Collisions

Project-Based Learning Module

High School Physics

PASCO®

PASCO Engineering Design Process

PASCO's STEM Modules guide students through the multi-step engineering design process outlined below. Students work individually and in groups to design, build, test, and evaluate their engineering prototype.

1 Initial Design Ideas

Students work individually to develop design ideas based on the design requirements and constraints of the engineering challenge.

2 Research

Students work in groups to carry out the science and math activities of the module. In carrying out these standards-based activities, students investigate fundamental concepts that apply to the engineering challenge and acquire skill using the standard tools and techniques they will need to complete the challenge successfully.

3 Revise Design

Students work individually to revise, improve, or confirm their initial designs based on the science and math concepts explored in the research stage.

4 Develop Group Design

Students work in groups to produce a collaborative design based on the best elements of the various individual designs, observing the original design requirements and constraints.

5 Build a Prototype

Students work in groups to build a prototype of their group design.

6 Test and Evaluate

Using a standard test bed, students test their prototype and evaluate its success.

7 Design Review

Students analyze and evaluate the test results and propose changes to increase the effectiveness of their design.

Challenge: Collisions

Design and build a bumper that will minimize the force experienced by a model vehicle during a collision.

Activity: Momentum

Measure and compare the change of momentum of an object during an elastic and an inelastic collision.

PASCO Motion Sensor

Graphical Analysis, Algebra

Determine which type of collision, elastic or inelastic, produces the smallest change in momentum.

Activity: Area Under a Curve

An introduction to the use of rectangular approximations to find the area under a curve and to associate physical meaning to the area under a curve.

Construct a bumper that satisfies the design requirements and constraints using the information learned in the activities.

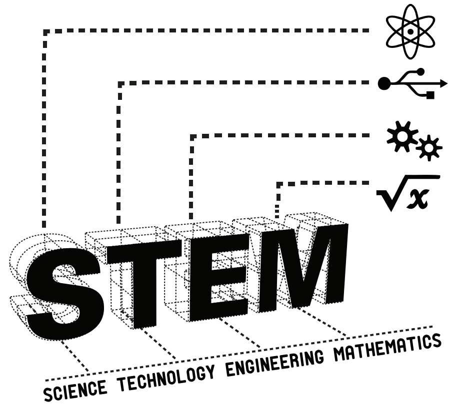
Activity: Impulse Momentum

Compare the change of momentum (before and after a collision) to the force experienced during the collision (impulse).

PASCO Force Sensor
PASCO Motion Sensor

Graphical Analysis, Algebra

Use the relationship between the impulse and the change in momentum to determine if your bumper should produce an elastic or inelastic collision to minimize the impulse.



Activity: Peak Force

Measure the peak force in a collision using different materials and structures for a bumper.

PASCO Force Sensor

Graphical Analysis, Algebra

Determine a bumper material and structure that will minimize the force experienced during a collision.

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Contents

NOTE: *Headings in bold type indicate student handouts*

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What Is STEM?

STEM education is a trans-disciplinary curriculum connecting **S**cience, **T**echnology, **E**ngineering, and **M**athematics, the combination of which promotes students' understanding of each of these fields and develops their abilities to become self-reliant researchers, innovators, and inventors. When faced with an idea or a problem, students learn how to develop solutions, how to analyze and evaluate different solutions, and how to collaborate with others to construct and test a product.

What this looks like in the classroom, however, is not always clear. In some cases, "S" is presented but not "M"—the math that explains the science. In other cases, STEM curriculum and materials focus on the "S" and the "M," leaving out the "T" and "E" —the technology element that generates solutions and gives rise to a deeper understanding of the science and math components, and the engineering element that centers on solving problems. The four parts of STEM have historically been taught separately and most of the time independently from each other; with STEM, science, technology, engineering, and math all play an important part in teaching these subjects as a whole.

PASCO's Project-Based Learning Modules

Module Principles

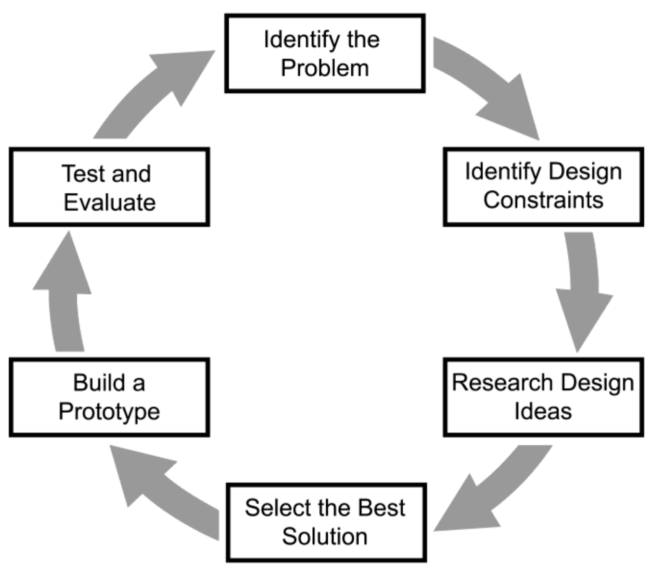
PASCO's Project-Based Learning Modules focus on all four components of S-T-E-M and are guided by various elements, including national standards; activity-, inquiry- and problem-based learning; the expectation of a tangible product or process as an outcome; and formative and summative assessments. They incorporate both independent and collaborative work, and rely on the engineering design process to bring all the pieces together.

A PASCO Project-Based Learning Module is centered on an open-ended Challenge in which students are given the task of designing, constructing, and implementing the solution to an engineering problem. The Challenge is based on fundamental science concepts in one or more genres of science: physics, chemistry, biology, and environmental science, and simulates a real-world problem that a modern engineer may encounter, with similar design constraints. Inside each Challenge are activities that focus on some or all of the key science and mathematics concepts of the Challenge and are part of the students' engineering design research.

These activities provide an opportunity for students to explore and research scientific concepts using PASCO's 21st Century Probeware and data collection systems. Students can then support their engineering designs with quantitative results from the activities. Through the activities, they obtain the science understanding, math skills, and familiarity with the techniques and tools of the field—background necessary to design and build the model or prototype.

Prototype development for a Challenge follows an engineering design process: students independently create initial solutions, they revise these solutions based on the results of the structured group activities, they analyze and evaluate the approaches of the students in their group, they finalize a group design, and they build a model or prototype for testing. Using the results of the test, they review their design and propose improvements.

Although the PASCO Engineering Design Process is shown (on the back of the title page) as a linear process that ends at the Design Review stage, engineering design is an iterative process, as shown in the circular diagram to the right. If time permits, students can use their analysis of the test results to begin again, creating an improved initial design, doing additional research, and building, testing, and analyzing the revised prototype.



Module Organization

A Project-Based Learning Module contains the student handouts and related information to assist the teacher in presenting, guiding, and assessing the students' work. Material is organized in a chronological manner, with the teacher information immediately following the handouts. For example, the pre-assessment handout is followed by the pre-assessment answer key and includes information that suggests ways to use the results and how to overcome misconceptions.

Each section of the student Challenge—Initial Design Ideas, Research, Revise Design, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review—conveys both the students' and the teacher's role for that stage of the engineering design process. The science and math activities (both student handouts and teacher notes) are included in the Research section. The Concluding the Module section provides wrap-up questions to use for discussion and lists possible misconceptions in order to look for changed understanding. The module concludes with a post-assessment handout for the students and answer key for the teacher.

The Challenge and Activity handouts are designed to be copied and used for multiple classes. Students should record all work in their notebook. If desired, you can change the handouts to be used to record the data by modifying the Microsoft® Word documents provided.

Paper versus SPARKlab™ Activities

In addition to the conventional paper format found in the Research section of this module, each activity in the Collisions Module is available on the accompanying storage device in an electronic SPARKlab format (".spk"). The content found in both the paper format and the SPARKlab format is nearly identical, with some small changes to the step sequence and wording. This provides you, the teacher, an opportunity to choose the format that will be best received by your students.

The SPARKlab activities are presented as fully configured, stand-alone activities used with either a SPARK Science Learning System™ or a computer running SPARKvue™ software. All instructions, procedural steps, data displays, and questions are pre-configured and included in the electronic file. There are two sets of electronic SPARKlabs provided on the accompanying storage device. The two sets of labs have identical content but different resolution.

	spark Science Learning System™	sparkvue™
SPARKlab folder	Collisions SPARK Science Learning System	Collisions SPARKvue
Sample file name	Impulse Momentum.spk	Impulse Momentum Sv.spk
Images	The images are optimized for the size of the SPARK screen.	The images have a higher resolution to take advantage of the size of a computer screen.
Copying files	Refer to your SPARK Science Learning System User's Guide, in the "Saving and Sharing" section under "Managing Files and Folders".	The files can be saved anywhere in your normal filing system. The labs are "read-only" to protect students writing over them.

For information on the different methods for submitting student work when using the SPARK Science Learning System or SPARKvue software, refer to the "Saving and Sharing" section of the appropriate User's Guide.

Projecting SPARKlab™ Activities Using the SPARKvue Emulator

The SPARKvue emulator can be used to demonstrate the SPARK Science Learning System interface. To model opening a SPARKlab, first save the SPARKlabs in the locations described below.

Windows XP:	C:\Documents and Settings\All Users\Documents\My SPARK Data\Experiments
Windows Vista/7:	C:\Users\Public\Documents\SPARK Data\Experiments
Mac OS X:	HD>Users>Shared>SPARK>Experiments

The Data Collection System

All activities are carried out on a PASCO data collection system. "Data collection system" refers to the data collection, display, and analysis device used to carry out the various PASCO Module activities. These include PASCO's DataStudio®, the Xplorer GLX®, SPARKvue™, and SPARK Science Learning System™.

Detailed explanations for using the data collection system to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. You can find these files on the storage device that accompanies this printed module, on the stand-alone storage device, and available for download with the module content.

Data Collection System	Tech Tip File
SPARK Science Learning System™	SPARK Tech Tips.pdf
SPARKvue™	SPARKvue Tech Tips.pdf
Xplorer GLX®	Xplorer GLX Tech Tips.pdf
DataStudio®	DataStudio Tech Tips.pdf

Using Project-Based Learning Modules with PASCO's 21st Century Science Guides

Science is a process of inquiry; an ongoing search to explain what goes on around us. PASCO's 21st Century Science Guides focus on students learning science through inquiry-based activities—presenting concepts in a way that develops critical thinking, procedural expertise, proficiency in design and construction, and analytical skills.

Using the Project-Based Learning Modules in conjunction with the 21st Century Science Guides further increases student skills and understanding. Students working on the Project-Based Learning Module Challenge are exercising the highest levels of critical and creative thinking: synthesis and evaluation—students design their prototypes by integrating the skills and knowledge gained in the activities, by comparing and discriminating between their own designs and those of others, and by appraising the strengths and weaknesses of their creation.

Teachers can use the Project-Based Learning Modules together with the 21st Century Science Guides in several ways. They can

- use only the Project-Based Learning Module to teach the unit
- extend a science unit with the activities in the Project-Based Learning Module after students complete related activities from the 21st Century Science Guide
- include additional activities from the 21st Century Science Guide to enhance the module
- use the Project-Based Learning Module as a capstone to review and integrate the topics already covered from the 21st Century Science Guide

In all of these approaches, challenging students with a Project-Based Learning Module enables them to apply their inquiry skills as they combine the science concepts and math skills to engineer something entirely new.

Content and Skills

The Collisions Module gives students a chance to learn and apply physics concepts to a real-world application. In this module, students learn about elastic and inelastic collisions, the momentum and impulse associated with them, and the relevance of these concepts to the skills and techniques used to design and construct impact-absorbing bumpers like those found on automobiles. Along with the physics concepts explored, students also spend time learning about area-under-a-curve approximations for continuous functions and how these are used to determine impulse. Below is a list of the specific topics and skills covered in the Collisions Module:

Concepts	Skills
Momentum	Perform first- and second-order area-under-a-curve approximations
Elastic versus inelastic collisions	Use a motion sensor to measure velocity
Impulse	Use a force sensor to measure impact force
Impulse and momentum	Use electronic graphing tools to determine the area under a curve
Impact/peak force and collisions	Calculate momentum and change in momentum in a collision
Area under a curve	Determine impulse from a Force versus Time curvegraph
	Determine peak force from a Force versus Time graph
	Analyze the effectiveness of different materials for reducing the peak force of a collision
	Make engineering decisions based on quantitative results

Students will benefit from prior knowledge of vectors and other prerequisite concepts when carrying out the research activities of this module. The Pre-Assessment handout can be useful in determining how well your students understand these prerequisite concepts. We recommended you administer the Pre-Assessment handout far enough in advance of the module to determine if additional instruction is required prior to starting the module.

Prerequisites

- Understanding of mass and velocity
- Understanding of vectors and vector addition
- Determining the values of points on a graph

Pacing Guide

The Collisions Module provides several different forms of student engagement including individual and group work, lab work, individual work that could be taken home, and work, discussions, prototype testing, and assessments to be done as a class. To determine how a lesson or activity in the module should be delivered (class work, individual work, group work, or lab work), refer to the last four columns of the table below. A check mark in the corresponding box indicates each lesson or activity's intended delivery form.

Each lab-based activity is designed to fit one 45-minute block of time (one "Day"), unless otherwise noted. The table below indicates a recommended pacing for all lessons and activities within the module, in chronological order. Lessons and activities with the same number in the Day column can be carried out on the same day. Lessons or activities requiring an entire 45-minute block of time are the only ones listed on that day.

This module could be accelerated to be completed in just one week, but the recommended pacing laid out below gives students time to think about and digest the concepts they learn before applying them. If time is still a problem, the first part of the Area Under the Curve activity can be done as homework.

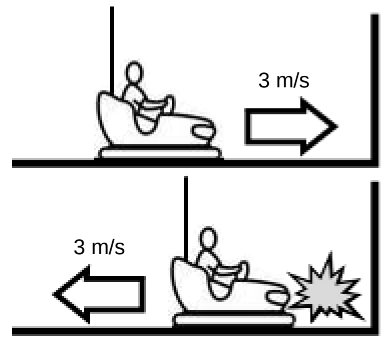
Day	Lessons/Activities	Instr. Led	Indiv. Work	Group Work	Lab Work
1	Pre-Assessment—based on the results, assemble student groups		✓		
1	Introducing Students to the Challenge	✓			
2	Collisions Challenge: Initial Design Ideas		✓		
2	Activity: Momentum			✓	✓
3	Activity: Area Under a Curve			✓	✓
4	Activity: Impulse Momentum			✓	✓
5	Activity: Peak Force*			✓	✓
6	Collisions Challenge: Revise Design		✓		
6	Collisions Challenge: Develop Group Design			✓	
7-8	Collisions Challenge: Build a Prototype			✓	
9	Collisions Challenge: Test and Evaluate	✓		✓	
9	Collisions Challenge: Design Review			✓	
10	Concluding the Module	✓			
10	Post-Assessment		✓		

*If time permits, this activity can be extended to two days.

Pre-Assessment

1. A 1,000-kg car travelling at 20 m/s has a head-on collision with a cement barricade that forces the car to come to a complete halt. What was the momentum of the car just before the collision?
   A. 20,000 kg·m/s
   B. 50 kg·m/s
   C. 30,000 kg·m/s
   D. 500 kg·m/s

2. Imagine a 250-kg bumper car driving on a flat surface. If the bumper car hits a wall traveling at 3.0 m/s and bounces straight back at 3.0 m/s, what is the change in momentum of the bumper car? Assume the collision is head-on and the wall is perpendicular to the cart's path.
   A. –1,500 kg·m/s
   B. 125 kg·m/s
   C. 0 kg·m/s
   D. –50 kg·m/s



3. If a northbound car enters a curve at 30 kph and exits the curve heading east at 30 kph, did the automobile's momentum change? Why?

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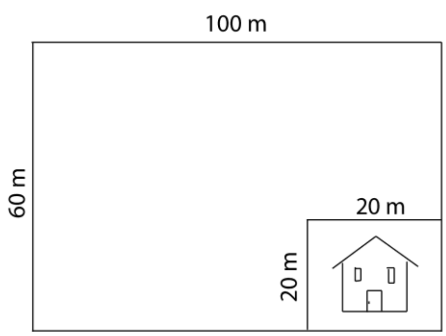
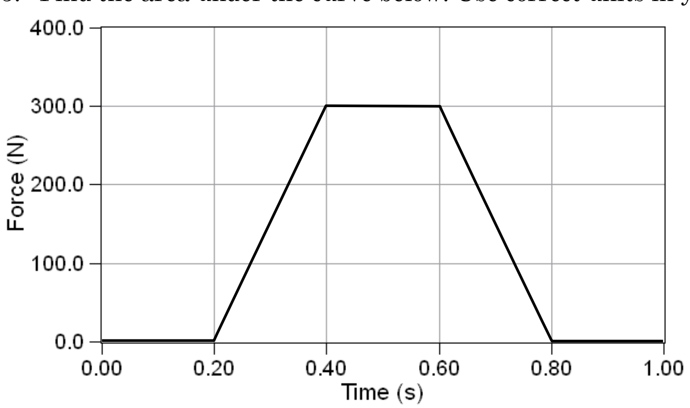
4. A farmer wants to find the area of his field without including his house and yard, as shown. What is the area?



5. Find the area under the curve below. Use correct units in your response.



6. What does an object with constant velocity and mass need to experience before its momentum will change?
   A. Zero gravity
   B. An unbalanced force over a given period of time
   C. An impulse
   D. Both B and C are correct because they are the same.
7. Just before re-entry, an orbiting space shuttle is traveling through space with a constant velocity of 9,400 m/s. Before starting re-entry, the shuttle needs to reduce its velocity using a reverse thrust rocket. If the rocket fires for 30.0 minutes with a constant force of –70,001 N, and the shuttle's mass is 78,001 kg, what is the velocity of the shuttle at re-entry?
8. If a 1,500-kg vehicle traveling at 20 m/s collides with a parked bus so that the vehicle comes to a complete stop, what is the impulse experienced by the vehicle?
   A. 30,000 kg·m/s
   B. 750 kg·m/s
   C. –30,000 N·s
   D. –750 kg·N·s
9. If a glass pane of a greenhouse roof can withstand up to 981 N of force before it breaks, will it survive if 100.0 kg of snow falls out of a tree from 3 m above and lands on the glass pane?
   A. No, because the snow will experience an impulse that will cause the peak force to exceed 981 N.
   B. No, because the peak force it will experience at impact will be exactly 2,940 N.
   C. Yes, because the snow will spread out and absorb the impact, lowering the peak force below 981 N.
   D. Yes, because the peak force it will experience at impact will be exactly 981 N.
10. Jennifer uses a force sensor to measure the force on a plastic ball as it hits the ground after being dropped from a height of 1 m and discovers that the ball experiences a peak force of 10 N. Jennifer decides to repeat the procedure, but this time she puts a soft cushion on the floor where the ball will land. What do you think Jennifer will observe in this trial? Circle your prediction.
    A. The peak force will be greater.
    B. The ball will not experience any force.
    C. The peak force will be less.
    D. The peak force will be the same.

Explain your thinking. Is there a "rule" you used to determine your answer?

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Pre-Assessment Answer Key

Pre- and post-assessment tests are provided and designed to help determine students' knowledge of the topics within the module prior to and after its completion. The pre-assessment test offers questions that synthesize each of the four topics covered in the research activities, while the post-assessment test offers similar content questions with dissimilar approaches. Having contrast in approach between the pre- and post- assessment tests provides a good metric for determining student progress and knowledge base once the module is finished.

Questions from the Pre-Assessment handout are identified by number in the first column in the table below. The second column indicates the correct answer to each question. The third column in the key includes notes about correct and incorrect answers, how the answers relate to the information that students will learn in this module, and associated misconceptions.

Question	Correct Answer	Assessment Information
1	A	Momentum is equal to the product of an object's mass and velocity, which is an important topic covered in the Momentum research activity.
2	A	The change in momentum of an object is equal to the product of the object's mass and its change in velocity. In this case, the change in velocity is equal to –6 m/s; because velocity is a vector quantity, directionality should be given to either the velocity before or after the collision (one must be negative). Students who answer "C" show a good understanding that momentum is the product of an object's mass and velocity, but fail to identify velocity as a vector quantity. Students who answer B or D may not understand that momentum is equal to the product of an object's mass and velocity. This topic is covered in the Momentum research activity.
3	Yes	The answer is "yes" because an object's momentum changes if either its mass or velocity changes. In this case the object's mass does not change, its direction does. Velocity is a vector quantity, so it has both magnitude and direction. A change in direction means there is a change in velocity, even though the object's speed is not changing. This topic is covered in the Momentum research activity.
4	5600 m^2	The area of the field is equal to the total area of the property ($60\ m \times 100\ m = 6{,}000\ m^2$) minus the area of the house and yard ($20\ m \times 20\ m = 400\ m^2$): $6{,}000\ m^2 - 400\ m^2 = 5{,}400\ m^2$. Calculating and estimating area is a topic covered in the Area Under a Curve research activity.
5	120 N·s	The area should be calculated by breaking the area under the curve into three pieces: two right triangles with base equal to 0.20 s and height equal to 300.0 N, and a rectangle with base equal to 0.20 s and height equal to 300.0 N. $\text{Area} = 2\left[\frac{1}{2}\ \text{base}_T \times \text{height}_T\right] + \text{base}_R \times \text{height}_R$ $\text{Area} = 2\left[\frac{1}{2}\ 0.20\ s \times 300.0\ N\right] + 0.20\ s \times 300.0\ N$ $\text{Area} = 2\left[\frac{1}{2}\ 60\ N \cdot s\right] + 60\ N \cdot s$ $\text{Area} = 120\ N \cdot s$ Students will explore area approximation techniques similar to this in the Area Under a Curve research activity.
6	B, C, or D	Although B and C are correct answers, D is the best answer to this question. An object in motion requires an impulse to change its momentum, but an impulse is simply a non-zero (unbalanced) net force imparted to the object over a given time. This question is designed to indirectly show a connection between Newton's Law and impulse, which will be done algebraically in the Impulse Momentum research activity

Question	Correct Answer	Assessment Information
7	7,780 m/s	Students can answer this question correctly using either the relationship between change in momentum and impulse, or the proper kinematic equation. In either approach, the algebraic result should be $\boldsymbol{v}_f = \boldsymbol{v}_i + (\boldsymbol{F}\Delta t)/m$: Using impulse = change in momentum: $\Delta\boldsymbol{p} = \boldsymbol{I}$ $m\Delta\boldsymbol{v} = \boldsymbol{F}\Delta t$ $\boldsymbol{v}_f - \boldsymbol{v}_i = \frac{\boldsymbol{F}\Delta t}{m}$ $\boldsymbol{v}_f = \boldsymbol{v}_i + \frac{\boldsymbol{F}\Delta t}{m}$ Using kinematics: $\boldsymbol{v}_f = \boldsymbol{v}_i + \boldsymbol{a}\Delta t$ $\boldsymbol{F} = m\boldsymbol{a}$ $\boldsymbol{v}_f = \boldsymbol{v}_i + \frac{\boldsymbol{F}}{m}\Delta t$ $v_f = 9{,}400 \text{ m/s} + \frac{-70{,}001 \text{ N} \quad 1.80 \times 10^3 \text{ s}}{78{,}001 \text{ kg}} = 7{,}780 \text{ m/s}$ The relationship between impulse and change in momentum is explored in the Impulse Momentum research activity.
8	C	Students who answer this correctly understand: how to calculate the change in momentum, the equivalence of impulse and change of momentum, the force applied is in the opposite direction of the initial velocity, and the units of impulse. These concepts are covered in the Impulse Momentum research activity.
9	A	The force from 100.0 kg of snow at rest on the glass pane would be equal to 981 N ($F = mg$, where g = 9.81 m/s^2). If the same mass of snow impacts the glass pane with a non-zero velocity, the glass pane will experience an impulse that will cause the peak force to be greater than the force of it at rest which will exceed the breaking strength of the glass. The concept of impulse is covered in the Impulse Momentum research activity; peak force is covered in the Peak Force research activity.
10	C	By placing a cushion under the ball, Jennifer reduced the change in momentum and the impulse experienced by the ball. The cushion created an inelastic collision and increased the impact time. This kept the impulse the same but spread it out over a greater time period, resulting in a lower peak force. Maintaining impulse, but reducing peak force by creating a longer contact time between impacting objects is a topic covered in the Peak Force research activity.

Introducing Students to the Challenge

Read the Identify the Problem section (on the Challenge handout) to the class. Then distribute the Collisions Challenge handout. The stages described on the handout follow, chronologically, the stages of the engineering design process as listed in the PASCO's Project-Based Learning Modules, Module Principles section. Each stage is identified by title in the Challenge handout and includes instructions or questions, or both, requiring students to respond in their notebooks. When beginning the Challenge, make certain that students are aware of this and that they each have a notebook for their responses and data.

The first section of the Challenge handout (Identify the Problem) outlines the real world application of a similar engineering challenge that should be discussed as a class. When introducing the Challenge, be certain to discuss the Challenge topic and design requirements and constraints (outlined on the Challenge handout) with your students, making certain they understand that failure to stay within those requirements and constraints will affect their overall grade.

Students will work individually and in groups throughout the Collisions Challenge. After introducing the Challenge, it is a good idea to assign students to groups for the group stages of the Challenge (Research, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review). Although you, as the teacher, will know what grouping method best suits your class, the Pre-Assessment results may provide additional insight. For example, if the Pre-Assessment reveals that your students have a variety of prior concept knowledge, they may benefit from being in groups that distribute this knowledge. We suggest that these groups be the same groups for the research throughout all the stages of the Challenge where students work in groups.

Challenge Rubric

To give students a better understanding of what is expected of them throughout the Challenge, you may choose to pass out the Challenge Rubric with the Challenge handout, which indicates the suggested grading criteria. If you feel that the suggested grading criteria are not suitable for your class, the rubric is available in an editable electronic format (HS STEM Collisions Challenge Rubric.doc file) that allows you to change it as you find necessary.

Materials

The following list of suggested materials appears on the Challenge handout and should construct all three bumpers.

- Cardboard, 1 m^2
- Sheets of paper (unlimited)
- Rubber balloons (3)
- Aluminum foil, 1 m^2
- Soft clay, 113 g
- Rubber bands (10)
- Toothpicks (20)
- Duct tape, 50 cm
- Masking tape, unlimited
- Glue other than epoxy, unlimited

Additional items can be added or substituted, such as cotton balls, foam, or paper clips. If you choose, students can also bring materials from home or around school, but if you arrange this, take time to discuss materials with students and lay out any ground rules for safety. The Challenge handout is also available in an editable electronic format (HS STEM Collisions Challenge.doc), making it easy to include (or exclude) different materials in the Design Requirements and Constraints section.

Challenge: Collisions

Identify the Problem

Automobile accidents are an unfortunate but inevitable part of highway and city driving. Automobile manufacturers take the safety of their customers seriously and invest millions of dollars in research to design a vehicle that minimizes damage to the vehicle and its passengers in an accident. Most modern vehicle designs include sophisticated crumple zones and strategically placed impact absorbers, but the first structural line of defense for a motor vehicle is its bumper.

Designed to absorb the impact of slow speed collisions, the bumper has historically served as protection against critical structural damage and injury. Materials have become more advanced, and new developments in structural design allow for the same shock absorbing power in a more compact footprint (the shape and size of the area it occupies). Manufacturers must revisit their current bumper designs to reduce cost and weight while maintaining or increasing the impact absorbing power.

Your challenge in this module is to serve as an engineer helping the automotive industry to re-design a compact bumper that maximizes impact-absorbing capability while minimizing its size and weight.

Challenge

Design and construct a bumper for a model vehicle that minimizes the impact force experienced in a collision while also minimizing size and weight. Your prototype bumper will be tested in three separate trials. The lowest peak force from the three trials will be used to evaluate how well the Challenge was executed.

Design Requirements and Constraints

- Use only the items listed in the Materials section.
- The bumper must not impede the cart's ability to move.
- It cannot extend more than 5.0 cm from the front of the cart.
- It must not add more than 200 g to the mass of the cart.
- It must be constructed so that it attaches firmly to the front of the cart, but can be removed.
- Three replicate prototypes of your bumper must be made to test in three separate trials. (The materials list below should construct all three bumpers.)

Materials

- Cardboard, 1 m^2
- Sheets of paper (unlimited)
- Rubber balloons (3)
- Aluminum foil, 1 m^2
- Soft clay, 113 g
- Rubber bands (10)
- Toothpicks (20)
- Duct tape, 50 cm
- Masking tape, unlimited
- Glue other than epoxy, unlimited

1 ☐

Initial Design Ideas

If you were to design a bumper for a model vehicle right now, how would you construct it and what materials would you use? Keep in mind that the bumper should be designed to minimize the force experienced in a collision and cannot be longer than 5.0 cm or have a mass greater than 200 g.

Sketch two possible designs in your notebook and explain your proposals, listing three reasons for choosing each design. Include safety concerns.

2 ☐

Research

Carry out the activities listed below. These will help you revise or validate your initial design ideas in order to complete the challenge successfully. After completing an activity, answer the questions following its description. All questions must be answered before you proceed to the Revise Design portion of the Challenge.

NOTE: When you see the symbol "�" with a number following a step in an activity, refer to the Tech Tip with that number for detailed instructions as needed. Tech Tips will be provided by your teacher.

Momentum

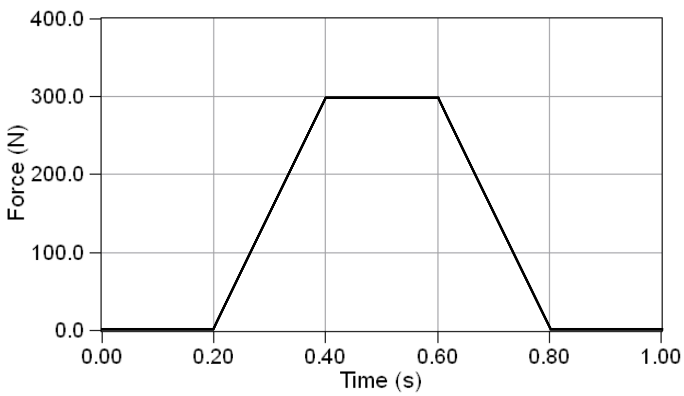
☐ When a moving object is involved in a collision, its momentum changes. This change in momentum is dependent on the type of collision that occurs, elastic or inelastic. This activity explores how momentum changes in each type of collision, and identifies which type will result in the least change in momentum. This is an important concept to consider when you design your bumper.

1. Which type of collision had less change of momentum? Why?
2. When a moving car hits a fixed object, like a wall or telephone pole, what type of collision do you see most often, elastic or inelastic? Explain why you think this type of collision occurs most often.

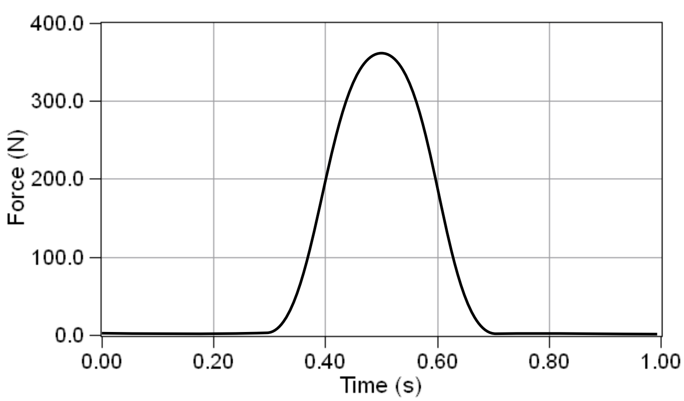
Area Under a Curve

☐ For an object to experience a change in momentum, an impulse must be imparted to that object, that is, a force must act on the object over some amount of time. Impulse is defined as the area under a force versus time curve. This activity introduces you to an approximation method for determining the area under a curve and then outlines a method for determining the same area using your data collection system.

1. The curve below represents the force experienced by a car bumper in a collision. Determine the impulse associated with the collision.



2. The curve below represents the force experienced by a car bumper during a collision. Imagine the same collision, but this time a different bumper is used that reduces the maximum (peak) force to 200 N, although the impulse stays the same. How would the shape of the force versus time curve be different for the second collision?



Impulse Momentum

In this activity you determine how an object's change in momentum is related to the impulse imparted to it in a collision, and then use that relationship to determine which type of collision, elastic or inelastic, is preferable when a car hits an immovable object.

1. Imagine a car crash like the ones often seen in movies. What type of collision usually occurs in these crashes, elastic or inelastic?
2. Given the relationship between impulse and momentum you discovered in your experiment, and the results from the Momentum activity, which type of collision, elastic or inelastic, would produce the smallest impulse associated with a collision? Explain your answer.

Peak Force

Minimizing impulse is important when designing a device to absorb impact; however, a car involved in a collision can experience a large impulse and still not sustain damage if the impulse is a small force over a long period of time. What generally causes damage is the peak force experienced by an object in a collision. This activity gives you the opportunity to test different materials and structures to help determine the bumper design that will minimize the peak force in a collision.

1. What material and construction method for your test bumper worked best to minimize the peak force, and why do you think they worked so well?

3 Revise Design

After completing the four activities in this Challenge and answering all the research questions, you should have the conceptual tools necessary to construct a cart bumper that will minimize the peak force in a collision. In this stage of the engineering design process, you have an opportunity to revise your original design ideas based on the information learned in the research stage. Refer to your initial design ideas to answer the following questions:

1. Based on the information you have learned from the research activities, do your initial ideas still work? Explain why they work or how those initial thoughts have changed and why.
2. Sketch your revised design, including approximate dimensions, in your notebook and explain your proposal, indicating the important pieces of the design. Does the data from the research activities support the materials and revised design you chose? If yes, how?

4 Develop Group Design

Discuss as a group the different designs made by each group member and agree on a collaborative design that will be most effective. After deciding on an approach, draw the group's final design as accurately as possible, including dimensions, and have your teacher approve your group's proposal, which should include the items below. Every group member should have a copy of the proposal.

1. Record in your notebook the important design points and explain why you chose to construct it the way you did.

5 Build a Prototype

Using your collaborative design and following the design requirements and constraints, prepare your three prototypes in your group.

1. After constructing your group's prototypes, list in your notebook your specific responsibilities during the construction process.
2. Often a prototype will not exactly match its design due to some unforeseen construction challenges. Were any design points changed during the construction process? Do your group's prototypes exactly match the original design? If you did make changes, list those changes in your notebook and explain why your group made those changes.
3. Record in your notebook the mass of the three bumpers and the distance each extends from the front of the cart. Label the bumpers so you will be able to identify which one is used in which trial.

6 Test and Evaluate

☐

Choose one person from your group to test your cart bumper. Follow your teacher's instructions for attaching your bumper to the cart and executing each trial.

Test your bumper in three separate trials using one of the group's three identical prototypes in each trial. In your notebook, record the peak force and which of the three prototypes was used for that trial. The lowest peak force of the three collisions will be used to evaluate how well the group Challenge was executed.

After each trial, inspect the bumper and record in your notebook any damage it received, aspects of the design that worked, and those that failed.

7 Design Review

☐

Now that your group has tested its bumper design, it is important that you review the design as a group to determine where it succeeded, where it failed, and how you could change the design to make it better.

1. What was the lowest peak force recorded by the class? How did this value compare to your group's lowest peak force value?
2. Look at other groups' designs. What was different about their designs and how do you think those differences affected their performance relative to yours—what made some more effective and some less effective?
3. What would you change in your group's design to make it more effective? Why do you think these changes would make the design more effective?

Congratulations! You have finished the Collisions Challenge. Complete the information in your notebook and turn it in to your teacher.

Challenge Rubric

	Excellent			Good			Fair		
Initial Design Ideas	▪ Used logical reasoning that incorporated design constraints. ▪ Included a detailed explanation of the materials used and the role each material plays in the designs.			▪ Included a detailed explanation of the materials used. ▪ Drawings were clearly labeled and easily understood.			▪ Independently drew two initial designs in a notebook. ▪ Included reasoning for each drawing. ▪ Included a brief explanation of the materials used.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Research	▪ Answers showed excellent understanding of all concepts. ▪ Noted how the activity concepts affect the initial design ▪ Showed excellent understanding of the sensors and data collection system used in each activity.			▪ Answers to questions in activities and Challenge handout showed basic understanding of the concepts. ▪ Showed basic understanding of the sensors and data collection system used in each activity.			▪ Completed all group research activities. ▪ Answered activity questions from the Challenge handout in a notebook showing a partial understanding of the concepts.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Revise Design	▪ Explained how the activities changed or affirmed their initial design with evidence. ▪ Provided a revised design with detailed notes, measurements with units, calculations, and detailed explanations of changes.			▪ Explained how the activities changed or affirmed their initial design ideas. ▪ Included measurements and units in drawings. ▪ Drawing was clearly labeled and easily under stood.			▪ Provided a roughly drawn revised design. ▪ Included brief explanations of how the initial design ideas have or haven't changed.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Develop Group Design	▪ Worked well in the group to draw a design based on solid reasoning. ▪ Indicated how the design is based on or is supported by concepts explored in research activities. ▪ Indicated each group member's design contribution.			▪ Participated in the group to devise a group design. ▪ Included measurements and units in drawings. ▪ Drawing was clear labeled and easily under stood.			▪ Had limited involvement in the group design. ▪ Group design was based on design ideas from group members. ▪ Has a rough copy of the proposal and listed materials used.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Build a Prototype	▪ Took responsibility in the group for producing three well-constructed prototypes. ▪ Recorded and clearly explained design changes made during construction.			▪ Participated in building the prototype. ▪ Had notes on the prototype development and recorded measurements. ▪ Noted prototype development responsibilities.			▪ Had limited involvement in building the prototype. ▪ Had some notes on the prototype development.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Test and Evaluate	▪ Took responsibility during testing. ▪ Recorded detailed notes indicating where the design worked or failed. ▪ Bumpers met all requirements and constraints and successfully minimized peak force in each collision.			▪ Participated in testing the bumpers. ▪ Recorded peak force values for all three prototypes. ▪ Recorded notes indicating where the design worked and failed.			▪ Had limited involvement in testing the prototypes. ▪ Recorded some data.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Design Review	▪ Included ideas based on research activities about how the group design failed and succeeded. ▪ Included redesign ideas supported by concepts explored in research activities.			▪ Included ideas as to where the group design failed and succeeded. ▪ Offered several reasonable redesign ideas.			▪ Answered design review questions in a notebook.		
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
	Total Score								

1

Initial Design Ideas

Have students read the Initial Design Ideas section in their Challenge handouts and give them a fixed period of time (10 to15 minutes) to sketch two ideas for an initial bumper design. If you have not done so already, show the students the size of the carts they will be using. Encourage your students to include annotations that describe their thoughts about each design. Your students should understand they are not being assessed on artistic merit, but on their ability to effectively communicate their initial thoughts. There is no right answer, and it is likely that they will change their design as they work through the various Challenge stages.

Addressing Preconceptions

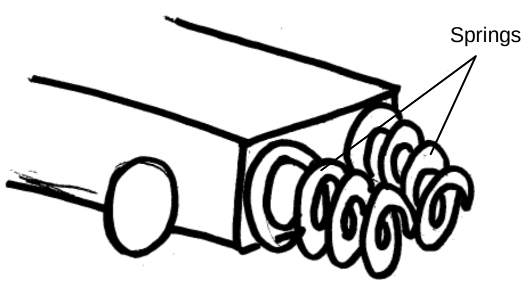
With the variety of collisions that students view in the popular media, any number of preconceptions could influence student thinking. To address some of the grossest, you might demonstrate a collision using a cart and track and note the lack of spontaneous fireballs, that the cart remains intact, and that the cart does not fly off in an unlikely direction. Students familiar with conservation of momentum may be expecting to see the momentum after a collision be the same as the momentum before the collision. This is an opportunity to talk briefly about the different ways that energy is transferred or dissipated in a collision, such as sound or deformation.

Possible Student Designs

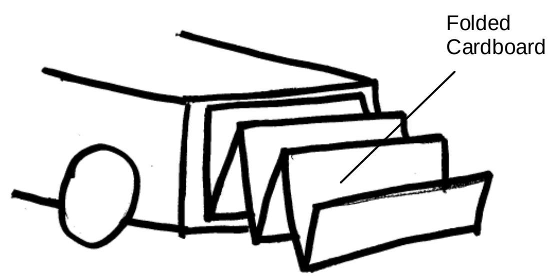
Students may sketch an array of springs, or a soft, fluffy pad, or some form of airbag. It is not important at this point to have a complete system mapped out, but it is important to have the reasoning explained so they can compare their experimental results to their original ideas.

Here are examples of student drawings:

Design #1



Design #2



Sample Response
Design #1
Reason 1. The springs will absorb the impact much like a pogo stick absorbs impact when a person jumps up and down on one.
Reason 2. The springs are light and will help the bumper to stay within the mass limit of the design requirement.
Reason 3. The metal springs will stick to the magnets within the cart, making it easy to mount.
Design #2
Reason 1. The folded cardboard will act like an accordion and absorb impact.
Reason 2. The cardboard is light and will help to keep the mass of the bumper small and well within the design requirements
Reason 3. The cardboard bumper will crush in a collision and not rebound like a crumple zone in a car.

2 Research

Engineering research and development is usually an iterative process: the engineering research determines how something can be made to function for a given purpose, and development is the process of building and testing prototypes or working models based on this research. While engineering research includes exploring other people's research, reading articles in journals, and investigating what has been done before, this section directs students to carry out scientific research activities which explore the science concepts and math skills related to the engineering challenge. In carrying out these activities, students will also become familiar with some of the standard tools and techniques of this field of study.

At a minimum, your students should complete each of the activities and answer the Challenge questions. This should provide them with enough information and experience to complete the Challenge. However, you can encourage your faster students to research the materials used in automotive construction and explain why they may or may not be appropriate for this Challenge. If you are going to have students bring their own materials, it is important to give them time to research and test the materials they wish to use. (They can test the materials during the Peak Force activity.) If your students are using a fixed list of materials, they may wish to experiment with them. It is best to allow time for material testing once students are in their design groups, to encourage group interaction and debate.

In addition to monitoring student progress through the activities, it is important to ensure that they are relating their work back to the Challenge. At a minimum, be sure they are answering the Challenge questions, but they will gain even more if they include notes relating the activity to their design as they add to their growing body of knowledge. Encourage students to record their thoughts and observations in writing, particularly if there will be a substantial amount of time between activities.

How Do the Activities Prepare Students for the Challenge?

To understand how to design the most effective bumper, students begin with the Momentum activity. Here they learn that a collision results in a change of momentum and that different types of collisions, elastic and inelastic, change the momentum differently, even when the mass remains the same and the initial velocity is the same. The Area Under a Curve activity introduces students to the definition of impulse and shows how impulse can be roughly determined using first- and second-order graphical approximations, and then more accurately using electronic graphing tools. The Impulse Momentum activity is a discovery-based activity in which students empirically show how impulse is related to change in momentum and which of the two collision types, elastic or inelastic, results in the smallest change in momentum and, therefore, the smallest impulse. Finally, in the Peak Force activity students test materials and bumper designs to see which will produce the smallest peak force during a collision. Using the concepts from the research activities, students should be able to design a bumper that minimizes the impulse and the peak force of an inelastic collision.

All Research questions must be answered before students proceed to the Revise Design portion of the Challenge.

NOTE: *Students use a variety of technical procedures in the activities. Detailed explanations for using the data collection system* to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. Please make copies of these instructions available for your students. (Tech Tips are identified in the activities by the "�" symbol followed by the Tech Tip number.)*

You can find these files on the flash drive that accompanies this printed module, on the stand-alone flash drive, and available for download with the module content.

Data Collection System	**Tech Tip File**
SPARK Science Learning System	SPARK Tech Tips.pdf
SPARKvue	SPARKvue Tech Tips.pdf
Xplorer GLX	Xplorer GLX Tech Tips.pdf
DataStudio	DataStudio Tech Tips.pdf

**Data collection system refers to the data collection, display, and analysis device used to carry out the various activities and includes PASCO's DataStudio, the Xplorer GLX, SPARKvue, and SPARK Science Learning System.*

SPARKlab Activities

In addition to the conventional paper format found in this section of the Collisions Module, each activity is available in an electronic SPARKlab format. All electronic SPARKlab files can be found on the accompanying flash drive with a .spk file extension and the title of each activity within the filename, for example, "Peak Force" and "HS STEM Peak Force.spk". For instructions on how to move the electronic SPARKlab files from the flash drive to your SPARK Science Learning System, please refer to your SPARK Science Learning System User’s Guide, "Managing Files and Folders" section.

For information on the different methods for submitting student work when using the SPARK Science Learning System, refer to the "Saving and Sharing" section of the SPARK Science Learning System User's Guide.

Activity: Momentum

Objective

Determine the change in momentum of a cart during a collision and explore how the change in momentum differs between an elastic and inelastic collision.

Materials and Equipment

- Data collection system
- Motion sensor
- Dynamics track
- Dynamics cart
- Pivot clamp
- Force accessory bracket with light spring bumper, force sensor clay bumper cup, and clay
- Large base and support rod
- Balance, 2,000-g capacity (1 per class)

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*

Procedure

☐ 1. Measure and record the mass of the cart in your notebook.

☐ 2. Use the pivot clamp to mount the track to the rod stand at a shallow angle (~5°).

☐ 3. Mount the motion sensor to the top of the track. Mount the force accessory bracket to the bottom of the track so the tab on the bracket points downward and faces up the track.

☐ 4. Attach the light spring bumper to the tab of the force accessory bracket.

☐ 5. Start a new experiment on the data collection system �(1.2) and then connect the motion sensor to the data collection system. � (2.1) Make sure the switch on the top of the motion sensor is set to the cart position.

☐ 6. Create a graph of Velocity versus Time � (7.1.1). Then set the sampling rate to 40 samples per second. � (5.1)

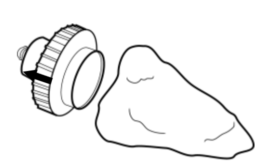
☐ 7. Mark a point on the track approximately 15 cm from the motion sensor. This is the point to place the front end of the cart for each run.

☐ 8. Hold the cart in place on the track at your mark, start recording data, and then release the cart. � (6.2)

☐ 9. Stop recording data after the collision. � (6.2)

☐ 10. Repeat the same steps to record a total of 3 runs of data using the spring bumper.

☐ 11. After you have recorded 3 runs of data using the spring bumper, take a small piece of clay (about the same size as the spring bumper) and form it into a cone. Attach it to the bumper cup as shown in the picture to the right.



☐ 12. Remove the spring bumper from the force accessory bracket and replace it with the clay bumper.

☐ 13. Record 3 more runs of data using the clay bumper � (6.2), forming the clay back into a cone shape before each run.

☐ 14. Copy Tables 1 and 2 into your notebook and then use the tools on your data collection system to determine the velocity of the cart just before (initial velocity) and just after (final velocity) each collision. � (9.1)

Table 1: Collision characteristics using a spring bumper (elastic collision)

Spring Bumper	**Mass of the Cart (g)**	**Velocity (m/s)**		**Momentum (kg·m/s)**		**Change in Momentum (kg·m/s)**
		Initial	**Final**	**Initial**	**Final**	
Run 1						
Run 2		RECORD YOUR ANSWERS IN YOUR NOTEBOOK.				
Run 3						
Average						

Table 2: Collision characteristics using a clay bumper (inelastic collision)

Clay Bumper	**Mass of the Cart (g)**	**Velocity (m/s)**		**Momentum (kg·m/s)**		**Change in Momentum (kg·m/s)**
		Initial	**Final**	**Initial**	**Final**	
Run 4						
Run 5		RECORD YOUR ANSWERS IN YOUR NOTEBOOK.				
Run 6						
Average						

☐ 15. Momentum $\boldsymbol{p}$ is defined as the product of mass and velocity. Calculate and record in Tables 1 and 2 the momentum just before and just after each collision.

☐ 16. Change in momentum is defined as the final momentum minus the initial momentum. Calculate and record the change of momentum for each run in Tables 1 and 2. Record the average change in momentum for each type of bumper in Tables 1 and 2.

Questions

1. Is there a significant difference in the change of momentum from run to run with the same bumper? Use your data to explain your answer.
2. For an elastic collision, how does the momentum before the collision compare to the momentum after the collision? For an inelastic collision, how does the momentum before the collision compare to the momentum after the collision?
3. How does the average change in momentum for an elastic collision with the spring compare to the average change of momentum for an inelastic collision with the clay?
4. How would using a cart with twice the mass affect the change in momentum?
5. Complete the questions in the Challenge: Collisions handout for this activity.

Teacher Notes: Momentum

Learning Objectives

Determine the change in momentum of a cart during a collision and explore how the change in momentum differs between an elastic and inelastic collision.

Activity Introduction

TYPES OF COLLISIONS

Momentum is the product of velocity and mass ($\boldsymbol{p} = m\boldsymbol{v}$). So what does a 9.7 g bullet fired from a rifle, traveling 866 m/s, have in common with a 1-kg baseball thrown at 8.4 m/s and a 100-kg man crawling at three-tenths of a kilometer per hour? They all have approximately the same momentum.

According to Newton's 1st Law, an object's momentum is constant unless acted on by an external, unbalanced force. This is where impulse plays a big role. For an object to have its momentum changed, an impulse (a force acting on an object over some length of time) must be imparted to the object. In other words, a force must act on that object to change its velocity.

For instance, a car traveling at a constant velocity on a frictionless surface will continue traveling at that velocity until something causes its velocity (and therefore, its momentum) to change. One way the velocity would change is if the car were to strike a fixed object (such as a parked car, wall, or telephone pole). Newton's 3rd Law implies that the fixed object applies an equal and opposite force on the car, so when the car collides with the fixed object, the car's velocity and momentum changes due to the impulse applied by the fixed object.

Two types of collisions, elastic and inelastic, are possible in this example. When a moving car strikes a fixed object, the car will either impact and stop (inelastic) or impact and rebound with some velocity in the opposite direction (elastic). Have students discuss which object (parked car, wall, and telephone pole) would result in which type of collision. In this activity, students observe the difference between these two types of collisions and learn which type results in the lowest change in momentum, an important concept for students to consider during the Impulse Momentum activity and when they design their bumpers.

FRAME OF REFERENCE

Momentum is a vector quantity, which implies it has direction. To do the lab successfully, students need to establish a frame of reference to specify which direction of momentum and velocity is positive and which is negative. For a good pre-lab classroom discussion, identify a desk or table and ask students, "What is the table's momentum?" Most students will say, "Zero, because the table is not moving." This is a bit of a trick question because you have not given a frame of reference. Now ask, "What is the table's momentum relative to the sun?" Take a minute to review the idea of frame of reference, and then rephrase the first question, "What is the momentum of the table relative to the room?"

The momentum is zero because the velocity of the desk is zero relative to the room.

Set up a graph of Velocity versus Time with a motion sensor for students to view and have a student come to the front. Position the student approximately 0.5 m in front of the motion sensor, and then record the velocity as the student moves away from the motion sensor for several meters, and then moves back toward the starting position. Pick velocities from different points on the curve to calculate the student's momentum. Point out that the student's motion is relative to the motion sensor and that moving away from the sensor appears on the graph in the positive direction and moving toward it appears as the negative direction.

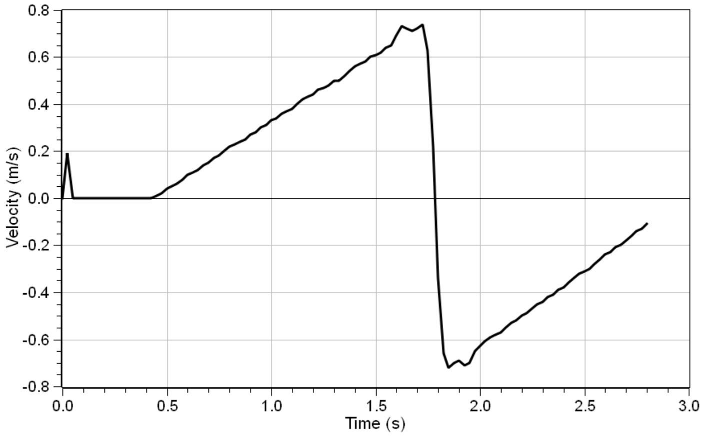
NOTE: *Be sure the switch on the top of the motion sensor is set to the person (far), not the cart (near).*

Teacher Tips

Students unfamiliar with the motion sensor may try to move from side to side. It may be beneficial to demonstrate the sensor for the class, and emphasize that it is collecting data in one dimension only. Showing students what happens when an object moves out of the beam of the sensor prepares them for that eventuality, and helps them develop their graphical interpretation skills.

Sample Data

Cart colliding with a spring bumper



Cart colliding with a clay bumper

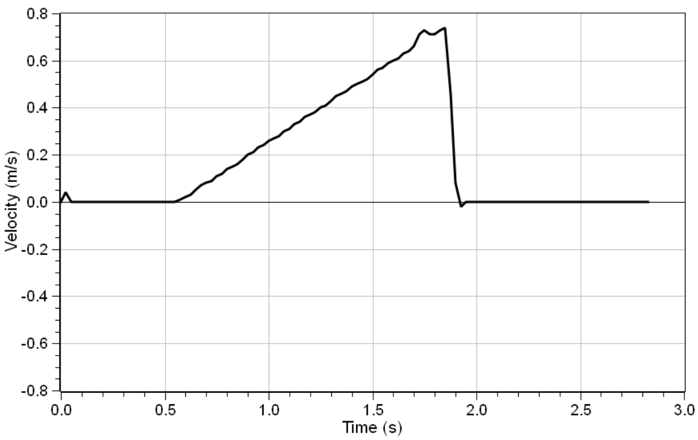


Table 1: Collision characteristics using a spring bumper (elastic collision)

Spring Bumper	Mass of the Cart (g)	Velocity (m/s)		Momentum (kg·m/s)		Change in Momentum (kg·m/s)
		Initial	Final	Initial	Final	
Run 1	0.250 kg	0.83	–0.80	0.21	–0.20	–0.41
Run 2		0.83	–0.83	0.21	–0.21	–0.42
Run 3		0.84	–0.83	0.21	–0.21	–0.42
Average						–0.42

Table 2: Collision characteristics using a clay bumper (inelastic collision)

Clay Bumper	Mass of the Cart (g)	Velocity (m/s)		Momentum (kg·m/s)		Change in Momentum (kg·m/s)
		Initial	Final	Initial	Final	
Run 4	0.250 kg	0.80	0.0	0.20	0.0	–0.20
Run 5		0.83	0.0	0.21	0.0	–0.21
Run 6		0.85	0.0	0.21	0.0	–0.21
Average						–0.21

Answer Key

Below are sample responses to the questions found in the Momentum activity handout. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE MOMENTUM ACTIVITY HANDOUT

Questions		Sample Response
Handout	SPARKlab	
1	S1	No, there is not a significant difference in the change in momentum between runs, or with the same bumper. The average change in momentum for the spring bumper in each trial was –0.42 kg·m/s, and the average change in momentum for the clay bumper in each trial was –0.21 kg·m/s.
2	S2 and S3	The momentum after the elastic collision is nearly equal in magnitude but opposite in direction. The momentum after the inelastic collision is zero but the momentum before is non-zero.
3	S5	According to the sample data, the average change in momentum for the inelastic collision was half the average change in momentum for the elastic collision.
4	S6	The change in momentum doubles if the mass of the cart doubles [$\Delta \boldsymbol{p} = m(\boldsymbol{v}_f - \boldsymbol{v}_i)$].

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect their data to the Challenge, discuss how the change in momentum due to different types of collisions relates to a car bumper's ability to absorb, rather than redirect momentum: An effective automotive bumper is one that changes shape during a collision, just like the clay in the experiment, which absorbed the momentum and energy of the colliding vehicle (inelastic collision). A bumper made of springs (elastic collision) would not absorb energy in a collision, but would cause the vehicle to rebound with nearly equal and opposite momentum, which could perpetuate further collisions.

SAMPLE RESPONSES TO THE MOMENTUM RESEARCH QUESTIONS

Question	Sample Response
1	The inelastic collision had the smaller change in momentum because the clay changed shape, absorbing the momentum of the car rather than redirecting it like the spring.
2	When a moving car hits a fixed object, an inelastic collision occurs most often because the impact is being absorbed by the bumper, rather than redirected like a spring.

Activity: Area Under a Curve

Objective

Define the concept of impulse and learn how to determine the area under a curve using approximations, and then more accurately using electronic graphing tools.

Materials and Equipment

- Data collection system
- Force sensor with hook
- Pencil
- Ruler

***NOTE**: Record all work, including tables, data, diagrams, and answers into your notebook.*

Procedure – Estimating Area

☐ 1. For a farmer, understanding the area of a field is critical to economic success. It is the only way to know how much seed and fertilizer are required to grow a crop. If a farmer has a rectangular field, the calculation is relatively simple. Calculate the area of a rectangular field whose length is 150 m and width is 100 m. Record your work and answer in your notebook.

☐ 2. Not every field is rectangular, so how might a farmer measure the area of a field with an irregular border like the river in your handout? To obtain a first-order approximation of the area, multiply the widest distance by the longest distance. If each fence post in the diagram in your handout is 2 meters apart, what is a first-order approximation of the area of the field between the fences and the river?

☐ 3. A second-order approximation uses known points to make smaller rectangles, such as the fence posts along the bottom of the field. From each fence post on the bottom of the field, draw a line straight up, parallel to the fence on the left, until the line crosses the river.

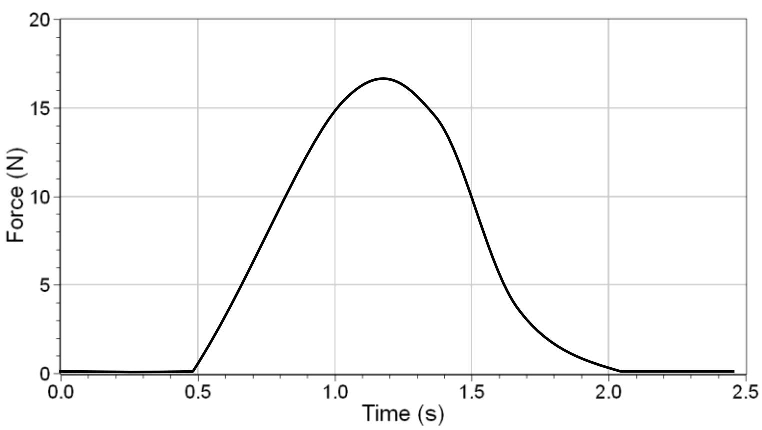
☐ 4. From the point where the line intersects the lower bank of the river, complete a rectangle by drawing a horizontal line from that point to the left until you hit the fence line or previous parallel line, whichever is closer. It is okay if your horizontal lines extend into the river.

☐ 5. Calculate the area of each rectangle and add the areas together (round each rectangle height to the nearest fence post). How does this result compare to your first-order approximation?

☐ 6. What could you do to make the approximation better?

Procedure – Area Under a Curve

☐ 7. Impulse, a very important concept when discussing collisions, is defined as the area under a Force versus Time curve. You can find the impulse due to a collision the same way you estimated area. If the graph below represents data collected during a collision, with force (in newtons) on the y-axis and time (in seconds) on the x-axis, estimate the impulse. Record your estimate, and the method you used to make the estimate, in your notebook.



☐ 8. What are the units of impulse? Hint: Think of how the impulse was calculated.

Procedure – Electronic Graphs

- ☐ 9. There are many different methods for determining the area under a curve. Often, calculus is needed to determine the exact value for the area. However, electronic tools on your data collection system can determine the area under a curve.
- ☐ 10. Start a new experiment on the data collection system �(1.2), connect the force sensor to it �(2.1), and then show a graph of Force (push positive) versus Time. �(7.1.1)
- ☐ 11. Attach the force sensor hook to the force sensor and then press the Zero button on the top of the sensor. Lay the force sensor flat on the lab table. Have one member of the group press down on the top of the sensor to hold it in place.
- ☐ 12. Record a run of data for about 3 seconds while a second group member pushes on the force sensor hook trying to slide the sensor toward the person pressing on it. Even though someone is pressing down on the top of the sensor, it should move slightly. Do not exceed 50 N of force.
- ☐ 13. Use the Area Tool on your data collection system to determine the impulse (area under the Force versus Time curve) needed to push the sensor toward the person pressing on it. �(9.7) Record the impulse value, with units, in your notebook.
- ☐ 14. Record a second run of data for about 3 seconds, but this time pull on the force sensor hook rather than push. Even though someone is pressing down on the top of the sensor, it should move slightly. Do not exceed –50 N of force.
- ☐ 15. Use the Area Tool on your data collection system to determine the impulse needed to pull the sensor away from the person pressing on it. �(9.7) Record the impulse value, with units, in your notebook.

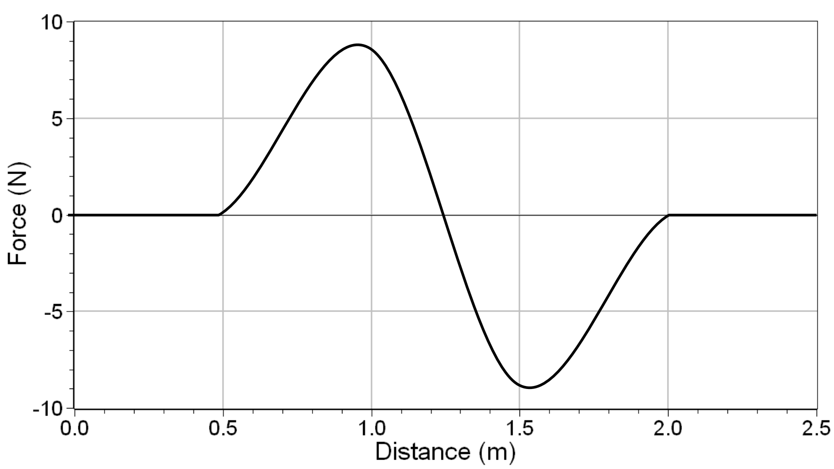
Questions

1. If the first-order approximation of the area of a field is 300 m^2, and the second-order approximation of the same field is 275 m^2, which of the following is most likely the area of the field?

   A. 90,000 m^2 C. 263 m^2

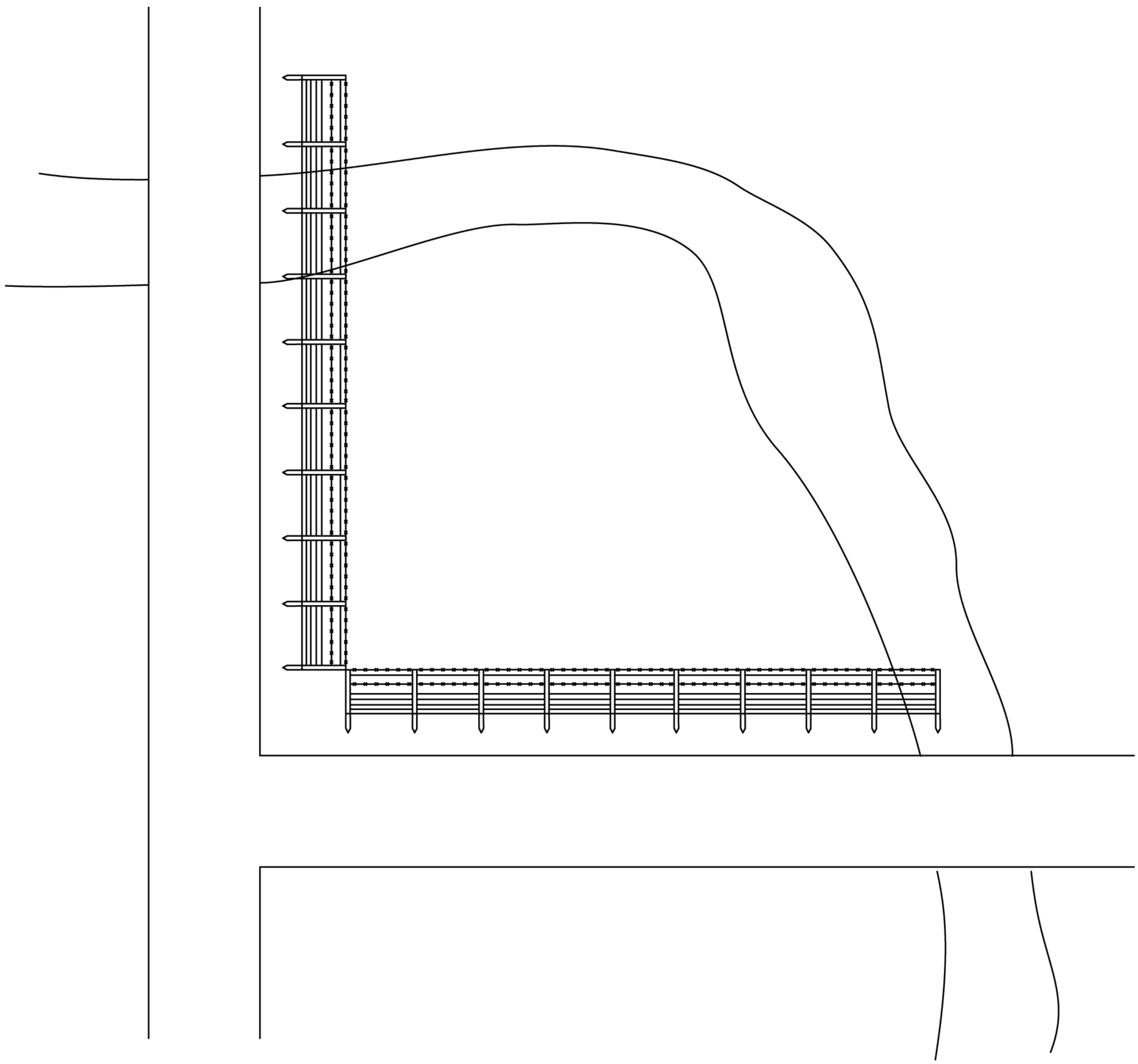
   B. 75,625 m^2 D. 254 m

2. Given the way we defined a first-order approximation above, is it possible for a first-order approximation to be smaller than the actual area under a curve? Why?
3. Is it possible for a second-order approximation to be the same as the actual area under a curve? Why?
4. You should have 2 runs of data on your data collection system—one where you pushed the sensor and one where you pulled it. How are the areas under the curves different between the two? Explain why they are different.
5. Estimate the area under the curve below. Be sure to use correct units, and explain your answer.



6. Complete the questions in the Challenge: Collisions handout for this activity.

Handout: Area Under a Curve—Estimating Area



Teacher Notes: Area Under a Curve

Learning Objectives

Define the concept of impulse and learn how to determine the area under a curve using approximations, and then more accurately using electronic graphing tools.

Activity Preparation

Provide each student with a copy of the Area Under a Curve—Estimating Area handout above, in addition to the activity.

Activity Introduction

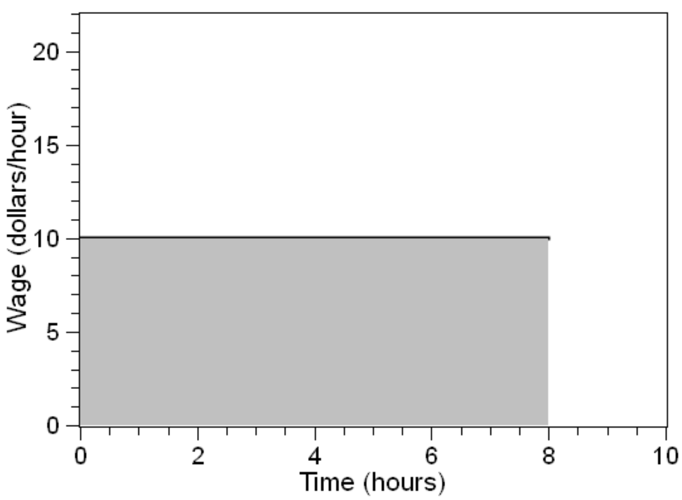
“Area under a curve” is possibly a new concept for your students, but they should be familiar with calculating “area.” When making the transition from “area” as a physical space to “area” as a mathematical object, you may want to start with an example they can relate to everyday life.

Most students will be able to relate to a wage or salary. Draw a tall rectangle and label the width “2 hr” and the height “10 dollars/hour.” Ask your students what the height and width represent and then what the area of the rectangle represents.

The height represents wages in dollars/hour, the width represents the amount of time worked, and the area represents the total dollars earned:10 dollars/hour × 2 hours = 20 dollars.

Now draw a copy of the wage graph below on the board and ask students what they think the graph represents.

The graph represents working an eight-hour day at a wage of 10 dollars/hour.



What is the total money earned for the day?

The total money earned is $80, the total area under the curve (10 dollars/hour × 8 hours = 80 dollars).

Have students pay close attention to how the area was calculated, how the resultant value had units of “dollars,” and where the units came from—the product of the x- and y-axis units.

Now redraw the graph but change the units and scales on both axes.

- y-axis: from dollars/hour to dollars/year, from 0 to 100,000 on the y-axis, and
- x-axis: from hours to years, from 0 to 30 on the x-axis.

Then draw a straight line at Wage = $50,000 from 0 to 30 years. Tell students that this graph represents the wages of a working person for the 30 years from the hire date.

Have students answer the following questions as a class:

What is the total dollar amount earned by this worker?

Total amount earned: 50,000 dollars/year × 30 years = $1,500,000

How would the graph change if the worker got a raise or decrease in pay after ten years?

The line would step upward for pay raises and downward for decreases in pay.

If the graph showed increases and decreases in pay, how would you calculate the total dollar amount earned?

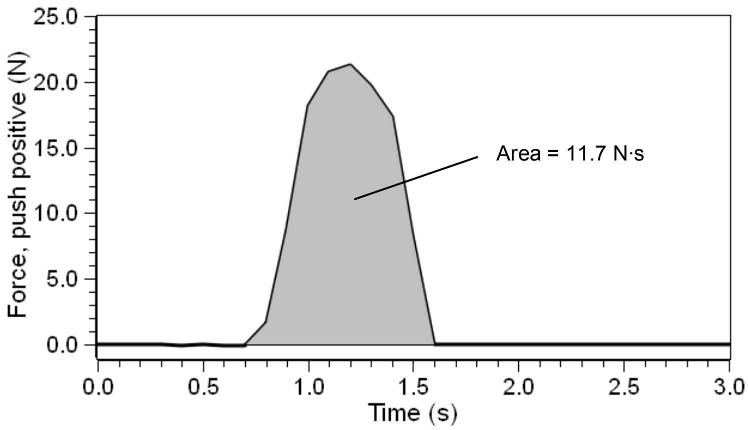
Calculate the area of the rectangles formed by each pay rate and the specified number of years, and then sum all the areas.

Teacher Tips

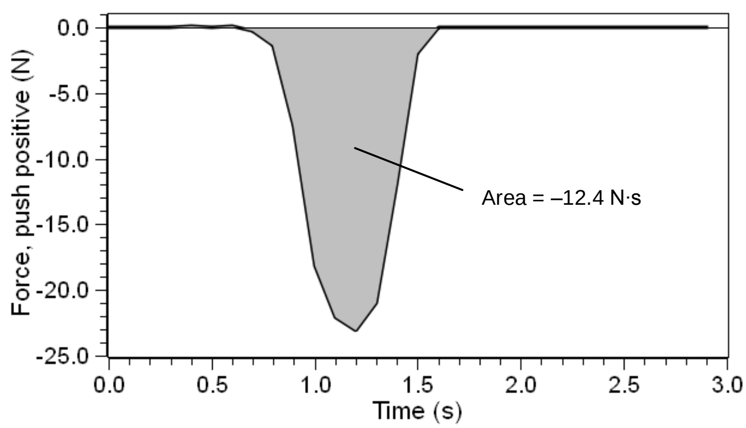
In the Electronic Graphs section of the activity, the group member pressing down on the force sensor should press with enough force to add resistance to the horizontal force from the other group member, but not so much force that the other group member cannot move the sensor slightly when pushing or pulling. Students do not need to push and pull for the entire 3 seconds of data collection. Shorter "bursts" of force will better simulate a collision.

Sample Data

Impulse due to pushing the force sensor



Impulse due to pulling the force sensor

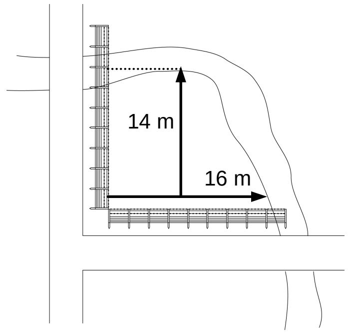


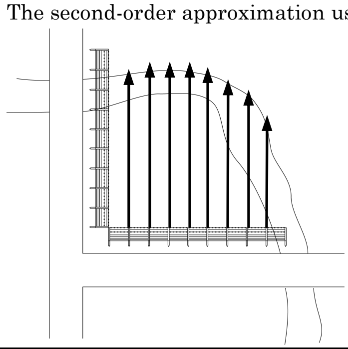
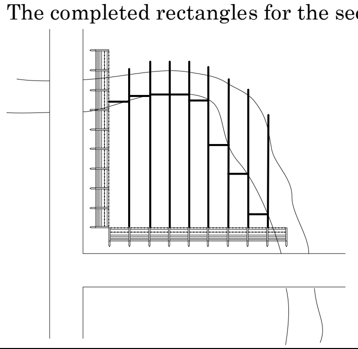
Answer Key

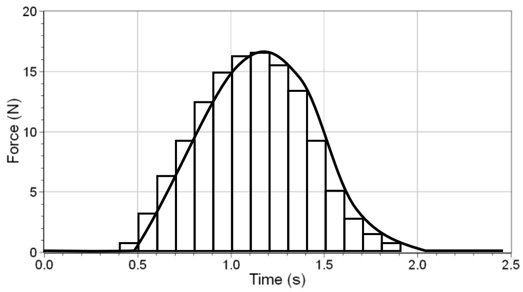
Below are sample responses to the questions found in the Area Under a Curve activity handout. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE AREA UNDER A CURVE ACTIVITY HANDOUT

Procedure		Sample Response
Handout	**SPARKlab**	
1		The area of the rectangular field is: Area = Length × Width Area = 150 m × 100 m = 15,000 m^2

<table>
<tr><th colspan="2">Procedure</th><th rowspan="2">Sample Response</th></tr>
<tr><th>Handout</th><th>SPARKlab</th></tr>
<tr><td>2</td><td></td><td>The first-order approximation of the field bordered by a river is obtained by multiplying the widest part of the field by the longest part:


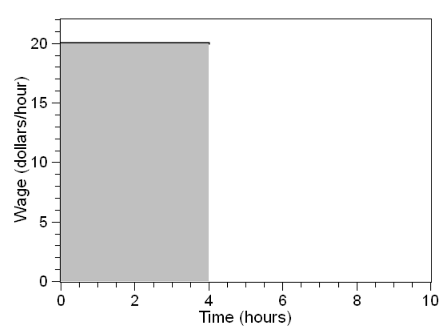
$\text{Area} = \text{Length} \times \text{Width}$
$\text{Area} = 14\text{ m} \times 16\text{ m} = 224\text{ m}^2$</td></tr>
<tr><td>3</td><td></td><td>The second-order approximation uses rectangles created by lines from the fence post to the river.
</td></tr>
<tr><td>4</td><td></td><td>The completed rectangles for the second-order approximation:
</td></tr>
<tr><td>5</td><td></td><td>Summing the areas of the rectangle for the second-order approximation:
$\text{Total Area} = \sum \text{Length} \times \text{Width}$
$\text{Total Area} = 12\text{ m} \times 2\text{ m} + 14\text{ m} \times 2\text{ m} + 14\text{ m} \times 2\text{ m} + 14\text{ m} \times 2\text{ m} + 12\text{ m} \times 2\text{ m}$
$+ 8\text{ m} \times 2\text{ m} + 6\text{ m} \times 2\text{ m} + 2\text{ m} \times 2\text{ m}$
$\text{Total Area} = 24\text{ m}^2 + 28\text{ m}^2 + 28\text{ m}^2 + 28\text{ m}^2 + 24\text{ m}^2 + 16\text{ m}^2 + 12\text{ m}^2 + 4\text{ m}^2$
$\text{Total Area} = 164\text{ m}^2$
The area from the second-order approximation, 164 m^2, is much smaller than the first-order approximation, 224 m^2.</td></tr>
<tr><td>6</td><td></td><td>The approximation could be improved if we use narrower rectangles.</td></tr>
</table>

Procedure		Sample Response
Handout	**SPARKlab**	
7		The impulse is estimated using a second-order approximation of the area under the curve:  $\text{Total Area} = \sum \text{Length} \times \text{Width}$ $\text{Total Area} = 1\text{ N} \times 0.1\text{ s} + 3\text{ N} \times 0.1\text{ s} + 6\text{ N} \times 0.1\text{ s} + 9\text{ N} \times 0.1\text{ s}$ $+ 12\text{ N} \times 0.1\text{ s} + 15\text{ N} \times 0.1\text{ s} + 16\text{ N} \times 0.1\text{ s} + 16\text{ N} \times 0.1\text{ s} + 15\text{ N} \times 0.1\text{ s}$ $+ 14\text{ N} \times 0.1\text{ s} + 9\text{ N} \times 0.1\text{ s} + 5\text{ N} \times 0.1\text{ s} + 3\text{ N} \times 0.1\text{ s} + 2\text{ N} \times 0.1\text{ s} + 1\text{ N} \times 0.1\text{ s}$ $\text{Total Area} = 12.7\text{ N·s}$ (A first-order approximation, width × length, results in a large value: 1.5 s ×16 N = 24 N·s.)
8		The units of impulse are newton × seconds, or kg·m/s.
13	S13	According to the sample data, the area under the curve (the impulse that pushed the sensor toward the person pressing on it) is 11.7 N·s.
15	S13	According to the sample data, the area under the curve (the impulse that pulled the sensor away from the person pressing on it) is –12.4 N·s.

Questions		Sample Response
Handout	**SPARKlab**	
1		C. 263 m². First-order approximations will always be greater than second-order approximations, so the area cannot be greater than the first-order approximation (A. or B.) and the units of D. indicate a line, not an area.
2		Based on our definition of a first-order approximation, it is impossible for that approximation to be smaller than the actual area under a curve. The product of the longest and widest part of a graph will always be greater than or equal to the area under a curve.
3		The way we have defined a first-order approximation, it is possible for the approximation to be equal to the actual area under a curve if the curve is rectangular.
4	S4	The two runs of data collected show that the "push" curve has a positive area under the curve, while the "pull" curve has a negative area. This is because the direction of the force was different between the two, designated by being positive in the "push" direction and negative in the "pull" direction.
5	S5	The total area under the curve appears to be equal to 0 N·m because the positive area appears equal to the negative area (the curves are similar, both are 0.75 m wide on the x-axis, and both have a maximum force of 8 N, although in different directions).

Connecting the Activity to the Challenge

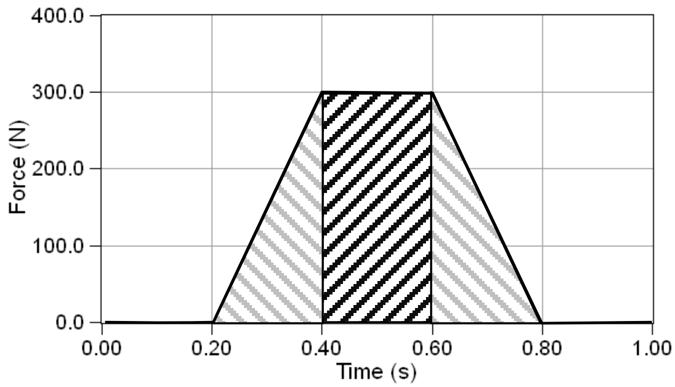
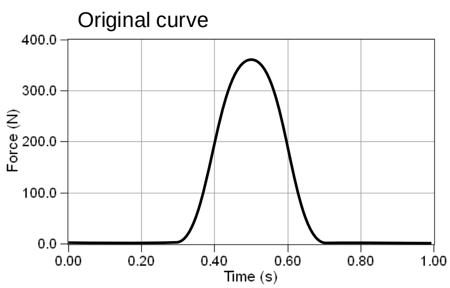
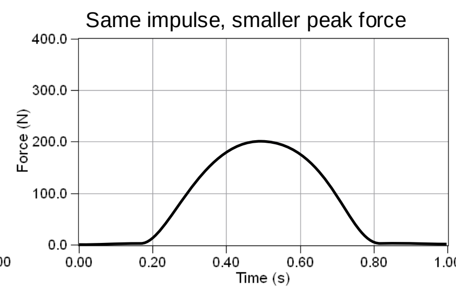
As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect their data to the Challenge, discuss the Wage versus Time graph from the Activity Introduction. Ask students how the graph would have to change if a worker wanted to work part time (4 hours per day) but earn the same amount of money.



The area under the curve (total money earned) would not change, but the shape of the curve would have to change to accommodate the change in time and pay rate (the worker would have to be paid twice as much per hour).

After completing the Area Under a Curve activity, students should have a good understanding of impulse, using an approximation method, and the analysis ability of the electronic graphing tools to determine the area under a curve. Familiarity with the graphing tools is important for carrying out the Impulse Momentum activity, in which students must graphically determine the impulse associated with different collisions and show how that impulse is related to change in momentum. Students will find that the peak force of the impulse should be minimized when designing an effective bumper.

SAMPLE RESPONSES TO THE AREA UNDER A CURVE RESEARCH QUESTIONS

Question	Sample Response
1	The impulse due to the collision is calculated by determining the area under the curve. The area is determined by breaking the curve into three recognizable geometric shapes. Shapes for which the area can be easily calculated.  $\text{Impulse} = \text{Total Area} = \frac{300.0\ \text{N} \times 0.20\ \text{s}}{2} + 300.0\ \text{N} \times 0.20\ \text{s} + \frac{300.0\ \text{N} \times 0.20\ \text{s}}{2}$ $\text{Impulse} = 120\ \text{N·s}$
2	The curve of an identical collision but with a bumper that reduces the maximum force (peak force) to 200 N would be shorter and wider, as the area under the curve is the same if the impulse is the same.  

Activity: Impulse Momentum

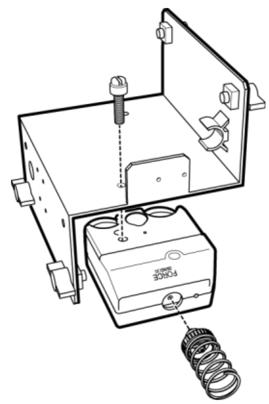
Objective

Determine the relationship between the change of momentum of an object and the impulse it experiences during a collision, where *impulse* is defined as the force experienced by that object over the time during which the force acts, in this case, during the collision.

Materials and Equipment

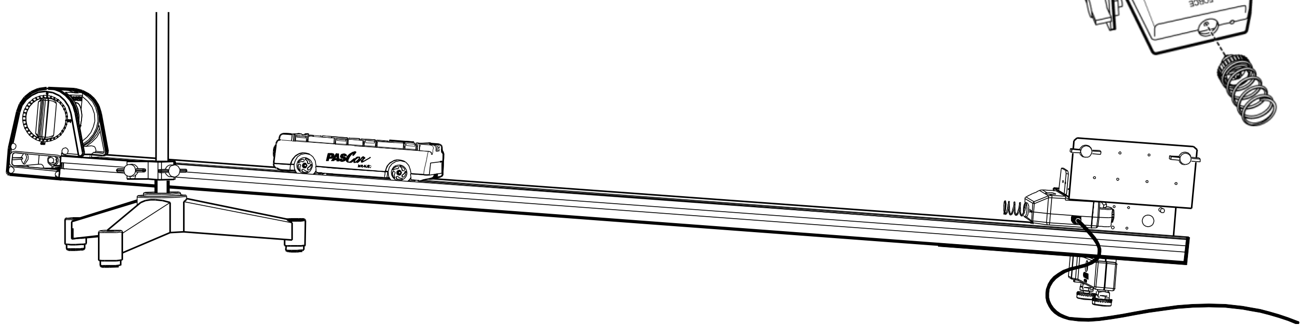
- Data collection system
- Force sensor
- Motion sensor
- Dynamics cart
- Dynamics track with feet
- Pivot clamp
- Large base and support rod
- Force accessory bracket with light spring bumper
- Balance, 2000-g capacity (1 per class)

Procedure



☐ 1. Attach the light spring bumper to the front of the force sensor and then mount the sensor to the force accessory bracket as in the picture to the right.

☐ 2. Assemble the accessory bracket with the force sensor and the remainder of your equipment as in the picture below. The face of the motion sensor should point down the length of the track. Make sure that the angle on the track is very shallow (about 5°)



☐ 3. Start a new experiment on the data collection system (1.2) and then connect the motion sensor and force sensor to the data collection system. (2.1) Make sure the switch on the top of the motion sensor is set to the cart position.

☐ 4. Create two graphs, one of Velocity versus Time, and one of Force, pull positive, versus Time (7.1.1). Set the sample rate to 100 samples per second. (5.1)

☐ 5. Hold the cart on the track so the front of the cart is 15 cm from the spring bumper.

☐ 6. Press the Zero button on the top of the force sensor, start recording data, and release the cart. (6.2)

☐ 7. Stop recording data after the cart hits the spring bumper. (6.2)

☐ 8. Repeat the same procedure to record a second and third run of data, but for the second run, release the cart 30 cm from the bumper, and for the third, 45 cm from the bumper.

☐ 9. Copy Table 1 into your notebook. Then use the tools on your data collection system and your graph of Velocity versus Time to determine the velocity of the cart immediately before (the initial velocity) and immediately after (the final velocity) each collision. �(9.1) Record all values into Table 1 in your notebook.

Table 1: Change in momentum for collisions with different initial velocities using the light spring bumper

Run	Initial Velocity (m/s)	Final Velocity (m/s)	Initial Momentum (kg·m/s)	Final Momentum (kg·m/s)	Change in Momentum (kg·m/s)	Impulse (N·s)
1						
2						
3						

RECORD YOUR ANSWERS IN YOUR NOTEBOOK.

☐ 10. Use a balance to measure the mass of your cart. Record your cart's mass into your notebook.

☐ 11. Use the mass of the cart and the values in Table 1 to calculate the initial momentum, final momentum, and change in momentum for each run of data. Record your results into Table 1 in your notebook

☐ 12. Use the Area Tool �(9.7) on your data collection system to determine the area under the Force versus Time curve (for the part of the curve corresponding to the collision) �(7.1.4) for each run. Record the value of each impulse in Table 1.

NOTE: *The area (impulse) measurements should have 2 significant digits. To add or remove significant digits in the impulse measurements, use the Data Properties screen to increase or decrease the number of digits to the right of the decimal.* �(5.4)

Questions

1. What are the units of change in momentum? What are the units of impulse? How do the units from the two different quantities compare?
2. Based on your results, how does the change in momentum compare to the impulse for each run?
3. Based on your results, explain the relationship between the *change in momentum* in a collision and the *impulse* associated with that collision, using one or two complete sentences.
4. Based on your observations and your explanation for the previous question, what is the impulse experienced by a 900.0 kg car that hit a wall at a speed of 2.2 m/s and bounced back at a speed of 1.5 m/s in the opposite direction?
5. Complete the questions in the Challenge: Collisions handout for this activity.

Teacher Notes: Impulse Momentum

Learning Objectives

Determine the relationship between the change of momentum of an object and the impulse it experiences, where *impulse* is defined as the force experienced by that object over the time during which the force acts, in this case, during the collision.

Activity Introduction

As this is a discovery-based activity, avoid telling students about the relationship between change in momentum and impulse before and during the lab activity. It is suitable to tell students that they will be performing a lab in which they will be responsible for determining this relationship and to provide some mention of how momentum and impulse were defined and determined in previous activities. You can use the post-lab discussion below to help confirm student findings after the lab.

Post-Lab Discussion

After students have completed the activity, use the following algebraic manipulation to help confirm student findings by showing how the relationship between change in momentum and impulse is derived.

Begin by asking students what they know about momentum and what components of an object's motion make up momentum. Students will have seen in the Momentum activity that the momentum of an object in motion, with constant mass, is equal to the product of the object's mass and velocity. Draw the equation for momentum on the whiteboard:

$$\boldsymbol{p} = m\boldsymbol{v}$$

Have students picture an object with a constant mass in motion and traveling with some velocity (v).

- Ask them what will change that object's momentum.

  Since the objects have a constant mass, the only way to change the object's momentum is to change its velocity (any change in speed or direction or both). According to Newton's 1st Law, an object's motion (velocity) can change only when an unbalanced force acts on the object over some time interval (Δt). Students will likely know that an unbalanced force is needed to change the velocity of, and thus the momentum of, an object in motion.

- Use Newton's 2nd Law to help describe the force needed to change the momentum of an object in motion.

  Have students help you write Newton's 2nd Law equation on the whiteboard, either by having them explain what the equation is, or having a volunteer come to the whiteboard and draw the equation:

  $$\boldsymbol{F} = m\boldsymbol{a}$$

- Ask students if there is a way to describe force in terms of velocity rather than acceleration.

  The goal is to derive a new equation for Newton's 2nd Law that uses a change in velocity with respect to time rather than acceleration, ending up with the equation:

  $$\boldsymbol{F} = m\frac{\Delta \boldsymbol{v}}{\Delta t}$$

- Ask students if they can see any similarities between this new equation and the original equation for momentum. Then go a step further by having them try to identify change in momentum.

  Have a volunteer come up to the whiteboard and write the equation in terms of momentum rather than velocity. The equation should be:

  $$\boldsymbol{F} = \frac{\Delta \boldsymbol{p}}{\Delta t}$$

  Where $m\Delta v$ is equal to the change in momentum Δp.

- Finally, ask students to algebraically isolate change in momentum and see what values end up on the opposite side of the equal sign:

  $$\boldsymbol{F}\Delta t = \Delta \boldsymbol{p}$$

Students should identify the left side of the equation ($\boldsymbol{F}\Delta t$) as impulse, or the area under a Force versus Time curve. If students need further proof that impulse is equal to the change in momentum of an object, have them determine the units for both sides of the equation and compare. Students will see that the units do indeed match.

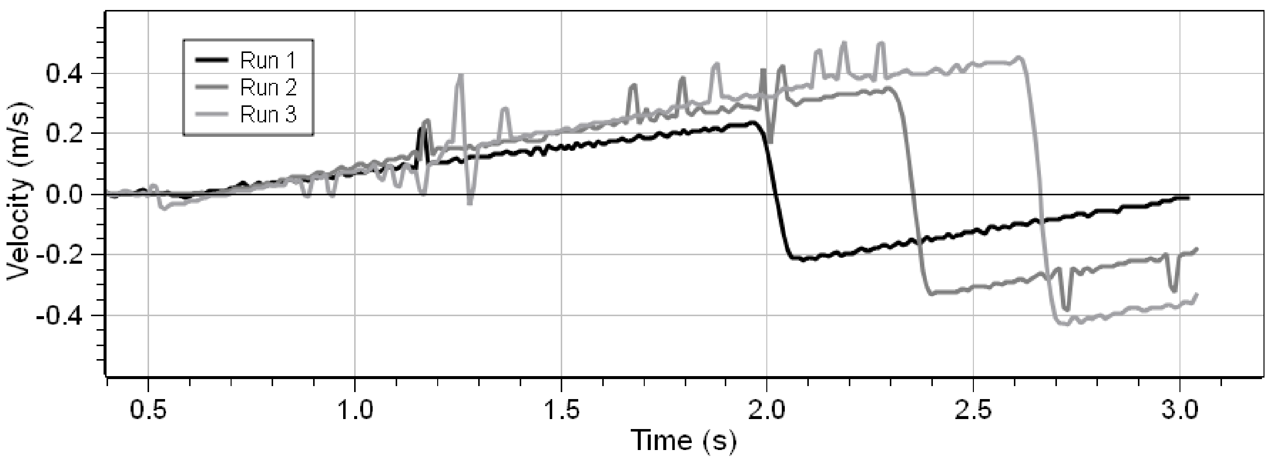
Teacher Tips

The instructions in step 4 of the Impulse Momentum activity handout assume that the data collection system which your students are using does not allow for independent control of individual sensor sample rates. Students are instructed in the handout to set the sample rate to 100 Hz, which provides a sufficient number of data points to display the force associated with the impact of the cart with the force sensor, while not sampling at too high a rate for the motion sensor (a sample rate of 100 Hz or less is recommended when using the motion sensor). However, 100 Hz is not ideal, and if your students are using a data collection system that allows for independent control of the sample rate for each sensor, we recommend that you have students disregard the 100 Hz sample rate and set the motion sensor sample rate to 40 Hz, and the force sensor sample rate to 500 Hz.

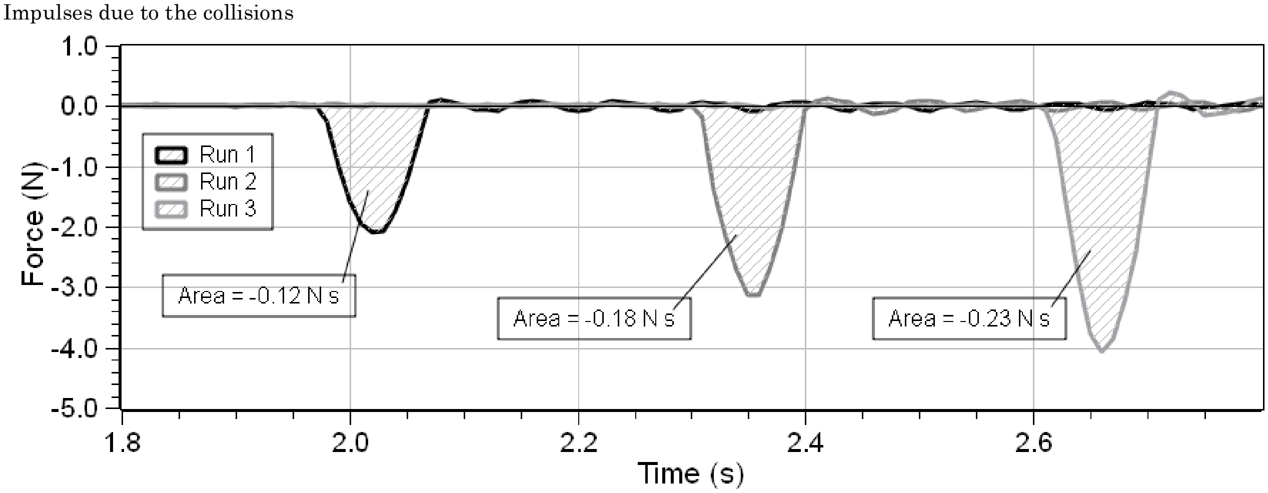
The activity handout instructs students to show two significant digits in their measurements when they measure the area under their Force versus Time curves. If their data collection systems do not automatically show two significant digits, they can add or remove significant digits by increasing or decreasing the number of digits to the right of the decimal for their force measurements. This is done in the Data Properties screen on the data collection system. (See Tech Tip 5.4.)

Sample Data

Change in velocity due to the collisions



Impulses due to the collisions



Mass of the cart: 0.254 kg

Table 1: Change in momentum for collisions with different initial velocities using the light spring bumper

Run	Initial Velocity (m/s)	Final Velocity (m/s)	Initial Momentum (kg·m/s)	Final Momentum (kg·m/s)	Change in Momentum (kg·m/s)	Impulse (N·s)
1	0.24	–0.21	0.061	–0.053	–0.11	–0.12
2	0.35	–0.34	0.089	–0.086	–0.18	–0.18
3	0.45	–0.43	0.11	–0.11	–0.22	–0.23

Answer Key

Below are sample responses to the questions found in the Impulse Momentum activity handout. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an “S” to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE IMPULSE MOMENTUM ACTIVITY HANDOUT

Questions		Sample Response
Handout	SPARKlab	
1	S2	The units for change in momentum are kg·m/s. The units for impulse are N·s. The two units are the same because N is equivalent to kg·m/s^2 so N·s expands to (kg·m/s^2) × s, which simplifies to kg·m/s.
2	S1	In Sample Data Table 1, the change in momentum for Run 2 is equal to the impulse, and the change in momentum for Runs 1 and 3 are close to their corresponding impulses.
3	S3	The change in momentum experienced by an object in a collision is equal to the impulse associated with that same collision.
4	S4	The impulse experienced by the car is the same as its change in momentum: $\boldsymbol{I} = \Delta\boldsymbol{p}$ $\boldsymbol{I} = m\ \boldsymbol{v}_f - \boldsymbol{v}_i$ $\boldsymbol{I} = 900.0\ \text{kg}\ -1.5\ \text{m/s} - 2.2\ \text{m/s}$ $\boldsymbol{I} = -3{,}300\ \text{N}\cdot\text{s}$

Connecting the Activity to the Challenge

The Impulse Momentum activity introduces students to the relationship between *change in momentum* and *impulse*. At the end of the activity, students should know that when an object (with constant mass) experiences an impulse, its momentum will change as a result. Impulses are the cause for abrupt changes in motion such as those experienced by a car in a collision, and if the students’ goal is to design an effective bumper, impulse is a quantity that should be minimized.

The goal now is to help students connect their understanding of this relationship with how bumpers work. Use the following questions as a guide to help the students make some of these connections.

- Which type of collision, elastic or inelastic, produced a greater change in momentum?

  An elastic collision produces a greater change in momentum than an inelastic collision. If the initial velocity of an object is identical for both types of collision, the final velocity is equal and opposite for an elastic collision, and zero for an inelastic collision. Therefore, $\Delta\boldsymbol{v}$ is greater for an elastic collision, resulting in a greater change in momentum and a greater impulse.

- How does knowing about these collision types help when designing a car bumper?

  Finding that the change in momentum equals the impulse, a quantity to minimize, provides evidence that a bumper should produce an inelastic collision, rather than an elastic collision.

After this discussion, have students answer the Research Questions for the Impulse Momentum activity on the Challenge handout.

SAMPLE RESPONSES TO THE IMPULSE MOMENTUM RESEARCH QUESTIONS

Question	Sample Response
1	In movies, the type of collision that is shown most often is an inelastic collision. The car hits an immovable object and stops; it does not bounce back.
2	Given that the impulse due to a collision is equal to the change in momentum of that collision, and since (as found in the Momentum activity) an inelastic collision produces a smaller change in momentum than an elastic collision, the impulse of the inelastic collision would also be smaller than the impulse of the elastic collision. (This assumes the initial velocity and mass were the same for the object in both types of collision.) (Recall that if the initial velocity of an object was identical for both types of collision, the final velocity would be equal and opposite for an elastic collision, and zero for an inelastic collision. Therefore, the $\Delta\boldsymbol{v}$ would be greater for an elastic collision, resulting in a greater change in momentum and greater impulse.)

Activity: Peak Force

Objective

Test and identify materials and structures that minimize the peak force in a collision.

Materials and Equipment

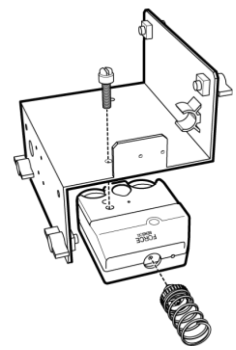
- Data collection system
- Force sensor
- Dynamics cart
- Dynamics track with feet
- Pivot clamp
- Force accessory bracket with both spring bumpers and the magnetic bumper
- Large base and support rod
- Materials to test
- Tape or Velcro® fasteners, several

Safety

Wear eye protection during this lab. Small bits of bumper material could fly off randomly during each collision.

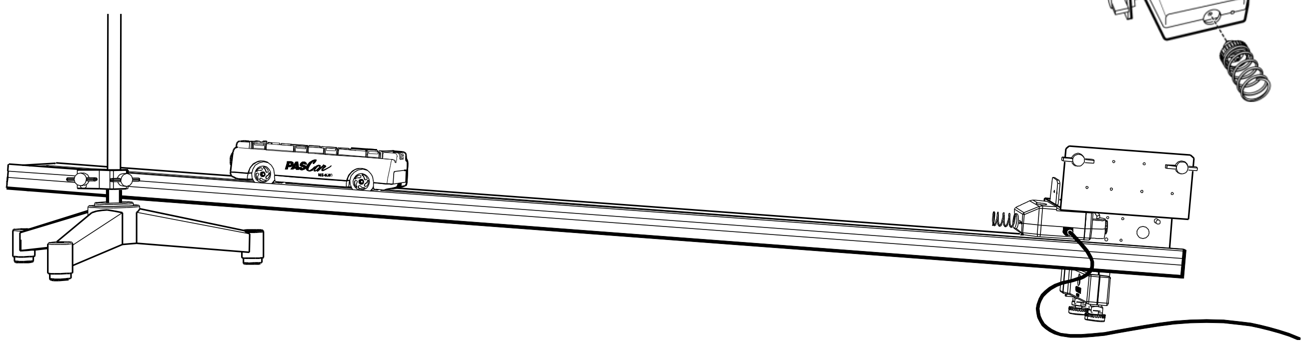
***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*

Procedure – Measuring Peak Force Using the Spring Bumpers



☐ 1. Attach the heavy spring bumper to the front of the force sensor. Then mount the sensor to the force accessory bracket, as in the picture to the right.

☐ 2. Assemble the accessory bracket with the force sensor and the other pieces of your equipment as in the picture below. Make sure that the angle on the track is very shallow (about 5°)



☐ 3. Connect the force sensor to your data collection system and start a new experiment. �(2.1)

☐ 4. Create a graph of Force, push positive, versus Time �(7.1.1), and then set the sample rate to 500 samples per second. �(5.1)

☐ 5. Hold the cart on the track so that the front of the cart is 60 cm away from the spring bumper. Press the Zero button on the top of the force sensor, start recording data, and release the cart. Stop recording data after the cart collides with the bumper. �(6.2)

***NOTE:** Be sure to release the cart from the same position for every run. Also, the collision force should be no greater than 50 N. Adjust the track angle to reduce the force, if necessary.*

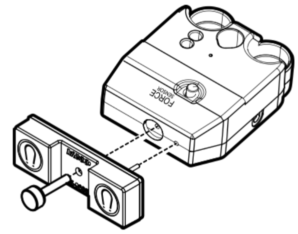
☐ 6. Switch the heavy spring bumper to the light spring bumper. Record another run of data. �(6.2)

☐ 7. Use the statistics tools on your data collection system to determine the impulse and peak force associated with each bumper collision. �(9.4) Record all four values into your notebook.

***NOTE:** Your impulse measurements should show two significant digits. To add or remove significant digits in your impulse measurements, use the Data Properties screen to increase or decrease the number of digits to the right of the decimal for your force measurements.* �(5.4)

☐ 8. How do the two impulse values compare? How do the two peak force values compare? How is it possible to have similar impulse values, but different peak force values in identical collision?

Procedure – Measuring Peak Force Using a Test Bumper



☐ 9. Switch the spring bumper to the magnetic bumper. The magnetic bumper attaches to the force sensor as in the picture to the right.

☐ 10. Use the materials provided by your teacher to construct a test bumper that will minimize the peak force on impact and mount to the front of the cart. This test bumper can be of any design, but consider the results when using the different springs, your initial design ideas, and the concepts learned in previous activities, as well as the project's design constraints.

☐ 11. Once you have constructed your test cart bumper, mount it to the front of the cart using tape or Velcro fasteners. Make sure the bumper is not so large that it interferes with the motion of the cart moving down the track.

☐ 12. Test the impact absorbing power of your test bumper by repeating the same data collection procedure as in the previous section.

☐ 13. Use the statistics tools on your data collection system to determine the peak force associated with the bumper collision. �(9.4) In your notebook, describe the construction of your test bumper (you can sketch a drawing of it to help explain) and indicate the peak force from the collision.

☐ 14. Make any alterations or overhauls to your test bumper to achieve a minimum peak force. Record a run of Force versus Time data for each different test bumper. Explain in your notebook any changes you made to your test bumper that helped lower the peak force, and indicate the lowest peak force achieved.

☐ 15. Sketch or attach a copy of your Force versus Time graph in your notebook.

Questions

1. What is a material not provided by your teacher that you believe would have worked better in your test bumper to minimize the peak force in the collision? Why would it have worked better?
2. Complete the questions in the Challenge: Collisions handout for this activity.

Teacher Notes: Peak Force

Learning Objectives

Students test and identify materials and structures that minimize the peak force in a collision.

Safety

Students should wear eye protection during this lab. Small bits of bumper material could fly off randomly during each collision.

Activity Introduction

In a collision, the moving object experiences an impulse that changes its momentum. While students should minimize the magnitude of the impulse experienced in a collision when designing their bumpers, it is not the magnitude of the impulse that is responsible for the damage sustained in a collision. Rather, it is the peak force associated with the impulse. A good way to demonstrate this is to compare the result of throwing an egg against a wall to the result of throwing an egg into a hanging sheet:

- For a dramatic demonstration, throw a raw egg against a wall (or have a volunteer do so).

  (If you'd prefer to avoid the mess and cleanup, you can simply have students explain the obvious outcome of throwing a raw egg against a wall.)

- Now have two volunteers hold up a large, non-fitted bed sheet as a new target. Have the students stand on chairs and hold up the top two corners so the sheet is taut horizontally, but hanging loose vertically. Place a pad or something on the floor that will catch the raw egg without breaking it when it falls from the bottom of the sheet. For safety reasons, be sure to have the two volunteers wear eye protection and possibly a lab coat or other garment covering.

  Ask students to predict what will happen when the egg is thrown into the sheet. Have them justify their predictions and then throw the egg into the sheet with the same force as it was thrown against the wall. The egg should hit and slide, unbroken, from the sheet to the floor. The egg should not break, regardless of the speed at which it hits the sheet.

The question students need to answer is: The change in momentum for both collisions (into a sheet versus into a wall) is the same, thus the impulse is the same, so why does the egg break when it hits the wall but not when it hits the sheet?

- Ask students to explain what happened when the egg hit the sheet and describe the forces acting on the egg as it hit the sheet.

  Students should be able to explain that the egg experienced a force as soon as it touched the sheet, but the force was small and increased slowly as it went further into the sheet.

- Ask students why the egg would break against the wall but not against the sheet.

  The force experienced by the egg when it hits a wall is much greater in magnitude, but only for a small period of time, while the force experienced when it hits the sheet is much smaller in magnitude, but applied for a much longer period of time.

Teacher Tips

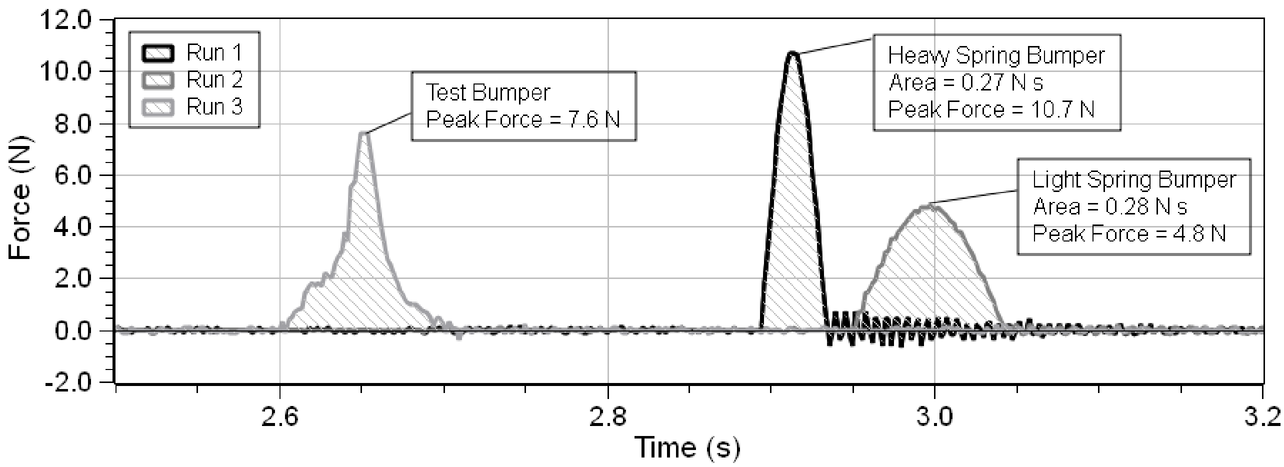
Students will use the Peak Force activity to evaluate different materials and structures for their bumpers. They may need time to reflect on those materials and structures that work best to minimize peak force. You can provide a second day of lab, an extension to this activity, so students can continue testing and examining different designs beyond what the activity calls for.

Students should be using their Force versus Time graphs to help identify where their bumpers are succeeding and where they are failing. Sharp spikes in force are an indication that not enough impact absorbing material is in place, or that there is contact with a hard material within their bumpers. Maximizing the amount of time it takes for the collision to occur will help minimize peak force. This may mean that a longer bumper will work better than a shorter one. However, remind students that the design constraints for the Challenge do not allow for bumpers longer than 5 cm.

If you extend this activity into a second day, have students answer the questions in the Challenge: Collisions handout for this activity after the second day.

Sample Data

Impulse and peak force for different bumpers



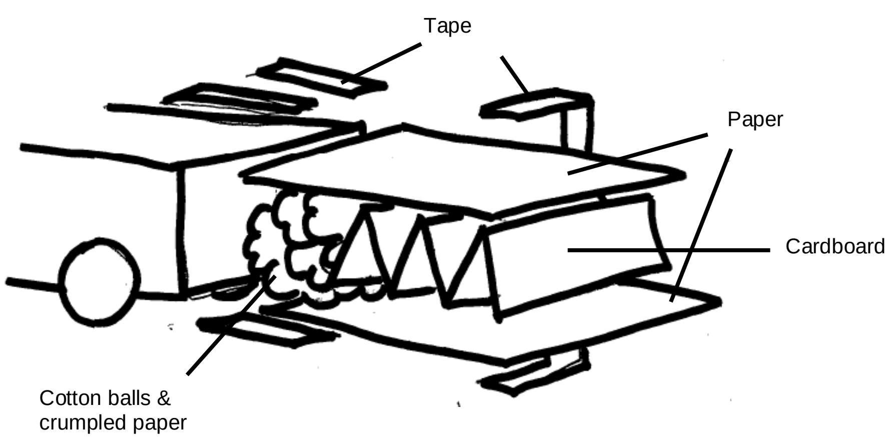
Recorded values for the three collisions

Run	Bumper	Impulse (N·s)	Peak Force (N)
1	Heavy spring	0.27	10.7
2	Light spring	0.28	4.8
3	Test bumper		7.6

Answer Key

Below are sample responses to the questions found in the Peak Force activity handout. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE PEAK FORCE ACTIVITY HANDOUT

Procedure		Sample Response
Handout	SPARKlab	
8	S13 and S14	In the Sample Data, the two impulse values are nearly the same, but the peak force is much higher for the heavy spring bumper because it is a much stiffer spring. It is possible to have similar impulse values but different peak forces because one spring was softer and was applying a smaller force for a longer period of time. Therefore, the areas under the Force versus Time curves could be the same.
13	S20 and S21	Our bumper was built from paper and cotton balls packed behind an accordion shaped piece of cardboard and then wrapped in paper to hold it all together. We used tape to secure it to the cart. The peak force during the collision was 7.6 N. Here is a drawing of our test bumper: 
14	S26	We replaced the paper in our original test bumper with aluminum foil, which greatly reduced the peak force. The lowest peak force achieved was 6.5 N.

Questions		Sample Response
Handout	SPARKlab	
1	S1	We believe that a piece of very soft rubber would have worked best because it would have absorbed more force as its shape changed during the collision, and it would have resulted in an inelastic collision.

Connecting the Activity to the Challenge

Discuss with students how they can apply the results of the Peak Force activity, considering the materials and the different structures they tested, to inform their bumper designs. Remind students that the design constraints require their bumpers to be no longer than 5 cm, nor add more than 200 g to the mass of the cart. If the structures that were tested were longer than 5 cm, students need to pare them down to fit with the design constraints.

SAMPLE RESPONSES TO THE PEAK FORCE RESEARCH QUESTIONS

Question	Sample Response
1	The materials and design that worked best was a tube made out of paper, filled with cotton balls and crumpled tape balls. We think this design worked best because of the three important design components: 1. The tube was designed to smash during the collision and not rebound, preventing an elastic collision. 2. The crumpled tape inside the tube helped to keep the tube from rebounding when it was crushed, while the cotton balls absorbed most of the impact. 3. The tube was made to be 5 cm long to help maximize the contact time during the collision in order to distribute the force over a longer period of time.

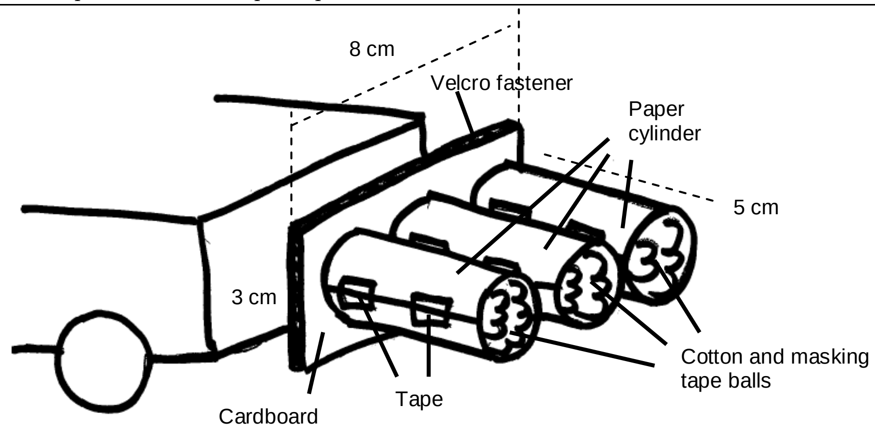
3 Revise Design

Provide students a specific amount of time to revise their design. Ideally, they will use their notes and data from the research section to change part or all of their original concepts. Encourage your students to note specific decisions they make and the reasons behind the decision.

Make sure to provide enough time for your students to get their ideas down on paper. Encourage them to note the changes they make and the parts they chose not to change, and their reasoning for that as well. This will give them a solid basis for their group work.

At this point your students should have their updated sketches, drawings, descriptions, and justifications to bring to their group for discussion and debate.

SAMPLE RESPONSES TO THE QUESTIONS IN THE CHALLENGE HANDOUT REVISE DESIGN SECTION

Question	Sample Response
1	My original design ideas would have worked, but they needed improvement. My new design has been adapted to produce an inelastic collision rather than an elastic one, and to be much longer to help prolong the impact time the bumper experiences before the cart comes to rest.
2	 My new design uses three paper cylinders filled with cotton balls and wadded masking tape balls , attached to a flat piece of cardboard with a Velcro® fastener to mount the bumper to the cart. Our data from the Peak Force activity supports this new design because the same design using one cylinder resulted in the lowest measured peak force of all the designs we tested.

4 Develop Group Design

Divide your students into their design groups. This can be the same group they did research with, but arranging groups that consist of students with different perspectives can make the discussion and synthesis process much more instructive for your students. If possible, groups should contain an odd number of students to prevent deadlocks in decisions.

Encourage students to assign roles prior to beginning their discussions. Roles might include a discussion leader or arbiter, a decision recorder, or a requirements reviewer. Help your students to establish their own set of ground rules before they start, such as “one person talks at a time,” or “everyone presents their ideas before asking questions.”

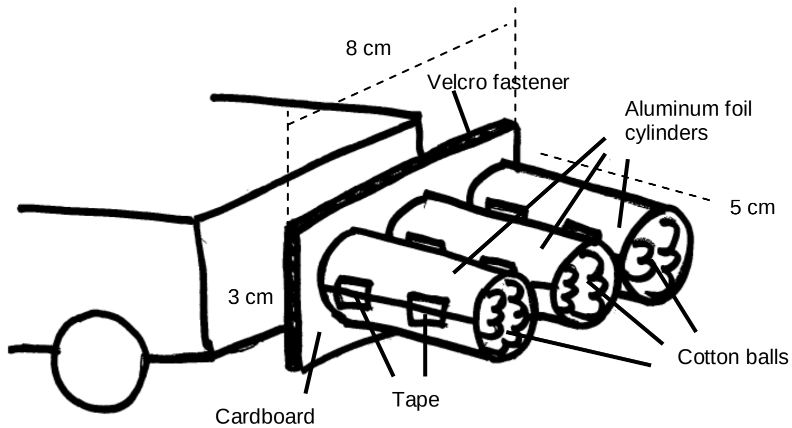
During this part of the process, each student should have the opportunity to present their design ideas, evaluate and discuss the ideas of the group, and help the group come to consensus. Student discussions can get heated, and part of your role will be to help them resolve their disagreements. If groups come to an impasse, help them find a way around. It may take a simple majority vote, and it may take a more creative path, such as constructing two separate prototypes to test within the group before presenting a final design to the class.

Throughout the process, ensure your students are carefully noting their choices and outcomes. Individually they should note the differences between their own design and the final group design, and the reasons for the differences. Encourage students to focus on the elements of design and ideas rather than individuals. Ultimately, you may need to reorganize disharmonious groups, but it will be much more instructive for students to find ways to work with group members with whom they might not otherwise interact. Establish a timeline for your students and help them stay on track.

By the end of this process each design group should have a design for their prototype(s). Be sure students clarify any points of obscurity before you sign off on each design and they launch into building. This is also your opportunity to check for any safety issues the students have not considered. If you decide to allow students to bring materials from outside the classroom, inspect the materials for any safety hazards before you let your students begin the building process.

Engineering research is not necessarily a linear process. There are many different and equally valid ways to solve the same problem, so expect a variety of proposed solutions.

SAMPLE RESPONSES TO THE QUESTIONS IN THE CHALLENGE HANDOUT DEVELOP GROUP DESIGN SECTION

Question	Sample Response
1	We decided to use a design that has three cylinders extending from a flat piece of cardboard. On the back of the cardboard is a Velcro fastener to attach the bumper to the cart. Each cylinder is a rolled piece of aluminum foil filled with cotton balls:  We decided to use cylinders because a similar design was tested in the Peak Force activity and it had the smallest peak force out of all the designs. Aluminum foil was used because once it is crumpled in the collision it won't rebound, producing an inelastic collision. The cotton balls are to help keep the foil from crumpling during construction and to increase impact absorption. The cylinders will be 4.5 cm long. This maximizes their length, increasing the contact time during the collision to increase the length of time the force is felt by the bumper. This will lower the peak force experienced by the cart.

5 Build a Prototype

Give your students a sufficient amount of time to construct their prototypes. Each group should follow the design constraints to create its prototype and restrict itself to the materials list that you provide. Each group should construct three identical prototypes to test with the class in three different trials.

Monitor student progress to ensure safe construction practices and to keep the groups cognizant of their time limitations. To best observe student progress, we recommend that student construction time be restricted to the classroom. If your schedule does not permit in-class construction, encourage your students to meet as study groups or provide them with a meeting room outside of class time.

By the end of the prototype construction phase, each group should have three identical bumpers ready for evaluation.

SAMPLE RESPONSES TO THE QUESTIONS IN THE CHALLENGE HANDOUT BUILD A PROTOTYPE SECTION

Question	Sample Response
1	My specific responsibility during the construction process was to entirely build one of the three test bumpers, making it identical to the other two.
2	Our prototypes exactly match our group design and no design points were changed during the construction process.
3	The mass of our bumpers are 185 g, 180 g and 195 g. The lengths of our bumpers are 4.8 cm, 5.0 cm, and 5.0 cm, respectively.

6 Test and Evaluate

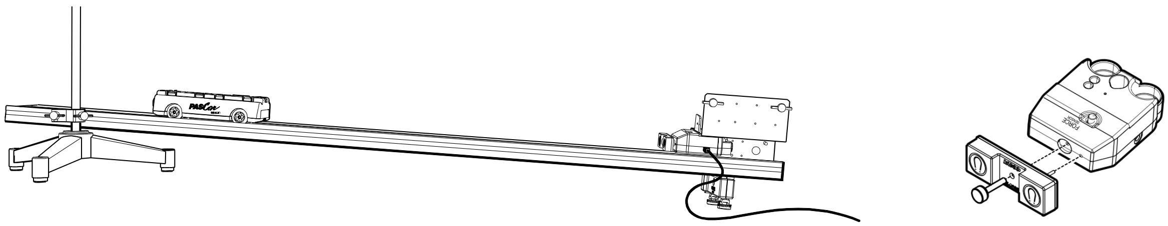
For the evaluation process, use one cart and track setup to test the bumpers. The test bed should be consistent for all groups and each trial. The equipment and setup are described here:

Materials and Equipment

- Data collection system
- Force sensor
- Dynamics cart (as test cart)
- Dynamics track with feet
- Force Accessory Bracket with magnetic bumper
- Pivot clamp
- Large base and support rod

Setup

Configure the equipment as in the picture below:



No specific angle is required for the track, but it is important not to have impact forces exceed 50 N (which will damage the force sensor). It is also important to use the same angle for all trials. A track angle between 10° and 15° is recommended.

Connect the force sensor to the data collection system and build a graph of Force, push positive, versus Time. � (7.1.1) After the graph is built, increase the sample rate to 500 Hz. � (5.1)

Test

Have each group test their bumpers, one group at a time, at the teacher setup station. Test all three prototypes from one group before moving on to the next group. Before testing begins, decide what an appropriate distance is to release the test cart on the track. This distance should be the same across all trials and all groups. Releasing the cart from a distance too close to the force sensor will result in low peak force measurements and a disappointing collision for students. Releasing it from too great a distance will result in peak forces that exceed 50 N, which will damage the force sensor. It is recommended that a distance of approximately 65 cm be used with a track angle between 10° and 15°. Measure this distance from the front of each group's bumper to the front of the force sensor bumper to ensure each group's cart will have the same velocity at the time of impact.

To test, have the testing group mount their first bumper to the front of the test cart (the end of the cart without the magnets) and then place the cart onto the track, holding it in place at the specified distance. Begin recording data. �(6.2) then have the student release the cart. After it collides with the force sensor, stop recording data. Use the statistics tools on the data collection system to determine the maximum force during the collision. �(9.4) Have the students in the group record the maximum force value and note which of their three bumpers was used.

Repeat the procedure to test the remaining two bumpers, and then continue testing until every group has tested all three of their prototypes.

Each group's collision graphs may be useful for comparison in a class discussion later. It is recommended that all data recorded at the test station be done so in a continuous manner (data for group 1 will be runs 1, 2 , and 3; data for group two will be runs 4, 5, and 6; and so on) and saved using the data collection system. � (11.1)

Evaluate

Students should examine each of their prototypes closely to evaluate and record how their design succeeded and what failed. Students will need these observations for the Design Review stage of this Challenge.

When all groups have finished testing, have one person from each group record the lowest peak force from the cart's three trials in a central location (on the whiteboard at the front of the class, for example) so every group can see each group's lowest peak force value. Students will need these values to answer questions in the following section.

7 Design Review

Once testing has finished, allow students time to reflect as a group on the successes or failures of their design and to answer the design review questions in their Challenge: Collisions handout in their groups. Students will need the overall class peak force values recorded in a central location after the testing to help answer these questions.

Be sure to encourage more critical thinking in groups when students are reviewing their designs. Ask that students recall the scientific concepts explored throughout the module and to consider them when answering the design review questions in the Challenge: Collisions handout. At this point, when students are analyzing their design and the designs of other groups, they should identify components that minimize peak force in an impact by minimizing change in momentum (impulse) and maximizing the contact time between the bumper and the object it is impacting. Both will lower the overall peak force experienced in a collision.

SAMPLE RESPONSES TO THE QUESTIONS IN THE CHALLENGE HANDOUT DESIGN REVIEW SECTION

Question	Sample Response
1	The lowest peak force recorded by the class was 0.20 N while our lowest peak force was 0.24 N.
2	Most groups didn't use aluminum foil, which we think made it possible to have such a smooth inelastic collision. We also think that having our bumper be the maximum length of 5 cm allowed us to maximize the contact time, which helped lower the peak force but kept the total impulse the same.
3	One thing we would change is to use more aluminum foil near the base of the bumper. The force spiked because the foil crumpled too easily. More aluminum foil at the base of the bumper might add more strength to the aluminum foil so all of it doesn't compress right away, but undergoes a more staged crumpling—quickly at first but harder and slower the more it crumples.

Concluding the Module

To conclude the STEM Collision Module, have a class discussion about aspects of their designs that worked and those that did not. Have students work together in their groups to create a list of the components that worked well in their design and components that did not. For those that worked, have students identify the physical concepts that were covered in the research activities that apply to those components. You may want to use data saved during the Test and Evaluate section to confirm these concepts. Bring up once again some of the misconceptions that students had before the research activities and have students discuss how this project affected those ideas.

After each group has created a list, discuss as a class each group's list and how items on one group's list may have been used in other groups' designs. Discuss why the design worked and other ways the same effect could have been achieved using a different design.

Have students review and complete their notebooks and submit them for assessment.

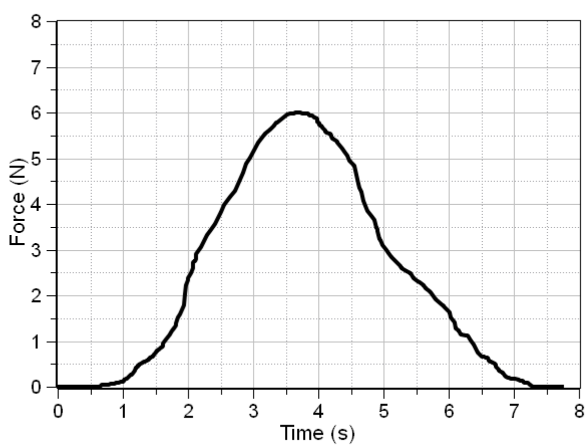
Post-Assessment

1. What is the momentum of a 1,270 kg car traveling east at 28.0 m/s?
   A. 45.4 kg·m/s
   B. 45.4 kg·m/s east
   C. 3.56×10^4 kg·m/s
   D. 3.56×10^4 kg·m/s east

2. A basketball player drops a 0.5 kg basketball straight down and it bounces off the floor. If the velocity of the ball is –5 m/s just before it hits the floor, what is the ball's change in momentum? Assume that the ball experiences a perfectly elastic collision and bounces back with the same speed that it hit the floor with.
   A. 0 kg·m/s
   B. 5 kg·m/s
   C. –0.4 kg·m/s
   D. –5 kg·m/s

3. Does a satellite circling the earth with constant speed experience a change in momentum? Why or why not?

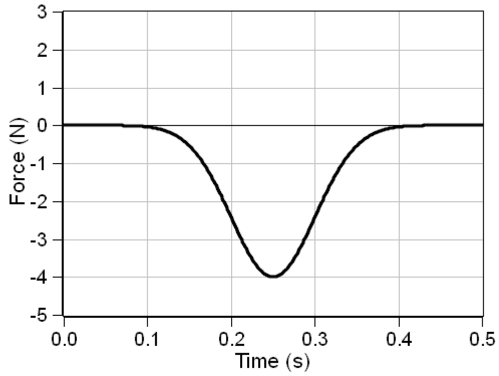
4. Which answer best describes the area under the curve below?



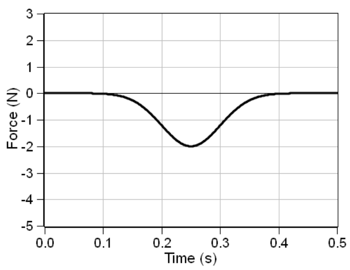
   A. 16.5 kg·m/s²
   B. 17.0 kg·m/s²
   C. 18.3 kg·m/s
   D. 19.5 kg·m/s

5. A 121-kg football player collides with a goalpost for 0.25 seconds and comes to a complete stop before falling over unconscious. If the goalpost experienced an impulse of 501 N·s, what was the impulse experienced by the player and what was the player's velocity before the collision?

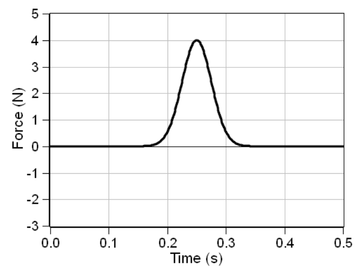
6. This graph shows the force experienced by a cart on a flat track when it collides with a spring bumper that produces a perfectly elastic collision.



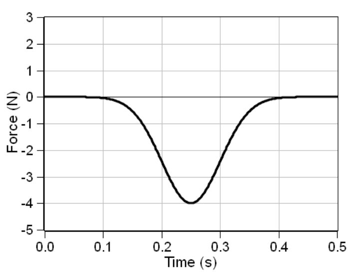
Which of the graphs below represents an equivalent collision (the same cart with the same initial velocity), but rather than colliding into a spring bumper, the cart collides into a soft piece of clay that prevents the cart from bouncing back.



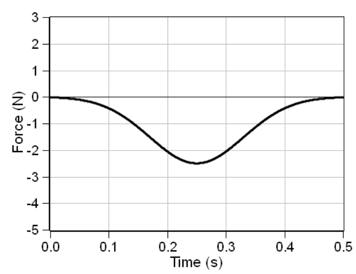
A.



B.



C.



D.

7. Imagine a fisherman in a boat using a fishing line with a breaking strength of 98.1 N. Assuming that there is no net, and the fisherman must bring any fish he catches into the boat using just the fishing line, will he be able to bring a 10 kg fish into the boat?

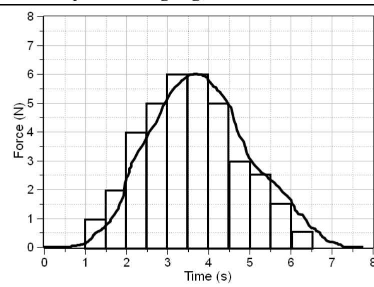
   A. Yes, because the peak force experienced by the fishing line from pulling the fish into the boat will not exceed 98.1 N.
   B. Yes, because the fishing line will stretch and absorb most of the force from pulling the fish into the boat.
   C. No, because the fish will experience an impulse when it is lifted that will cause the peak force experienced by the fishing line to exceed 98.1 N.
   D. No, because the peak force the line will experience at impact will be exactly 98.1 N.

8. If a person drops a raw egg on a soft floor and the egg does not break, which of the following best describes what happened?

   A. The impulse the egg experienced was conserved which prevented the eggshell from breaking.
   B. The eggshell absorbed the force from the impact which prevented it from breaking.
   C. The impulse the egg experienced did not exceed what the eggshell could withstand.
   D. The peak force experienced by the egg did not exceed the breaking strength of the eggshell.

Post-Assessment Answer Key

Questions from the Post-Assessment handout are identified by number in the first column in the table below. The second column indicates the correct answer to each question. Refer to the third column for a more detailed description of the question's assessment information.

Question	Correct Answer	Assessment Information
1	D	Momentum ***p*** is the product of an object's mass and velocity. In this case, mass = 1,270 kg and velocity = 28.0 m/s east. $\boldsymbol{p}$ = (1,270 kg)(28.0 m/s) = 3.56×10^4 kg·m/s east. Just like velocity is a vector quantity, momentum is also a vector quantity and must include direction. Students who answer C understand the algebraic form for momentum but have neglected to include its vector property of direction. Students who answer A or B have incorrectly guessed that momentum is equal to mass/velocity.
2	B	Change in momentum is defined as an object's final momentum minus its initial momentum. Because the ball experiences a perfectly elastic collision with the floor, its final velocity will be equal and opposite its initial velocity. Assuming the ball's mass does not change: $\Delta\boldsymbol{p} = m(\boldsymbol{v}_f - \boldsymbol{v}_i) = m(-2\boldsymbol{v}_i) = -2(0.5\text{ kg})(-5\text{ m/s}) = 5\text{ kg·m/s}$.
3	Yes	Assuming the satellite has a circular orbit, its speed is not changing but its direction is, which implies that the satellite's velocity is constantly changing. If an object's velocity is changing, its momentum is changing as well.
4	C	 Using the approximation shown above: Total area = (0.5 s)(1 + 2 + 4 + 5 + 6 + 6 + 5 + 3 + 2.5 + 1.5 + 0.5 N) = 18.3 N·s Students will answer D if a lower order approximation is used: rectangles with width wider than 1 s will return an area larger than ~18.5. Students will answer A or B if their rectangle approximations are drawn within the curve itself, when the appropriate method would be to draw some rectangle within the curve and some outside the curve like the example above.
5	Impulse = –501 N Velocity = 4.14 m/s	Newton's third law indicates that the force experienced by the football player in the collision must be equal and opposite the force experienced by the goalpost. Because impulse is the area under the Force versus Time curve, and the two curves must be equal and opposite, the impulses will be equal and opposite as well. So if the impulse experienced by the goalpost was 501 N·s, the impulse experienced by the football player is –501 N·s. The player's velocity can be calculated using the relationship between change in momentum and impulse : $\boldsymbol{I} = \Delta\boldsymbol{p} = m\Delta\boldsymbol{v} = m\ \boldsymbol{v}_f - \boldsymbol{v}_i$ $\boldsymbol{v}_i = -\frac{\boldsymbol{I}}{m} = -\frac{-501\text{ N}\cdot\text{s}}{121\text{ kg}} = 4.14\text{ m/s}$
6	A	If the clay prevents the cart from bouncing back, its final velocity after the collision will be zero, but its initial velocity will be unchanged. The result is an impulse that is half the magnitude and in the same direction. Graph B shows an impulse with half the magnitude, but in a different direction. Graph C shows no change to either impulse or peak force, which is incorrect because both will have changed. Graph D shows a smaller peak force, but an unchanged impulse.
7	C	If the fishing line were to hold the fish at rest, the tension on the fishing line would be equal to force from gravity on the fish ($\boldsymbol{F} = m\boldsymbol{g}$), 98.1 N, which would not break the fishing line; however, as soon as the fisherman tries to lift, the fish it will experience a change in momentum, which implies that it will experience an impulse. Any impulse upward will cause an increase in tension that will exceed the 98.1 N breaking strength of the line.

Question	Correct Answer	Assessment Information
8	D	As long as the force required to crack the eggshell is not reached, the egg will not break. Remind students who answer A or C that the impulse associated with two separate collisions may be the same while the peak force in both collisions can be quite different. Peak force can be lowered by increasing the time in which the force is applied in a collision.

Appendix – Master Materials and Equipment

Equipment by Activity

Teachers can conduct some lab activities with sensors other than those listed here. For assistance with substituting compatible sensors for a lab activity, contact PASCO Teacher Support (800-772-8700 inside the United States or http://www.pasco.com/support).

NOTE: *Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.*

Act	Title	Materials and Equipment	Qty
1	**Momentum (p. 23)** Use a motion sensor to measure and compare the change of momentum of an object during an elastic and an inelastic collision.	Data Collection System PASPORT Motion Sensor Force Accessory Bracket with light spring bumper, force sensor clay bumper cup, and clay Dynamics track Dynamics cart Pivot clamp Large base and support rod Balance, 2,000-g capacity	1 1 1 1 1 1 1 1 per class
2	**Area Under a Curve (p. 29)** Use a force sensor to connect the use of rectangular approximations to find the area under a curve to using electronic graphing tools to determine area under a curve.	Data Collection System PASPORT Force Sensor with hook *Ruler* *Pencil*	1 1 1 1
3	**Impulse Momentum (p. 39)** Use a force sensor and motion sensor to compare the change of momentum (before and after a collision), to the force experienced during the collision (impulse).	Data Collection System PASPORT Force Sensor PASPORT Motion Sensor Force Accessory Bracket with light spring bumper Dynamics cart Dynamics track with feet Pivot clamp Large base and support rod Balance, 2,000-g capacity	1 1 1 1 1 1 1 1 1 per class
4	**Peak Force (p. 45)** Use a force sensor to test different materials and structures for a bumper and determine which will achieve minimum peak force in a collision.	Data Collection System PASPORT Force Sensor Force Accessory Bracket with both spring bumpers and the magnetic bumper Dynamics track with feet Dynamics cart Pivot clamp Large base and support rod *Tape or Velcro® fasteners* *Materials to test (it is recommended to use the materials found in the Challenge handout materials list)*	1 1 1 1 1 1 1 Several Various

Activity by Equipment

Items Available from PASCO	Qty	Activity Where Used
Data Collection System	1	1, 2, 3, 4
PASPORT Motion Sensor	1	1, 3
PASPORT Force Sensor	1	2, 3, 4

Equipment for Bumper Construction

NOTE: *Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.*

Materials	Qty
Aluminum foil	1 m^2
Cardboard	1 m^2
Rubber balloons	3
Rubber bands	10
Sheets of paper	unlimited
Soft clay	113 g
Toothpicks	20
Duct tape	50 cm
Glue other than epoxy	unlimited
Masking tape	unimited

Equipment for Collisions Module

The following is a list of all the materials needed for the entire Collisions module. The quantity listed is the total needed for the entire module per student or group. To find the quantity used in each activity, refer to the Equipment by Activity and Equipment for Bumper Construction listed above.

NOTE: *Italicized entries indicate items not available from PASCO.*

Materials	Qty	Activity Where Used
Data Collection System	1	1, 2, 3, 4
PASPORT Motion Sensor	1	1,3
PASPORT Force Sensor with hook	1	2, 3, 4
Force Accessory Bracket with bumpers and clay	1	1, 3, 4
Dynamics cart	1	1, 3, 4
Dynamics track with feet	1	1, 3, 4
Pivot clamp	1	1, 3, 4
Large base and support rod	1	1, 3, 4
Balance, 2,000-g capacity	1 per class	1, 3
Tape or Velcro® fasteners	Several	4
Materials to test (it is recommended to use the materials found in the Challenge handout materials list)	Various	4
Pencil	1	2
Ruler	1	2
Aluminum foil	1 m^2	Bumper construction
Cardboard	1 m^2	Bumper construction
Rubber balloons	3	Bumper construction
Rubber bands	10	Bumper construction
Sheets of paper	unlimited	Bumper construction
Soft clay	113 g	Bumper construction
Toothpicks	20	Bumper construction
Duct tape	50 cm	Bumper construction
Glue other than epoxy	unlimited	Bumper construction
Masking tape	unlimited	Bumper construction