Completed Data Table in Figure 3 below).
11. If cameras are available on groups’ tablets or smartphones, have students take pictures of their cars with redesigned bumpers and save the files to the class’s online document storage folder. Have students label the files with their group members’ names and class period. If desired, have groups print a picture of each design to include with their completed activity sheets (See Figure 4 for photos of sample modified bumper designs).

Figure 2: Sample Data Table 2
Data Table 2. Crash Pulses with Modified Bumper
(see Figure 4: Sample 3 – modified bumper using cotton ball and Play-Doh®)

TRIAL #	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL #4
1	-4.46	
2	-1.55	
3	-2.80	
4	-4.78*	
5	-4.40	
6	-6.23	
7	-3.82	
8	-4.44	
9	-6.82	
10	-6.45	
AVG.	-4.58	



**see sample graph, green line is Z-axis*

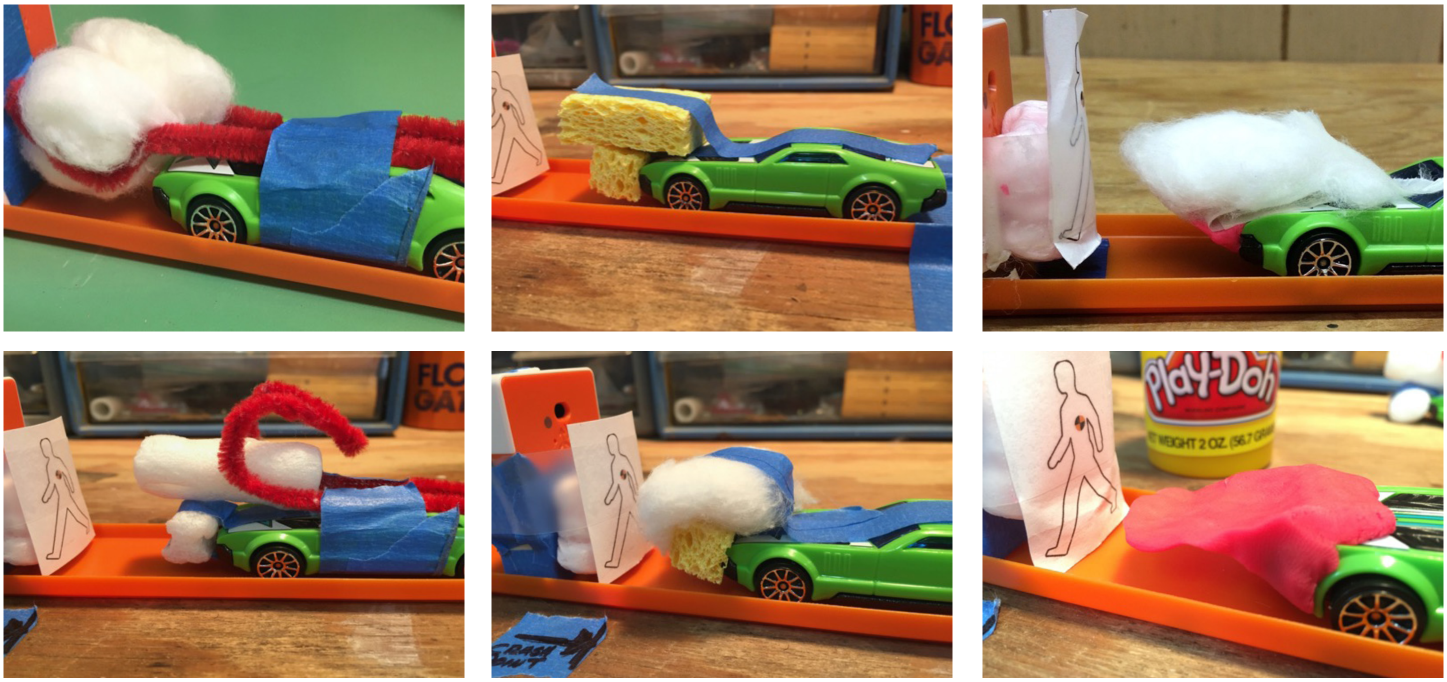
Figure 3: Sample Data Table 3
Data Table 3. Crash Pulses with Redesigned Bumper
(see Figure 4: Sample 3 – modified bumper using only Play-Doh®)

TRIAL #	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL #6
1	-2.83	
2	-3.23	
3	-3.18	
4	-3.92	
5	-3.01	
6	-3.22*	
7	-4.07	
8	-2.16	
9	-3.13	
10	-4.34	
AVG.	-3.30	

**see sample graph, green line is Z-axis*

Figure 4: Sample modified bumper designs and redesigns

SAMPLE 1 | **SAMPLE 2** | **SAMPLE 3**



SAMPLE 1

Modified Bumper (Top)
using cotton balls and pipe cleaners

Redesigned Bumper (Bottom)
using packing peanuts and pipe cleaners

SAMPLE 2

Modified Bumper (Top)
using pieces of dish sponge

Redesigned Bumper (Bottom)
using pieces of dish sponge and cotton

SAMPLE 3

Modified Bumper (Top)
using cotton ball and Play-Doh®

Redesigned Bumper (Bottom)
using Play-Doh®

12. After groups have completed all of their simulated collisions and recorded all required data in Data Tables 2 and 3, have them disassemble their crash tracks and cars with redesigned bumpers and return all supplies.

Procedure

Day 3 - Analyzing Project Results and Investigating Real-World Pedestrian-Vehicle Crash Safety Data and Testing Protocols

1. Divide students into their same groups and redistribute their completed “Project Pedestrian – Day 1” and “Project Pedestrian – Day 2” activity sheets along with the “Project Pedestrian – Day 3” sheet. Ask students to work collaboratively with their partners to answer the two Analysis Questions in **Part G - Analyzing Test Results and Drawing Conclusion**s.
2. Have groups share their responses to each Analysis Question and review correct responses using the answers provided at the end of this lesson plan.
3. Next, instruct students to work with their partners to answer Crash Questions 1 and 2 regarding pedestrian deaths at intersections.
4. Have groups share their responses and review the correct answers. If time permits, provide students with additional information regarding how crash safety engineers at auto manufacturing companies use the laws of physics to design or modify the front structures (i.e., bumpers, front grilles, hoods, and windshields) of passenger vehicles to reduce the severity of pedestrian injuries. Inform students that vehicle safety regulators in Europe, Japan, Korea and Australia have implemented vehicle-testing programs specifically aimed at protecting pedestrians. These testing programs focus on pedestrian interactions with the hood and bumper and in some cases the hood edge and the windshield. To perform well in these tests, engineers have designed several features to reduce impact force by extending the time of impact in a vehicle-pedestrian collision: A. more crumpling space between the hood and the engine, B. pop-up hoods that automatically lift up a few inches upon impact, C. adding pedestrian hood airbags that cover the parts of the windshield where pedestrians frequently hit their heads, and D. designing bumpers with more give.
5. Before working on Crash Question 3, have the whole class watch the IIHS News video from October 29, 2019 “**Performance of pedestrian crash prevention varies among midsize cars**” (running time 2:33) located in this lesson’s video gallery or on the IIHS website (iihs.org) at https://www.iihs.org/news/detail/performance-of-pedestrian-crash-prevention-varies-among-midsize-cars. **CAUTION - VIEWER DISCRETION IS ADVISED:** The video contains dramatic footage of a vehicle striking a child-size crash dummy and may not be suitable for younger students.
6. Inform students that the IIHS began rating pedestrian crash prevention systems in 2019. Explain that pedestrian detection systems continuously monitor traffic in front of vehicles and warn drivers of potential collisions with pedestrians. Many systems also automatically apply the brakes when a crash is imminent.
7. Next, refer to Figure 10 illustrating three common pedestrian crash scenarios used by the IIHS to tests the effectiveness of automatic emergency braking systems. Tell students to use the 4 criteria provided to compare and contrast the three scenarios.
8. Then instruct students to work collaboratively to answer Crash Question 3.
9. Have students share their responses and review correct answers. Show the Conclusion video located at classroom.iihs.org/project-pedestrian/.
10. If time permits, show the whole class the video “A New Chapter for IIHS Vehicle Research” located in this lesson’s Video Gallery or in the “How Can Cars Avoid a Crash” tile (both located at classroom.iihs.org) to provide additional information on automatic emergency braking systems and other crash avoidance technologies.

TEACHER LESSON PLAN

PROJECT PEDESTRIAN

Answers to Analysis Questions

1. Which of your group's designs (original unmodified car, car with modified bumper, or car with redesigned bumper) was most effective at reducing crash decelerations in your simulated collisions? Support your conclusion with observations about your most effective design features and data from your investigations.

Answers will vary, but typically, the most successful cars are the cars with redesigned bumpers that have one or more of the following design features:

- » Soft, flexible material to compress or "give" during the impact *(e.g., cotton balls, Styrofoam packing peanuts, sponges, and/or soft clay)*
- » Soft material extends outward in front of car
- » Wide bumper to increase the impact surface area
- » Sufficient soft material to also cover the front portion of the hood
- » Flexible framework that slides or gives during impact *(e.g., pipe cleaners, drinking straws)*

An example of a redesign that increases the time of impact is the long and wide Play-Doh® bumper seen in Figure 4 – Redesign of Sample 3. From the examples recorded in Data Tables 1, 2, and 3, the average decelerations dropped from 5.57 g to 4.58 g to 3.30 g (respectively). The redesigned bumper with the long and wide Play-Doh® front end had the lowest measured deceleration upon impact.

2. After your class review of the concepts of momentum, impulse, impact force, and impact time that were covered in your previous crash-related activities, use all four of these terms to explain how your group's modified or redesigned bumper decreased (or tried to decrease) the impact force during the impact with the pedestrian.

To reduce the crash deceleration upon impact with the pedestrian, the bumper must decrease the car's momentum during the collision by providing an impulse, which is the product of two variables – impact force x impact time. The more the redesigned or modified bumper "slows down" (i.e., increase the impact time of) the collision, the smaller the final impact force on the pedestrian will be. Using soft materials that "give" during impact helps increase the time of impact (i.e., helps the car decelerate more gradually) thereby reducing the sensor's crash deceleration.

Answers to Crash Questions

Pedestrian Deaths at Intersections

1. Rank the four age-groups (from most to least) by the percentage of deaths that occurred at intersections.

Most - ≥70 years (40%), 13-19 years (25%), 20-69 years (22%), <13 (17%) - Least

2. If you were a traffic engineer, describe an improvement you could make to intersections to possibly reduce the fatalities in the age-group with the highest percentage of deaths at intersections.

Since the ≥70 years age group has the percentage of deaths of the age groups at intersection, possible answers include: extending the time available for older pedestrians to cross intersections with signals, add more highly-visible pavement markings to encourage older pedestrians to look for turning vehicles, or spinning lights mounted to pedestrian crossing signs that spin when pedestrians are present to draw the attention of drivers to pedestrians.

Automatic Emergency Braking System Tests

3. **a. Based on your observations of these three scenarios and what you have learned about the physics of pedestrian-vehicle collisions, if you were an automotive engineer responsible for designing effective AEB systems, which scenario would you consider the <u>most challenging</u> for the AEB system to detect and brake in time to avoid a collision with a walking pedestrian?**

Scenario 1

b. Refer to the positions of the pedestrians and vehicles as well as the additional data provided for the scenarios to justify your answer.

In Scenario 1 (called the "perpendicular child scenario), the 45-inch-tall (114 cm) dummy, which represents an average-size 7 year-old, is hidden by a car and an SUV parked on the right side of the road as the test vehicle approaches. There is no clear line of sight for the AEB camera until the dummy begins emerging from behind the parked vehicles. At this point, the test vehicle traveling at 25 mph (40 km/h) is just under 2 seconds away, or 65 feet (20 m) away, from hitting the dummy. When the dummy fully enters the car's travel lane, the test vehicle is only about 1.5 seconds away from the dummy. Consequently, there is less time for the vehicle's software to detect the dummy and stop the vehicle.

Extensions/Modifications

1. If longer block period schedules are available or if working with gifted or advanced students, rather than providing each group with an identical set of materials for building their car bumpers on Day 2, a variety of potential bumper building materials could be provided in a central classroom location and groups could be given the freedom to choose the type and amount of bumper building materials they would like to use.

2. Have students visit IIHS.org, click on "Topics," select "Pedestrians and bicyclists" and peruse some of the following subtopics listed along the left margin of the webpage:

- By the numbers
- Bicycle helmets
- Vehicle speeds
- Design along roadways
- Intersections and mid-block crossings
- Vehicle design
- Crash avoidance technology

3. Have students further explore the classroom.iihs.org website to view other types of crash avoidance technologies by selecting the section entitled "How Cars Can Avoid a Crash."

STUDENT ACTIVITY

Name: ____________________ Class: __________ Date: ____________

PROJECT PEDESTRIAN

Day 1 - Measuring Baseline Crash Pulses of Unmodified Cars

DAY 1 MATERIALS NEEDED

For each group of 2-3 students

» 1 Hot Wheels® toy car or similar toy car
» 4 sections of Hot Wheels® track
» 3 Hot Wheels® track connectors
» 2 game dice or 4 pennies
» 4-6 textbooks or similar-sized track supports
» 1 pre-cut foam pad or similar soft padded object to cushion the sensor
» 1-2 pairs of scissors
» 1 metric ruler, 30 cm length
» 1 foam packing peanut
» 1 paper Pedestrian Crash Test Dummy outline
» 15 cm of transparent tape
» 50 cm of masking tape
» 1 wireless acceleration sensor
» 1 Bluetooth® 4.0 capable computing device (e.g., smartphone, tablet, laptop computer)

Per student

» 1 "Project Pedestrian" Student Activity Sheet
» 1 calculator
» 1 pair of safety glasses

Optional (per class)

» Wireless connection to online document storage site (e.g., Google Docs, iCloud, Dropbox)

Optional (per group)

» 1 camera-enabled device (e.g., smartphone or tablet with camera)

Safety notes for Day 1 and Day 2:

» Follow all general lab safety procedures.
» Use caution when working with scissors.
» Wear safety glasses when conducting collision simulations.
» Wash your hands with soap and water after completing this activity.

Key Question(s)

» How can the front ends of vehicles be designed to minimize pedestrian injuries in a crash?

Purpose

» To design a bumper for a small toy car that provides the best protection to a pedestrian crash test dummy in a simulated collision
» To analyze crash pulse graphs from simulated collisions to determine which types of materials and bumper designs provide the best protection to pedestrian crash test dummies in a simulated collision
» To describe a vehicle-pedestrian collision in terms of changing momentum, impulse, impact force, and impact time
» To analyze a data table to determine the age groups at greatest risk of death in vehicle-pedestrian collisions
» To make inferences about the potential effectiveness of automatic emergency braking systems in different vehicle-pedestrian scenarios

Did You Know?

In the past 10 years, the number of pedestrians killed by motor vehicles in the U.S. has drastically increased and most pedestrian crashes occur in cities. Along with vehicle crash avoidance technologies such as pedestrian detection sensors and automatic braking systems and traffic engineering improvements such as more sidewalks, overpasses, and medians and lower speed limits, vehicle front ends can also be designed to reduce the type and severity of pedestrian injuries in a collision and save lives. In this simulation activity, you will apply the same physics laws and concepts that automotive scientists and engineers use to design vehicle front ends that reduce pedestrian injuries and deaths in collisions.

STUDENT ACTIVITY

CRASH SCIENCE IN THE CLASSROOM

PROJECT PEDESTRIAN

Day 1 - Measuring Baseline Crash Pulses of Unmodified Cars

Procedure

Part A. Pedestrian Crash Test Track Assembly

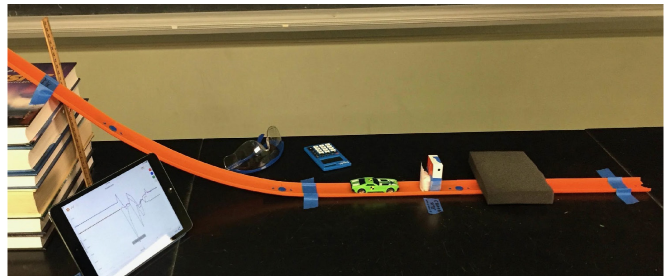


Figure 1- Crash Test Track Set-Up
Height of starting line above table (cm) = 23 cm

1. Watch the activity's Introduction video at classroom.iihs.org/project-pedestrian
2. Connect the four sections of Hot Wheels® track together using three track connectors.
3. With books as a support, create an elevated starting ramp for the toy car by securing one end of the track to the stack of books. See Figure 1.
4. Measure straight upwards from the table or floor to a spot on the track 23 cm above the table or floor. Mark this point as the starting line. Secure the top of the track to the books with a strip of tape (See Figure 1).
5. At the bottom of this elevated starting ramp, create a 60-cm long straightaway on a flat, hard surface (floor or table top) and use a strip of masking tape across the end of the track to secure it to the floor or table.
6. Place the piece of foam padding provided (e.g., small pillow, stuffed animal, etc.) at the end of track to catch the sensor and car after the collision (See Figure 1).

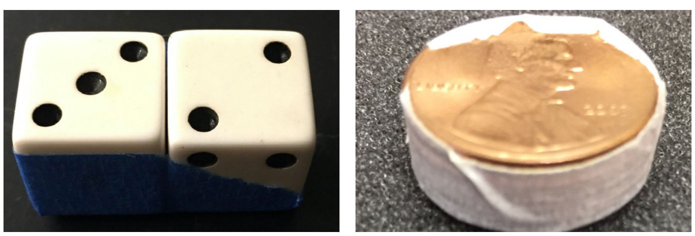


Figure 2 - Sensor base
(Left) Two dice or (Right) four pennies

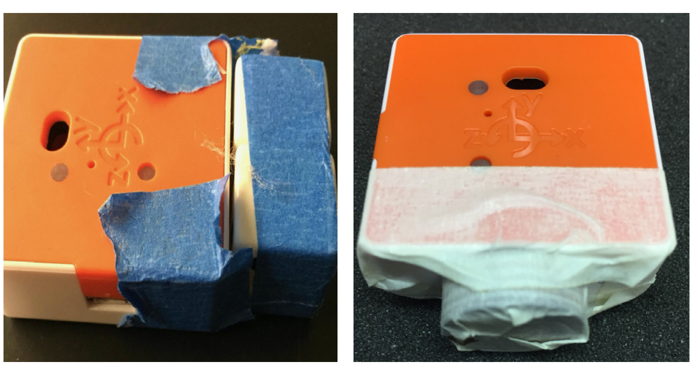


Figure 3 - Sensor attached to base
(Left) Sensor on dice or (Right) Sensor on pennies

Part B. Preparing the sensor

1. Tape two dice or a stack of four pennies together to form a small platform for the sensor (see Figure 2).
2. Tape the wireless sensor on top of the two-dice or stack of pennies (See Figure 3). The sensor will represent the Pedestrian Crash Test Dummy and will measure the impact of the crash on the dummy in g's.
3. Prepare the wireless sensor to record the impact by following these steps:
   a. Turn on the sensor.
   b. Pair the sensor with your computing device (e.g., tablet, smartphone, laptop, et.). If needed, refer to the sensor's owner's manual for pairing instructions.
   c. Open the sensor's app or software on your computing device. If the sensor can record multiple types of data (e.g., acceleration, light, altitude), select "acceleration."
   d. Adjust the sampling rate (i.e., how many data points are measured in one second) to at least 50 points per second.

STUDENT ACTIVITY

PROJECT PEDESTRIAN

Day 1 - Measuring Baseline Crash Pulses of Unmodified Cars

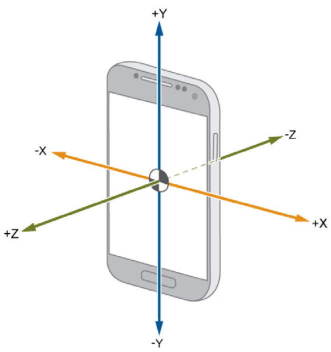


Figure 4 -Sample x, y, and z axes (z-axis measures front-to-back movement)

e. If the sensor is a 3-axis accelerometer, select the Z-axis. The Z-axis measures movement from the front face of the sensor toward its backside (as well as from the backside to the front). See Figure 4 for an example of X, Y, and Z-axes on a smartphone.

f. Select measurement units of g's for acceleration.

g. Test if sensor is recording on the Z-axis by tapping the front of the sensor with your finger while watching the sensor's application or software display on your computing device (e.g., tablet, smartphone, or laptop). You should see a downward "spike" (negative range) on the graph. **NOTE: The downward "spike" on the graph indicates the sensor is moving backwards so all of the g measurements you record should be written as negative numbers in your Data Tables.** The harder you tap on the front of the device, the bigger the "spike" will appear on the screen. Engineers and scientists call the graph's "spike" a crash pulse. Larger "spikes" or crash pulses mean bigger impacts.

h. In its role as the pedestrian in your simulated collisions, the car will strike the sensor when released. To help the sensor more accurately measure the impact of the crash on the Pedestrian Crash Test Dummy, tape one packing peanut along with the paper Pedestrian Crash Test Dummy outline against the lower front of the sensor as shown in Figures 5 and 6.

4. Place the sensor on the track's flat straightaway on the table or floor so that the front of the sensor is exactly 34 cm from the far end of the track. It is extremely important to place the sensor at this same spot for every trial. Mark this spot by writing "Crash Site" with a line below it on a piece of tape and securing the piece of tape next to the track so that the line on the piece of tape is exactly 34 cm from the far end of the track (See Figure 7)

Figure 5 - Packing peanut attached to sensor

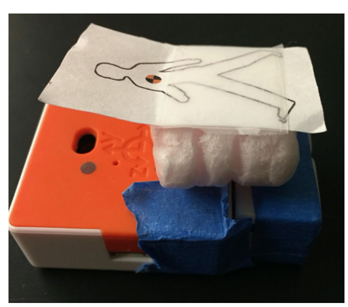


Figure 6 - Pedestrian Crash Test Dummy attached to packing peanut on sensor

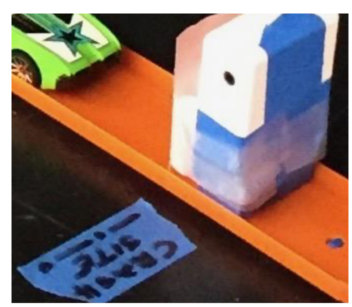


Figure 7 - Crash site marked at 34 cm from far end of track

Part C. Measuring Baseline Crash Pulses of Unmodified Cars

1. Place the toy car near the top of the track so its front end is at the starting line, 23cm above the tabletop/floor.
2. Find the “Start” recording button on the screen of your computing device (e.g., tablet, smartphone, or laptop). Press the “Start” button to begin data recording.
3. Release the toy car.
4. Press the “Stop” button to end data recording after the simulated collision.
5. Record the value displayed at the peak of the crash pulse as a negative number in the “Acceleration” column next to Trial #1 in Data Table 1.
6. Repeat Steps 1-5 for at least 5 trials.
7. After one of the trials, draw a copy of the crash pulse graph produced by the sensor’s software in the Data Table below (or if possible, take a screen shot and save the file to your class’s online document storage folder).
8. After all trials are completed, calculate the average of all of the accelerations recorded for all of your simulated collisions and record the average in the bottom of the Acceleration column.

Data Table 1. Baseline Crash Pulses of Unmodified Cars

TRIAL	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL # _____
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
AVG		

STUDENT ACTIVITY

Name: ____________________ Class: __________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

PROJECT PEDESTRIAN

Day 2 - Measuring Crash Pulses of Cars with Modified Bumpers

NOTE: Before designing and testing your modified toy car bumpers, assemble your Pedestrian Crash Test Track Assembly exactly as it was constructed on Day 1. Then, when instructed to by your teacher, collect the modified bumper design building materials listed below.

DAY 2 MATERIALS NEEDED

For each group of 2-3 students

» 2 cotton balls
» 2 cotton squares
» 2 pipe cleaners
» 3 plastic drinking straws
» 2 pre-cut pieces of dish sponge
» 1 quarter-sized lump of soft clay or Play-doh®
» 3 foam packing peanuts
» 1 pre-cut square of plastic bubble wrap

Engineering Challenge Rationale

Most struck pedestrians are hit by the front of a passenger vehicle. Most serious injuries result from pedestrians hitting vehicle bumpers, hoods, or the windshield area.

Engineering Design Challenge

Using the building materials provided, follow the design parameters below to design, build, test, redesign, and re-test a bumper attached to a toy car's front-end to reduce the crash decelerations (measured in g's) between the toy car and a pedestrian crash test dummy in a simulated collision.

Design Parameters

» Bumpers cannot touch or interfere with the car's wheels.
» Bumpers cannot touch the track.
» Nothing may be added to the track or sensor to slow the car.
» Building materials may only be selected from those provided by the teacher.
» You do <u>not</u> have to use all of the bumper construction materials provided.

Part D. Brainstorm, Design, and Build Modified Bumpers

1. Brainstorm ideas with your partners to design a bumper from the materials provided that reduces the crash decelerations recorded on the pedestrian crash test dummy's sensor in simulated collisions.
2. Draw your group's car with modified bumper design in the space below and use labels to indicate the materials used to build the bumper.

CAR WITH MODIFIED BUMPER DESIGN

PROJECT PEDESTRIAN

Day 2 - Measuring Crash Pulses of Cars with Modified Bumpers

1. Briefly describe your team's modified bumper and the reasoning behind your design and chosen materials. In other words, explain WHY you chose the particular design features and materials for your new bumper.

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2. Build and attach the modified bumper to the car. If possible, take a picture of the car with the modified bumper and save the file to your class's online document storage folder. Label the files with your group members' names and class period. If your teacher requests, print a picture of the design to include with this activity sheet.

Part E. Test, Gather Data, and Analyze Modified Bumper Performance

1. Place the car with the modified bumper at same starting line height used for the Unmodified Car on Day 1.

2. Find the "Start" recording button on the screen of your computing device (e.g., tablet, smartphone, or laptop). Press the "Start" button to begin data recording.

3. Release the toy car.

4. Press the "Stop" button to end data recording after the simulated collision.

5. Record the value displayed at the <u>peak of the crash pulse as a negative number</u> in the "Acceleration" column next to Trial #1 in Data Table 2.

6. Repeat Steps 1-5 for <u>at least 5 trials</u>.

7. After one of the trials, draw a copy of the crash pulse graph produced by the sensor's software in the Data Table below (or if possible, take a screen shot and save the file to your class's online document storage folder).

8. After all trials are completed, calculate the average of all of the accelerations recorded for all of your simulated collisions and record the average in the bottom of the Acceleration column.

Data Table 2. Crash Pulses with Modified Bumper

TRIAL	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL # _____
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
AVG		

PROJECT PEDESTRIAN

Day 2 - Measuring Crash Pulses of Cars with Modified Bumpers

9. Based upon your observations and the recorded accelerations, what worked well and what did not work well in your modified bumper design?

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Part F. Redesigning Modified Bumper Based on Observations and Data

1. Based on your observations and data from Part E, redesign the bumper to improve its performance.

2. Retest your new design by repeating Steps 1-8 above and complete Data Table 3.

Data Table 3. Crash Pulses with Redesigned Bumper

TRIAL	ACCELERATION (g)	CRASH PULSE GRAPH FROM TRIAL # _____
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
AVG		

3. If possible, take a picture of the redesigned bumper and save the file to your class's online document storage folder. Label the file with your group members' names and class period. If your teacher requests, print a picture of each design to include with your activity sheet.

STUDENT ACTIVITY

Name: ______________________ Class: ____________ Date: ____________

CRASH SCIENCE IN THE CLASSROOM

PROJECT PEDESTRIAN

Day 3 - Analyzing Project Results and Investigating Real-World Pedestrian-Vehicle Crash Safety Data and Testing Protocols

Part G. Analyzing Test Results and Drawing Conclusions

Analysis Questions

1. Which of your group's designs (original unmodified car, car with modified bumper, or car with redesigned bumper) was **most effective** at reducing crash decelerations in your simulated collisions? Support your conclusion with observations and data from your investigations."

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2. Watch the activity's Conclusion video at classroom.iihs.org/project-pedestrian. After your class review of the concepts of momentum, impulse, impact force, and impact time that were covered in your previous crash-related activities, use all four of these terms to explain how your group's modified or redesigned bumper decreased (or tried to decrease) the impact force during the impact with the pedestrian.

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Crash Questions - Investigating Real-World Crash Data and Testing Protocols

Pedestrian Deaths at Intersections

Traffic engineering improvements at intersections and mid-block crossings can reduce pedestrian crashes. For example, special warning signs and pavement markings can be used to encourage pedestrians to look for turning vehicles. Likewise, for drivers, rapid-flashing beacons at crossings can draw their attention to pedestrians.

Examine the data table in Figure 9 on pedestrian deaths at intersections and answer the following questions:

1. Rank the four age-groups (from most to least) by the percentage of deaths that occurred at intersections.

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2. If you were a traffic engineer, describe an improvement you could make to intersections to possibly reduce the fatalities in the age-group with the highest percentage of deaths at intersections.

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PEDESTRIAN DEATHS BY OCCURRENCE AT INTERSECTION AND AGE, 2018

	< 13 years		13 - 19 years		20 - 69 years		≥ 70 years		Total*	
	Number	%	Number	%	Number	%	Number	%	Number	%
Non-intersection	130	83	187	75	3,820	78	533	60	4,721	75
Intersection	27	17	64	25	1,091	22	357	40	1,562	25
Total*	157	100	251	100	4,911	100	890	100	6,283	100

**Total includes other and/or unknowns, data from the U.S. Department of Transportation's Fatality Analysis Reporting System*

Figure 9

Automatic Emergency Braking System Tests

Reducing pedestrian crashes is the goal of the IIHS tests of vehicle automatic emergency braking (AEB) systems. These systems bring the vehicle to a safe stop, or reduce its speed, before a pedestrian is struck. The tests address three common pedestrian crash scenarios.

3. Closely examine the drawings in Figure 10 depicting three IIHS pedestrian crash test scenarios. With your partner, identify and discuss the similarities and differences between these three scenarios using the following criteria:

i. The driver's ability to see the pedestrian (i.e., examine the driver's line of sight, look for anything blocking the driver's view of the pedestrian)

ii. The height of the pedestrian crash-test dummy

iii. The speed of the vehicle

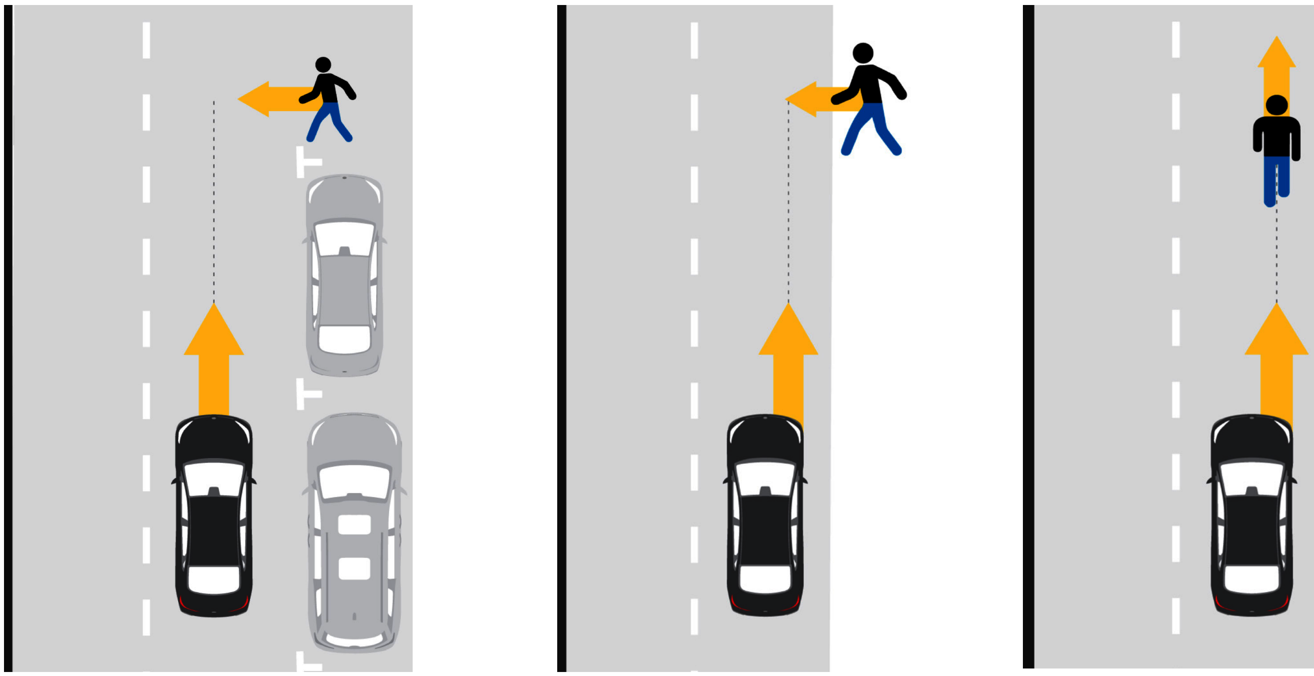
iv. The direction of pedestrian's motion compared to the road (i.e., pedestrian is walking parallel to the road, pedestrian walks perpendicular to the road)

STUDENT ACTIVITY

PROJECT PEDESTRIAN

Day 3 - Analyzing Project Results and Investigating Real-World Pedestrian-Vehicle Crash Safety Data and Testing Protocols

IIHS Pedestrian Crash Test Scenarios for AEB Systems



Scenario 1
Perpendicular child: Child runs into road; a parked car and SUV obstruct the view — tests run at 12 and 25 mph

Scenario 2
Perpendicular adult: Adult walks across road — tests run at 12 and 25 mph

Scenario 3
Parallel adult: Adult in right lane near edge of road, facing away from traffic — tests run at 25 and 37 mph

Figure 10

Additional crash test data:

» Child dummy is 45-inches tall (114 cm)
» Adult dummy is 6-feet tall (1.83 m)
» 12 mph = 19.3 km/h
» 25 mph = 40.2 km/h
» 37 mph = 59.5 km/h

a. Based on your observations of these three scenarios and what you have learned about the physics of pedestrian-vehicle collisions, if you were an automotive engineer responsible for designing effective AEB systems, which scenario would you consider the most challenging for the AEB system to detect and brake in time to avoid a collision with a walking pedestrian? CIRCLE ONE:

Scenario 1 Scenario 2 Scenario 3

b. Refer to the positions of the pedestrians and vehicles as well as the additional data provided for the scenarios to justify your answer.

APPENDICES

APPENDIX A

Phases and Actions of the 5E Instructional Model

Tables 1 and 2 provide specific information (i.e., teacher and student consistent and inconsistent actions) regarding the implementation of the 5E instructional model.

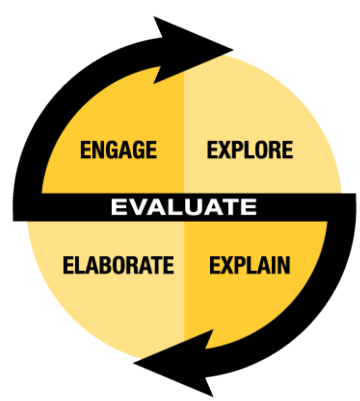
Table 1

What the Teacher Does		
Phases of the 5E Instructional Model	**These Are Consistent with the 5E Instructional Model**	**These Are Not Consistent with the 5E Instructional Model**
Engagement	• Piques students' curiosity and interest • Determines students' current understanding (prior knowledge) of a concept or idea • Invites students to express what they think • Invites students to raise their own questions	• Introduces vocabulary • Provides definitions and answers • Provides closure • Discourages students' ideas and questions
Exploration	• Encourages student-to-student interaction • Observes and listens to the students as they interact • Asks probing questions to redirect the students' investigation when necessary • Asks questions to help students make sense of their experiences • Provides time for student to puzzle through problems	• Provides answers • Proceeds too rapidly for students to understand • Provides closure • Tells the students that they are wrong • Gives information and facts that solve the problem • Leads the students step-by-step to a solution
Explanation	• Encourages students to use their common experiences and data to develop explanations • Ask questions that help students express understanding and explanations • Requests justification (evidence) for students' explanations • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Introduces terminology and alternative explanations after students express their ideas	• Neglects to solicit students' explanations • Ignores data and information students gathered from previous lessons • Dismisses students' ideas • Accepts explanations that are not supported by evidence • Introduces unrelated concepts or skills

APPENDIX A (CONTINUED)

What the Teacher Does		
Phases of the 5E Instructional Model	**These Are Consistent with the 5E Instructional Model**	**These Are Not Consistent with the 5E Instructional Model**
Elaboration	• Focuses students' attention on conceptual connections between new and past experiences • Encourages students to use what they have learned to explain a new event or idea • Reinforces students' use of scientific terms and descriptions previously introduced • Asks questions that help students draw reasonable conclusions for evidence	• Neglects to help students connect new and past experiences • Provides definitive answers • Tells the students that they are wrong • Leads students step-by-step to a solution
Evaluation	• Observes and records as students demonstrate their understanding of concepts and performance of skills • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Interviews students as a means of assessing their developing understanding • Encourages students to assess their own progress	• Tests vocabulary words, terms, and isolated facts • Creates ambiguity • Promotes open-ended discussion unrelated to the concept of skill

From: BSCS.org: Bioinformatics and the Human Genome Project



Phases of the 5E model

APPENDIX A (CONTINUED)

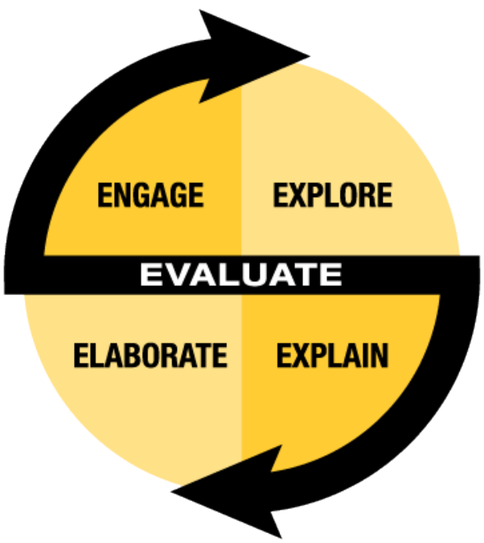
Table 2

What the Students Do		
Phases of the 5E Instructional Model	**These Are Consistent with the 5E Instructional Model**	**These Are Not Consistent with the 5E Instructional Model**
Engagement	• Become interested in and curious about the concept/topic • Express current understanding of a concept or idea • Raise questions such as, What do I already know about this? What do I want to know about this?	• Ask for the "right" answer • Offer the "right" answer • Insist on answers or explanations • Seek closure
Exploration	• "Mess around" with materials and ideas • Conduct investigations in which they observe, describe, and record data • Try different ways to answer a question • Acquire a common set of experiences so they can compare results and ideas • Compare their ideas with those of others	• Let others do the thinking and exploring • Work quietly with little or no interaction with others • Stop with one solution • Demand or seek closure
Explanation	• Explain concepts and ideas in their own words • Base their explanations on evidence acquires during previous investigations • Become involved in student-to-student conversations in which they debate their ideas • Record their ideas and current understanding • Reflect on and perhaps revise their ideas • Express their ideas with what scientists know and understand	• Propose explanations from "thin air" with no relationship to previous experiences • Bring up irrelevant experiences and examples • Accept explanations without justification • Ignore or dismiss other plausible explanations • Propose explanations without evidence to support their ideas

APPENDIX A (CONTINUED)

What the Students Do		
Phases of the 5E Instructional Model	**These Are Consistent with the 5E Instructional Model**	**These Are Not Consistent with the 5E Instructional Model**
Elaboration	• Make conceptual connections between new and past experiences • Use what they have learned to explain a new object, event, organism, or idea • Use scientific terms and descriptions • Draw reasonable conclusions from evidence and data • Communicate their understanding to others	• Ignore previous information or evidence • Draw conclusions from "thin" air • Use terminology appropriately and without understanding
Evaluation	• Demonstrate what they understand about the concepts and how well they can implement a thinking skill • Compare their current thinking with that of others and perhaps revise their ideas • Assess their own progress by comparing their current understanding with their prior knowledge • Ask new questions that take them deeper in a concept or topic area	• Disregard evidence or previously accepted explanations in drawing conclusions • Offer only yes-or-no or memorized answers • Fail to express satisfactory explanations in their own words • Introduce new, irrelevant topics

From: BSCS.org: Bioinformatics and the Human Genome Project



Phases of the 5E model.

APPENDIX B

Lesson correlation to NGSS Performance Expectations

High School

Next Generation Science Standards (NGSS) Alignment

NGSS Performance Expectations	Lessons													
High School	Penny for Your Thoughts	Pain in the Neck	Momentum Bashing 1	Momentum Bashing 2	Egg Crash!	Conservation: It's the Law!	Ball of Energy	Twirling Penny	Think Fast, Act Fast	Distracted Driving Dangers	Stressing Silly Putty	Stressing Over Pencil Pressure	Paper Car Crash!	Project Pedestrian
HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.			✓	✓	✓			✓	✓				✓	
HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.						✓	✓							
HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.		✓			✓								✓	✓
HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.											✓			
HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other components and energy flows in and out of the system are known.							✓							
HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).						✓								
HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.						✓								
HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.									✓					
HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.					✓					✓	✓	✓	✓	✓

APPENDIX B (CONTINUED)

Lesson correlation to NGSS Performance Expectations

Middle School

Next Generation Science Standards (NGSS) Alignment

NGSS Performance Expectations	Lessons													
Middle School	Penny for Your Thoughts	Pain in the Neck	Momentum Bashing 1	Momentum Bashing 2	Egg Crash!	Conservation: It's the Law!	Ball of Energy	Twirling Penny	Think Fast, Act Fast	Distracted Driving Dangers	Stressing Silly Putty	Stressing Over Pencil Pressure	Paper Car Crash!	Project Pedestrian
MS-PS- 2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.						✓								
MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	✓	✓	✓	✓	✓	✓		✓			✓			✓
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.				✓										
MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.						✓	✓				✓			
MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.									✓					
MS-LS1-8. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.									✓	✓				
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.				✓	✓								✓	✓
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.					✓								✓	✓
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.					✓								✓	✓
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.													✓	✓

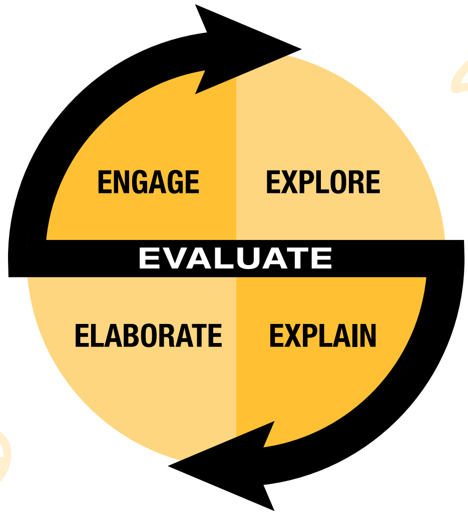
APPENDIX B (CONTINUED)

Lesson correlation to NGSS Performance Expectations

Grades 3-5

Next Generation Science Standards (NGSS) Alignment

NGSS Performance Expectations	Lessons													
Grades 3-5	Penny for Your Thoughts	Pain in the Neck	Momentum Bashing 1	Momentum Bashing 2	Egg Crash!	Conservation: It's the Law!	Ball of Energy	Twirling Penny	Think Fast, Act Fast	Distracted Driving Dangers	Stressing Silly Putty	Stressing Over Pencil Pressure	Paper Car Crash!	Project Pedestrian
5-PS1-3. Make observations and measurements to identify materials based on their property.	✓										✓			
5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.											✓			
5-PS2-1. Support an argument that the gravitational force exerted by Earth on objects is directed down.	✓		✓					✓			✓		✓	
4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.					✓	✓							✓	
4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.		✓												
4-LS1-2. Use a model to describe that animals receive different types of information through their senses, process information in the brain, and respond to the information in different ways.									✓	✓				
3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.	✓		✓	✓										✓
3-PS2-2. Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.			✓	✓										
3-5-ETS1-1. Define a simple design problem reflecting a need or want that includes specified criteria for success and constraints on materials, time, or cost.				✓	✓								✓	✓
3-5-ETS1-2. Generate and compare multiple solutions to a problem based on how well each is likely to meet the criteria and constraints of a problem.				✓	✓								✓	✓
3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.				✓	✓								✓	✓



This teaching guide will help you:

- utilize the award-winning **Understanding Car Crashes** videos
- teach inquiry-based lessons relevant to crash science
- fulfill science and engineering objectives aligned with national standards
- explore real-world applications of **STEM** concepts
- stimulate interest in modern crashworthiness and vehicle safety

Host Griff Jones, award-winning science educator

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