Egg Drop

Project-Based Learning Module

Middle School Physical Science

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: Egg Drop

Design and build a device that will carry a fresh raw egg and protect the egg from cracking as it is dropped from increasing heights.

Activity: Acceleration and Gravity

Analyze the constant acceleration produced by earth's gravity and determine how that acceleration affects the final velocity of falling objects just before impact.

PASCO Motion Sensor

Graphical Analysis, Algebra

Calculate the theoretical final velocity of your egg just before impact after being dropped from a height of 6 meters.

Activity: Reading Graphs

Use conventional and electronic graphing techniques to analyze the motion of a person walking in a straight line.

PASCO Motion Sensor

Practice interpreting graphs and using graphing skills, both conventionally and electronically.

Activity: Force

Show that the acceleration of an object is proportional to the force pushing or pulling it and inversely proportional to the mass of the object.

PASCO Motion Sensor and Force Sensor

Graphical Analysis, Algebra

Use Newton's 2nd Law to determine the force experienced by an egg upon impact with a final velocity equal to the theoretical final velocity previously calculated.

Design and construct an egg-drop apparatus that satisfies the design requirements and constraints using the information learned in the activities.

Activity: Air Drag

Measure the velocity of an object in free fall as its mass is changed and analyze the forces acting on the object as it falls. Show that air drag produces a force opposite the direction of fall.

PASCO Motion Sensor

Graphical Analysis, Algebra

Determine another method for reducing the net force on the egg-drop apparatus in free fall to reduce the force experienced by the egg on impact.

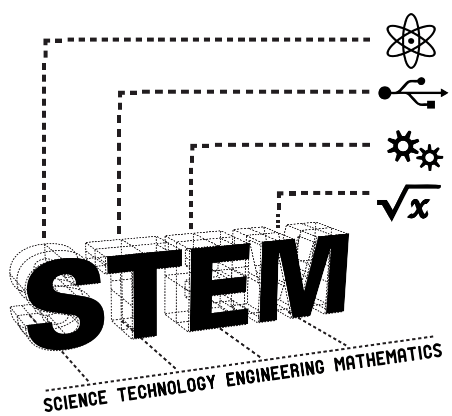
Activity: Impact Force

Analyze the force associated with collisions and determine how different materials used to absorb impact affect the shape of a force versus time graph.

PASCO Motion Sensor

Graphical Analysis, Algebra

Use force versus time graphs to determine a cushioning material that should help keep the egg from cracking by reducing the maximum force experienced on impact.



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Contents

***NOTE:** Headings in bold type indicate student handouts*

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

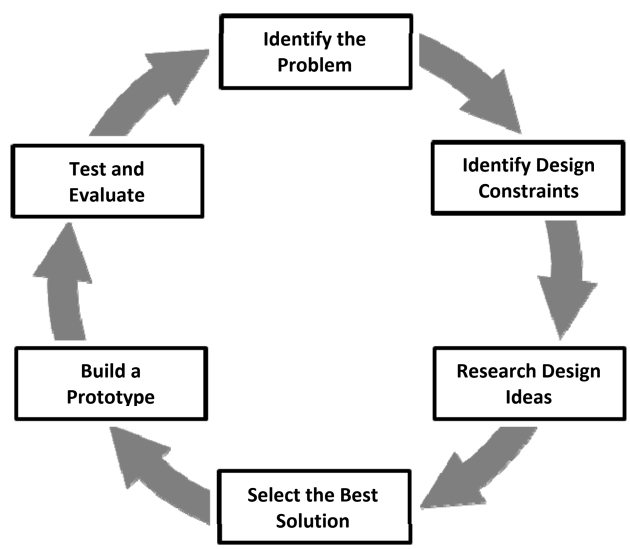
Module Principles

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 Egg Drop 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	Egg Drop SPARK Science Learning System	Egg Drop SPARKvue
Sample file name	MS STEM Air Drag.spk	MS STEM Air Drag 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 SPARAKvue emulator can be used to model the SPARK Science Learning System interface. To model opening a SPARKlab you need to 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 Egg Drop Module provides students an opportunity to apply two of the physical science topics covered in nearly every middle school classroom: motion and force. In the Egg Drop Module, students will build the skills and explore the concepts listed here:

Concepts
Velocity
Acceleration
Gravitational acceleration
Force and acceleration
Force and collisions
Newton's 2nd Law
Air drag
Net force
Impact force and cushions

Skills
Graphing skills: Interpret an *x-y* graph, obtain statistical data
Use a motion sensor to determine velocity
Use a force sensor to measure forces due to acceleration and collisions
Calculate acceleration using velocity and time
Calculate velocity using acceleration and time
Calculate the force of impact on a falling object
Determine maximum force from a force versus time graph
Calculate net force
Make engineering decisions based on quantitative results

To help assess student success and content knowledge, a Pre-Assessment and Post-Assessment handout is included in the Egg Drop Module. The Pre-Assessment handout focuses on concepts covered in the activities within the Egg Drop Module and also addresses some of the misconceptions associated with them. Math concepts are also covered in the Pre- and Post-Assessment handouts. If the Pre-Assessment reveals that your students have a variety of prior concept knowledge, your students may benefit from good, flexible grouping within each class.

The Challenge and activity handouts also include questions that can be used to assess student success and content knowledge.

Pacing Guide

The Egg Drop Module provides several different forms of student engagement including individual and group work, work that can only be done in the lab, work that could be taken home, and work or discussions that are intended to be done as a class and led by the instructor. To determine how a lesson or activity in the module should be delivered (instructor led, individual work, group work, or lab work), refer to the last four columns of the table below. A check mark in the corresponding box will indicate 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.

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	✓			
1	Egg Drop Challenge: Initial Design Ideas		✓		
2	Activity: Reading Graphs			✓	✓
3	Activity: Acceleration and Gravity			✓	✓
4	Activity: Force			✓	✓
5	Activity: Air Drag			✓	✓
6	Activity: Impact Force			✓	✓
7	Egg Drop Challenge: Revise Design		✓		
7	Egg Drop Challenge: Develop Group Design			✓	
8–9	Egg Drop Challenge: Build a Prototype			✓	
10	Egg Drop Challenge: Test and Evaluate	✓		✓	
10	Egg Drop Challenge: Design Review			✓	
11	Concluding the Module	✓			
11	Post-Assessment		✓		

Pre-Assessment

Answer each question to the best of your knowledge.

1. Below is a graph of position versus time data. Draw lines from each term, on the left, to its location(s) in the graph on the right.

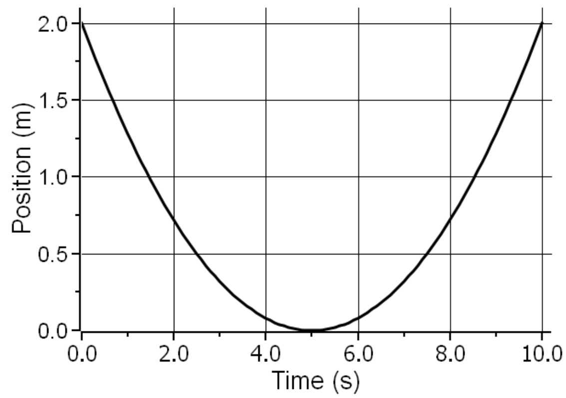
Terms

a. *x*-axis

b. *y*-axis

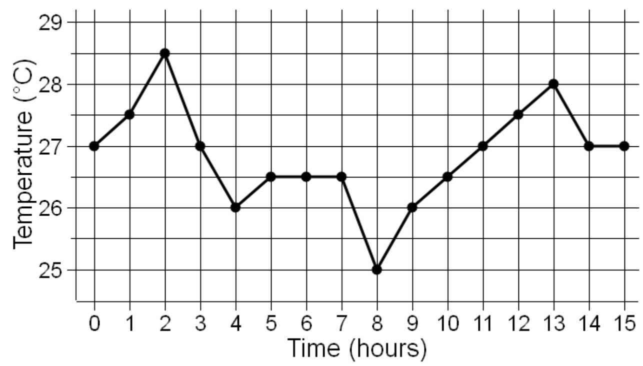
c. Maximum position

d. Minimum position



2. This graph shows the temperature in a room throughout a day. How long did it take for the temperature to go from maximum to minimum? What was the average (mean) temperature during that time? Circle the best answer combination.

   A. 6 hours; 26.8 °C
   B. 6 hours; 26.6 °C
   C. 8 hours; 26.8 °C
   D. 8 hours; 26.6 °C



3. Billy is standing on a bridge above a river. He takes a small pebble, about the size of a bean, drops it from the side of the bridge and counts the time it takes for the pebble to hit the water: 2 seconds. How long do you think Billy will have to count if he drops a larger rock, about the size of a baseball? Circle your prediction.

   A. Longer than 2 seconds.
   B. Shorter than 2 seconds.
   C. 2 seconds.

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

4. A car, stopped at a red light, has a velocity of 0 m/s. When the light turns green, the car speeds up for 2 s to a velocity of 10 m/s. What was the car's acceleration while it was speeding up? Circle the best answer.

   A. $\text{Acceleration} = 10\,\text{m/s} \times 2\text{ s} = 20\text{ m}$
   B. $\text{Acceleration} = 10\,\text{m/s} - 2\text{ s} = 8\text{ m/s}$
   C. $\text{Acceleration} = \dfrac{2\text{ s}}{(10\,\text{m/s} - 0\,\text{m/s})} = 0.2\ \text{s}^2/\text{m}$
   D. $\text{Acceleration} = \dfrac{(10\,\text{m/s} - 0\,\text{m/s})}{2\text{ s}} = 5\ \text{m/s}^2$

5. Two sisters, Sandy and Lisa, need to move a heavy box full of books across the floor to the other side of their room. Sandy pushes the box to slide it half-way across the floor and then Lisa pulls the box to slide it the rest of the way. Which of the sisters was using a force to move the box? Circle the best answer.
   A. Both. Force can be a push or a pull.
   B. Sandy, because force can only be a push and not a pull.
   C. Lisa, because force can only be a pull and not a push.
   D. Neither, because they didn't lift the box.
6. How much force is a truck using to pull a trailer if the trailer has an acceleration of 1.25 m/s^2 and a mass of 900.0 kg? Circle the best answer.
   A. Truck force $= \frac{1.25 \text{ m/s}^2}{900.0 \text{ kg}} = 0.00139$ N
   B. Truck force $= \frac{900.0 \text{ kg}}{1.25 \text{ m/s}^2} = 720$ N
   C. Truck force $= 900.0 \text{ kg} - 1.25 \text{ m/s}^2 = 898.8$ N
   D. Truck force $= 900.0 \text{ kg} \times 1.25 \text{ m/s}^2 = 1{,}130$ N
7. Jason uses a force sensor to measure the force on a small, hard plastic ball as it hits the ground after being dropped from a height of 1 m and discovers that the ball experiences a maximum force of 10 N. Jason decides to repeat the procedure, but this time he puts a soft cushion on the floor where the ball will land. What do you think Jason will observe in this trial? Circle your prediction.
   A. The maximum force will be greater.
   B. The ball will not experience any force.
   C. The maximum force will be less.
   D. The maximum force will be the same.

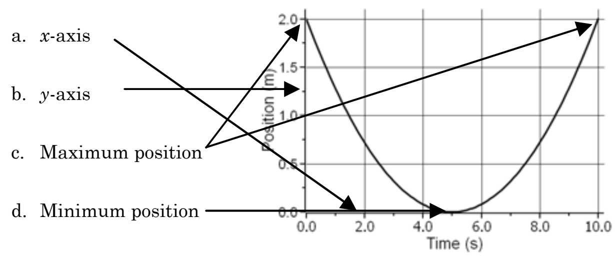
Explain your thinking. Is there a "rule" you used to determine your answer?

8. In the space provided, define *air drag* and explain where it exists in everyday life.

9. If the engines on a jumbo jet at cruising speed push with a force of 12,000 N, and the air drag experienced by the jet is 12,000 N, what is the net force on the jet? Circle the best answer.
   A. 0.0 N
   B. 24,000 N
   C. 12,000 N
   D. 6,000 N

Pre-Assessment Answer Key

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. If a question requires more than a multiple choice response, refer to the third column for a more detailed description of the question's assessment information.

Question	Correct Answer	Assessment Information
1	See Assessment Information	 Related to graphing and graphical analysis techniques: A correct answer shows good understanding of the pieces of a graph, and an excellent understanding of how to identify maximum and minimum values within a graph. Graphing tools and graphical analysis techniques will play an important role throughout the Egg Drop Module and are addressed in the Reading Graphs activity.
2	B	Related to graphing and graphical analysis techniques: Students who chose A or C failed to correctly calculate the mean temperature, taking the mean as half the temperature between the absolute minimum and maximum values. Students who chose either C or D, incorrectly assumed the change in time was equal to the absolute time of the lowest temperature. Both concepts are addressed in the Reading Graphs activity.
3	C	A common misconception is that gravity is different for objects of different size (volume and mass): Larger objects fall faster than smaller objects. An ideal response to this question will show understanding that the larger rock will take the same amount of time to hit the water, and conforms to a "rule" that gravity is constant and that objects will fall at the same rate regardless of their size or masses. This concept is addressed in the Acceleration and Gravity activity.
4	D	Students' answers to this question will indicate if your students have a concrete understanding of the basic mathematical representation for acceleration using changes in velocity and time, prior to the activity. The Acceleration and Gravity activity directs students to calculate the acceleration of different objects and compare those values to show that earth's gravitational acceleration is constant. Use the results of this question to map out the lesson or introduction that should precede the actual Acceleration and Gravity activity itself. Students who are not familiar with the equation, $\text{Acceleration} = \dfrac{\text{Change in velocity}}{\text{Change in time}}$ will need an introduction to it, so they can use it in the Acceleration and Gravity activity.
5	A	A force can be both a push and a pull and can be present even if the object being pushed or pulled isn't accelerating. If the object being pushed or pulled is not accelerating, the net force on the object is zero, a concept addressed in the Force activity as well as the Air Drag activity.
6	D	Newton's 2nd Law says that Force = Mass × Acceleration, a mathematical relationship that is explored in the Force activity. Answers A and B indicate that the student is familiar with the algebraic relationship between force, mass, and acceleration, but the algebra used to determine the answer was incorrect. Answer C shows a lack of unit consistency and no prior knowledge of the algebraic relationship between force, mass, and acceleration.
7	C	The maximum force will be less because the cushion lengthens the time of impact, and as a result the maximum force decreases. This concept is explored in the Impact Force activity. Students may state the rule that impulse (area under a force versus time curve) is conserved, and that the impulse may be the same in both trials but the maximum force will be less in trial 2 while the collision time increases.
8	See Assessment Information	Fair responses will describe air drag as a force due to air. Good responses will describe air drag as a force due to air, and indicate that the magnitude of the force is related to the size of the object traveling through air. Excellent responses will describe air drag as a force due to air whose magnitude is related to the size of the object traveling through it, as well as a force that opposes the motion of the object. The Air Drag activity explores the concept of air drag and net force.
9	A	Cruising speed is constant, meaning that acceleration is zero, which, according to Newton's 2nd Law, indicates that the net force is equal to zero. The Force and Air Drag activities explore the concept of net force.

Introducing Students to the Challenge

Student engagement begins by reading the Identify the Problem section (on the Challenge handout) to the class. Then distribute the Egg Drop Challenge handout. The stages described on the handout follow, chronologically, the stages of the engineering design process listed in the Pacing Guide. 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 Egg Drop 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. It is recommended that these groups be the same groups 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 will indicate 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 (Egg Drop Challenge Rubric.doc file) that allows you to change it as you find necessary.

Materials

There are no constraints on the materials that can be used by students when constructing their apparatus. However, you may find it necessary to constrain the types of materials used. The Challenge handout is also available in an editable electronic format (Egg Drop Challenge.doc), making it easy to include material constraints in the Design Requirements and Constraints section.

Challenge: Egg Drop

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

Identify the Problem

On December 4th 1996, NASA launched one of its few interplanetary vehicles to land on the surface of Mars. The Mars Pathfinder (later named the Carl Sagan Memorial Station) carried with it a "rover" designed to collect scientific samples of the Martian atmosphere, climate, and geology. One of the critical components of the Mars Pathfinder mission was the design of the mechanisms that would prevent the Pathfinder from being crushed during its high-impact landing on the surface of Mars.

NASA scientists created an innovative (and relatively inexpensive) system that would lessen the landing impact using reverse rockets, giant airbags, and a shock resistant capsule. The mission proved to be a success when the capsule was opened on the planet's surface after having entered its atmosphere at speeds greater than the speed of sound (371 m/s), and experiencing forces nearly 30 times the force of Earth's gravity.

Your challenge is to complete a task similar to the one given to NASA scientists except, rather than a $300 million space module, your precious cargo will be a fragile raw egg.

Challenge

Design and construct a device that will carry a fresh, raw egg and will protect the egg from cracking when it falls to the ground from a height of 6 meters.

Design Requirements and Constraints

- You may use any materials you have available.
- The total mass of the device plus the egg cannot be greater than 0.4 kg.
- You can choose to build your apparatus around the egg, or insert the egg once the apparatus has been constructed.

1 ☐ Initial Design Ideas

If you were to design this device right now, how would you construct it and what materials would you use?

1. Sketch two possible designs, including approximate dimensions, in your notebook and explain your proposals.
2. List three reasons for choosing each design.
3. Include a description of the materials you would use in both proposals and list any 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.

☐ *Reading Graphs*

Graphing is not always an easy thing to do correctly, and interpreting graphs can also be troublesome. Part of your research includes using data from graphs in mathematic equations. This activity is an introduction to interpreting graphs and using graphing skills to gather data.

1. Describe, in your own words, the process for determining the maximum value of a data set from a graph.
2. Describe, in your own words, the process for determining the minimum value of a data set from a graph.
3. Describe, in your own words, the process for determining the average (mean) value of a data set.

Acceleration and Gravity

☐ This activity introduces you to the concept of acceleration and the gravitational acceleration produced by the earth. Gravitational acceleration is the reason objects speed up as they fall. Understanding this concept will help you determine how fast an egg is moving just before it hits the ground after being dropped from a height of 6 meters.

1. Will your egg-drop apparatus fall faster, slower, or the same when the egg is inside it, versus when it is empty? Explain your answer.
2. The equation used to determine the acceleration of the falling objects in your activity was:

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$$

   Use algebra to change the equation to solve for final velocity. Show all your work in your notebook.
3. An important quantity that will help determine the force on your egg at impact is the final velocity of the apparatus just before impact. Use the equation you derived in the previous question to calculate the final velocity of the apparatus just before it hits the ground. Assume the initial velocity of your apparatus is zero, the acceleration due to gravity is 9.8 m/s^2, and that an object dropped from a height of 6 meters takes 1.1 seconds to hit the ground. Show your work and write your answer in your notebook.
4. Based on your understanding of earth's gravitational acceleration and your equation for final velocity from the previous two questions, what would the final velocity of a bowling ball be just before hitting the ground if it was dropped from a height of 6 meters? Explain your reasoning.

Force

☐ Show that the acceleration of an object is proportional to the force pushing or pulling it and inversely proportional to the mass of the object. Mathematically discover Newton’s 2nd Law and use it as a tool to determine the force experienced by your egg upon impact. By determining this force, you can deduce how much force must be overcome to protect the egg.

1. You will use Newton's 2nd Law to determine the force experienced by your egg at impact. However, you must first determine the acceleration of the egg at impact. To calculate this acceleration, you must know the change in velocity of the egg at impact: final velocity – initial velocity. What is the final velocity of an egg, dropped from about 6 meters, *after* it hits the ground?
2. Assuming that an egg at impact (dropped from 6 meters) takes 0.011 seconds to reach its final velocity, calculate the acceleration of the egg at impact using the following equation:

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$$

   Use the velocity calculated in research question 3 of the Acceleration and Gravity activity as the initial velocity in your calculation. Enter your answer into your notebook and show all of your work.
3. Use Newton's 2nd Law to calculate the force experienced by your egg at impact, assuming that the egg has a mass of 0.064 kg.

Air Drag

☐ This activity explores the concepts of air drag and net force during free fall. Free-falling objects traveling at a high speed just before hitting the ground will have a greater force associated with that collision than free-falling objects traveling at a slower speed. One way to reduce a falling object's speed is to counteract earth's gravitational force using the force of air drag.

1. In your notebook, sketch a picture of an egg-drop apparatus in free fall with arrows indicating the forces acting on the apparatus as it falls. Draw the arrow for each force in the direction that the force is acting: up for forces upward and down for forces downward. Draw the arrow for each force proportionally: larger arrows for larger forces and smaller arrows for smaller forces.
2. If we assume that the forces acting upward on an egg-drop apparatus in free fall do not change, how can we decrease the net force downward on the apparatus without changing the shape of the apparatus?
3. Can you think of a way not explored in this activity to increase the force from air drag on a falling object? How would you implement it in your design?

Impact Force

☐ This activity analyzes the shape of force versus time graphs associated with collisions and determines how cushioning affects the maximum force experienced. Using several different materials as cushions, you can explore how a cushion absorbs force during an impact and determine which material will make the best cushion for your egg.

1. To prevent a falling egg from cracking on impact, one must provide some cushion or other mechanism to reduce the force experienced by the egg. In this activity, you explored how different materials lessen the force experienced in collisions. Which of the materials used in this activity made the best cushion, and how did your data support this?
2. You have calculated the approximate force your egg will experience when it hits the ground after being dropped from 6 meters. Will the same amount of cushioning material used in the activity be sufficient for protecting your egg from the force experienced at impact? Explain why or why not.
3. How would you change the cushioning (either by scaling-up the amount of cushion material or changing the construction of your cushion) to help decrease the maximum force to be experienced by your egg at impact, considering that the force will be so much greater than the forces seen in this activity?

3 Revise Design

☐ After completing the five activities in this challenge and answering all the research questions, you should have the conceptual tools necessary to construct an egg-drop device that will prevent your egg from cracking when dropped from a height of 6 meters. 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. What type(s) of materials will you use to help cushion the egg on impact? Did you test how well the materials cushion a collision, or did you decide to use the material(s) based on other data?
3. Will you make any changes to the outer structure of the egg-carrying device? Explain why or why not.
4. Sketch your revised design, including approximate dimensions, in your notebook and explain your proposal, indicating the important pieces of the design.
5. Include a description of the materials you will use in your proposal and any safety concerns.

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.
2. Include a description of the materials you will use in your proposal and any safety concerns.

5 ☐ Build a Prototype

Using your collaborative design, construct your prototype together as a group.

1. After constructing your group's prototype, list in your notebook your individual responsibilities during the construction process.
2. Often a design will not exactly match its prototype due to some unseen design flaws that weren't clear until the actual construction began. Were any design points changed during the construction process, or does your group's prototype 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 device with the egg.

6 ☐ Test and Evaluate

Choose one person from your group to drop your prototype. Follow your teacher's instructions for dropping your egg-drop apparatus with the egg inside from 6 meters above the floor.

To make certain each group is dropping its apparatus from the same height, align the bottom of your group's egg-drop apparatus with the 6-m mark. After dropping your apparatus, inspect the egg and record in your notebook any damage the egg received.

7 ☐ Design Review

1. How successful was your prototype design? Did the egg crack after it was dropped? Was it undamaged, slightly damaged, or severely damaged?
2. Inspect your apparatus. If the egg was damaged, where did your design fail? List the parts of your design that failed and explain why you think they failed.
3. Look at another group's design that worked better than yours. What was different about their design and how do you think those differences helped their apparatus to be more effective?
4. If you were to redesign your apparatus, what would you do differently and why?

Congratulations! You have finished the Egg Drop 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 detailed explanation of the materials used and the role each material plays in the designs.			▪ Included measurements in drawings. ▪ Included measurement units in drawings. ▪ Drawings were clear and easily understandable.			▪ Independently drew two initial design drawings 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 to questions in activities and Challenge handout reflect excellent understanding of force and acceleration. ▪ 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 force and acceleration. ▪ 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.		
	9	8	7	6	5	4	3	2	1
Revise Design	▪ Indicated how design changes are based on or are supported by concepts explored in research activities.			▪ Included measurements in drawings. ▪ Included measurement units in drawings. ▪ Drawing was clear and easily understandable.			▪ Independently drew revised design drawings in a notebook. ▪ Included explanations as to how the initial design ideas have or haven't changed.		
	9	8	7	6	5	4	3	2	1
Develop Group Design	▪ Indicated how design changes are based on or are supported by concepts explored in research activities. ▪ Indicated each group member's design contribution.			▪ Included measurements in drawings. ▪ Included measurement units in drawings. ▪ Drawing was clear and easily understandable.			▪ Worked together as a group to draw a revised group design. ▪ Group design was based on design ideas from group members. ▪ Has a copy of the proposal and listed materials used.		
	9	8	7	6	5	4	3	2	1
Build a Prototype	▪ Any design changes made during construction were clearly indicated with an explanation.			▪ Mass of apparatus did not exceed 0.4 kg. ▪ Each individual's responsibilities during construction were clearly indicated. ▪ Satisfied all design constraints			▪ Group prototype was fully constructed based on the group design drawing.		
	9	8	7	6	5	4	3	2	1
Test and Evaluate	▪ Egg received no damage before or during testing.			▪ After dropping, the apparatus was inspected for design failure and observations were recorded in a notebook .			▪ Egg-drop apparatus was dropped from the designated height.		
	9	8	7	6	5	4	3	2	1
Design Review	▪ Included ideas based on research activities as to why the group design failed or succeeded. ▪ Included redesign ideas supported by concepts explored in research activities.			▪ Included thoughtful ideas as to why the group design failed or succeeded. ▪ Offered logical redesign ideas.			▪ Answered design review questions in a notebook.		
	9	8	7	6	5	4	3	2	1
	Total Score								

1

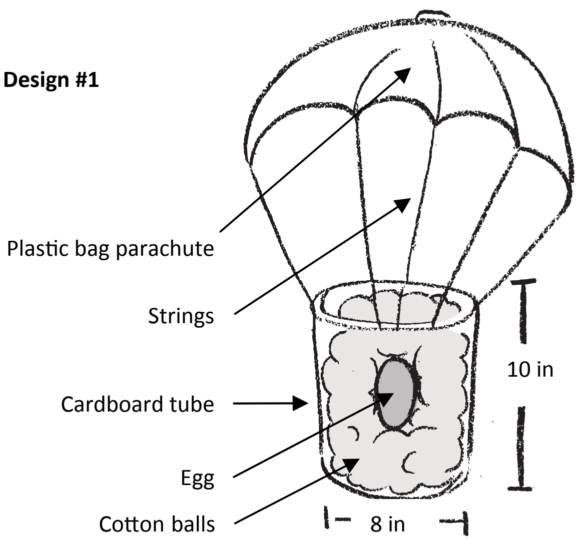
Initial Design Ideas

This stage provides an opportunity for students to display their creative and critical thinking skills. Students should be encouraged to draw their initial design ideas based on their prior knowledge of how a device like an egg-drop apparatus should be constructed. Students are expected to individually answer the three questions found in the Challenge. In their responses and drawings, have students include measurements, with units, and have them explain why they chose the design. Two sample student designs are shown below. At this point, students should be able to explain how their designs will protect their egg from the force of impact.

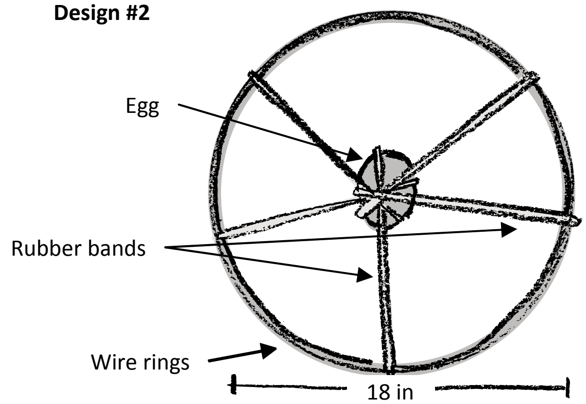
Possible Student Designs

These are sample designs as they would appear in a student notebook:

Design #1



Design #2



SAMPLE RESPONSES TO THE QUESTIONS IN THE INITIAL DESIGN IDEAS SECTION OF THE CHALLENGE

Question	Sample Response
1	Design #1 The egg goes inside a cardboard tube with cotton balls around it for protection. A parachute is attached to slow the apparatus as it falls. Design #2 The egg is held to several wire rings by rubber bands. The top or bottom ring will hit the ground and the rubber bands are flexible so they'll keep the egg from feeling the impact.
2	Design #1 Reason 1. The parachute will help slow the apparatus before it hits the ground. Reason 2. The cotton balls will help to soften the impact when it hits. Reason 3. The cardboard tube will absorb some of the impact. Design #2 Reason 1. The rubber bands will help absorb the impact when the apparatus hits the ground. Reason 2. The wire rings are needed to hold the rubber bands. Reason 3. The wire rings won't break when the apparatus hits the ground.
3	Design #1: I would use a cardboard tube because it won't crush when it hits the ground and the cotton balls inside the tube will protect the egg by absorbing the impact. The parachute is made out of plastic with strings holding it to the lid of the cardboard tube. Design #2: This design uses several metal rings that hold the egg in place using rubber bands. The rubber bands are wrapped around the egg.

Addressing Preconceptions

This stage provides a good opportunity to ask students questions about their designs to help identify some of the misconceptions they may have. Identifying these misconceptions will help to direct your approach to the remainder of the module and to the areas and topics that may require more attention. Examples of some common misconceptions are:

- Heavier objects will fall faster than lighter objects.
- The amount of force experienced by the egg at impact will be the same regardless of how the apparatus is designed.
- Only larger designs will work.

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.

Students are expected to work in groups to complete each activity while recording their results into their individual notebooks. Each student should write their own responses into their notebooks for the Activity questions and the Research stage questions for that activity in the Challenge handout. Graphs created on data collection systems can be printed and attached to notebooks for grading purposes. If students choose to hand draw their graphs, they should include *x*- and *y*-axes with clear labels and units on each axis.

At this stage in the engineering design process, students will be exploring some of the math and physics concepts involved in their engineering challenge. Students should take into consideration how these concepts can help the effectiveness of their design and how they should change their initial designs to implement them. The Research questions in the Challenge handout will help guide students when applying the concepts in each activity to their designs.

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 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

**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 Egg Drop module, each activity is available in an electronic SPARKlab format. All electronic SPARKlab files can be found on the accompanying storage device with a .spk file extension and the title of each activity within the filename, for example, "Air Drag" and "MS STEM Air Drag.spk". For instructions on how to move the electronic SPARKlab files from the storage device 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: Reading Graphs

Objective

Practice interpreting graphs and using the following graphing skills: graphing on *x*-*y* axes, determining maximum values from data trends, calculating and obtaining statistics, and determining changes in values (delta).

Materials and Equipment

- Data collection system
- Motion sensor
- Meter stick
- Pencils (2)

Procedure – Drawing Graphs

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

Table 1: Position–walking

Position (m)	Time (s)
0.0	0.0
0.5	1.0
1.0	2.0
1.5	3.0
1.5	4.0

☐ 1. The data in Table 1 represents a person walking forward in a straight line. At time = 0.0 s, the person's position was 0.0 m.

☐ 2. In your notebook, draw a set of *x*-*y* axes. Title the graph "Graph 1" and then plot the data from Table 1 into Graph 1. Time is the independent variable (*x*-axis) and position is the dependent variable (*y*-axis).

***NOTE:** Be sure to label the axes with the measurement name and unit, and connect the data points with lines between them.*

☐ 3. Look at Graph 1; what was the person's minimum position (the data point closest to the *x*-axis)?

☐ 4. What was the person's maximum position (the data point furthest from the *x*-axis)?

☐ 5. How much time passed when the person's position was between 0.5 m and 1.5 m?

☐ 6. Determine the person's average (mean) position: Add all of the position data points and then divide the sum by the total number of data points.

☐ 7. Copy Table 2 into your notebook. Use the position data in Table 1 and the equation below to calculate the person's velocity and enter your results into Table 2.

$$\text{Velocity} = \frac{\text{Change in position}}{\text{Change in time}} \left(\text{or } \frac{\Delta\ \text{Position}}{\Delta\ \text{Time}}\right)$$

***NOTE:** Change in position is the difference between two neighboring position values, and change in time is the difference between two neighboring time values. (A change in a value is commonly indicated by the delta symbol, Δ.)*

Table 2: Velocity–walking

Velocity (m/s)	Time (s)
RECORD YOUR ANSWERS IN YOUR NOTEBOOK.	0.5
	1.5
	2.5
	3.5

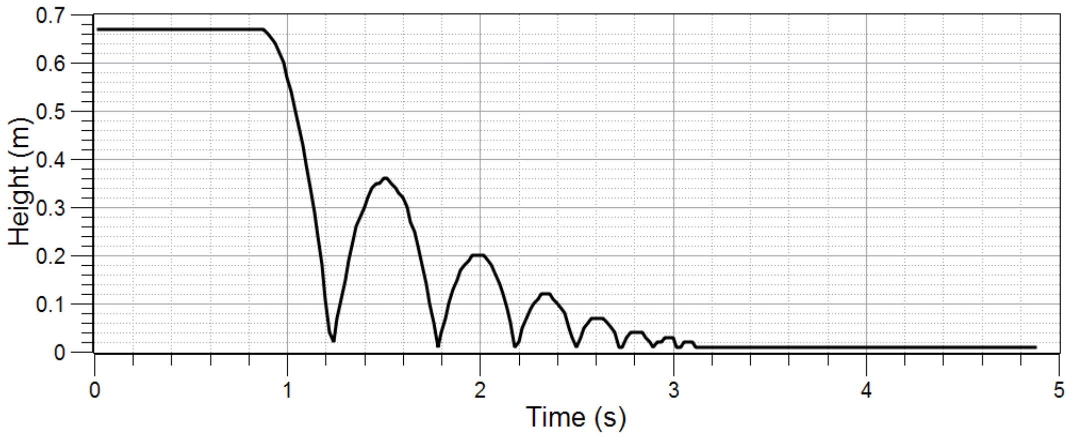
☐ 8. In your notebook, draw a new set of *x*-*y* axes and plot the data from Table 2 into the graph. Title the graph "Graph 2."

☐ 9. What was the person's minimum and maximum velocity, and at what times did they occur?

☐ 10. What is the person's average velocity?

Procedure – Reading Graphs

Graph 3: Height of a ball as it bounces vertically on the floor



Use Graph 3 to perform the next three steps. Use the instructions under each step as a guide.

☐ 11. Determine the height at which the ball was dropped and record the answer in your notebook.

a. Find the first section of the graph where the ball's height was not changing.

b. Determine the height, on the *y*-axis, corresponding to the data points in that region.

☐ 12. Determine the time it took the ball to stop bouncing once it was released. Record the answer in your notebook.

a. Find the data point where the ball stopped bouncing and determine the time, on the *x*-axis, of that data point.

b. Find the data point where the ball was dropped and determine the time of that data point.

c. Subtract the time at which the ball was dropped from the time at which it stopped bouncing.

☐ 13. Determine the maximum height of the ball during each of its 7 bounces. Record the results in your notebook.

a. Each bounce looks like a large bump in the graph. Find the data point at the very top of each bump.

b. Determine the corresponding height for each of those data points.

Procedure – Reading Electronic Graphs

NOTE*: Record all work, including calculations and answers, into your notebook.*

☐ 14. Start a new experiment on the data collection system �(1.2), connect the motion sensor to it �(2.1), show a graph of position versus time �(7.1.1), and then adjust the sample rate to 25 samples per second (25 Hz). �(5.1)

☐ 15. Adjust the switch on the top of the motion sensor to the long range setting (stick figure) and then set the motion sensor on the edge of a table with the sensor pointing horizontally away from the table. Clear all objects from the floor within a straight line 4 meters from the sensor.

☐ 16. Prepare the area so one group member can walk toward and away from (walking backward) the sensor in a straight line, moving from 1 meter to 4 meters from the sensor, as another group member records data.

- The person walking should be able to see the screen of the data collection system as they walk.
- Place a pencil on the floor at 1 m and 4 m from the sensor.

☐ 17. Begin recording data with the person standing about 1 m away from the sensor. �(6.2) Have the person walking match their motion to this description:

a. Walk away from the sensor at a constant pace and stop at 4 m.

b. Stand still for a few seconds.

c. Walk back toward the sensor at a constant pace and stop at 1 m.

d. Stand still for a few seconds.

e. Walk quickly away from the sensor and stop at 4 m.

f. Walk quickly back toward the sensor and stop at 1 m.

g. Stand still for a few seconds.

☐ 18. Stop recording data. �(6.2)

☐ 19. The data collection system can display statistics like minimum, maximum, and average (mean) for the data in your new graph. Use this functionality to answer the following questions in your notebook. If you are not familiar with these functions, use the Tech Tips as a guide.

a. Determine the minimum, maximum, and average distance the person moved from the sensor during the entire trip. �(9.4)

b. Determine the minimum, maximum, and average position for the first trip away and back. �(9.4)

c. Determine the minimum, maximum, and average position for the second trip away and back. �(9.4) Was the average position the same for the first and second trip away and back?

d. Determine the time it took to make the first trip away and back. �(9.2)

e. Determine the time it took to make the second trip away and back. �(9.2) According to the graph, which took less time, the first trip or the second?

☐ 20. Complete the questions in the Challenge: Egg Drop handout for this activity.

Teacher Notes: Reading Graphs

Learning Objectives

Practice graphing on *x-y* axes, determining maximum values from data trends, calculating and obtaining statistics, and determining changes in values (delta).

Activity Introduction

The Reading Graphs activity addresses some of the important graphing skills that will be used throughout most of the other activities within this module. The activity includes a graphing portion where students focus on conventional graphing skills, including drawing graphs in a Cartesian coordinate system and identifying values such as minimum, maximum, change in time, and average (mean).

Students then map those skills to the technology-centered environment on their data collection system, using a motion sensor to produce a position versus time graph and then using their data collection system's statistical analysis tools to identify values such as minimum, maximum, change in time, and average.

As with the other activities in this module, there is an electronic SPARKlab version of this one you may choose to implement rather than use the paper handout. However, because the first two parts of the Reading Graphs activity focus on conventional graphing skills using paper and pencil, the Reading Graphs SPARKlab only includes the “Reading Electronic Graphs" procedure found in the paper handout.

If you opt to use the Reading Graphs SPARKlab, you can choose to omit the procedures that focus on conventional graphing skills (in the paper handout) and focus only on the content in the SPARKlab, or you can offer students both the Reading Graphs paper handout, in which they will complete the first two procedures “Drawing Graphs” and "Reading Graphs," and the Reading Graphs SPARKlab, in which they will complete the “Reading Electronic Graphs” procedure.

Teacher Tips

In the Reading Graphs section of the procedure students are asked to perform three steps (procedure numbers 11 through 13) in which they analyze a sample graph. Under each step is a set of instructions to guide students. Students are not expected to formulate responses for each of the instructions, just the three top level steps.

The Reading Graphs activity uses "high-level" instructions when implementing the data collection system. To help students navigate these instructions at first, it is recommended that you provide to each lab group a copy of the Tech Tips, for your particular data collection system, used in this activity. The techniques and instructions used in this activity will be used in other activities. By introducing students to the Tech Tips now, the need for referencing them will become less in later activities.

Sample Data

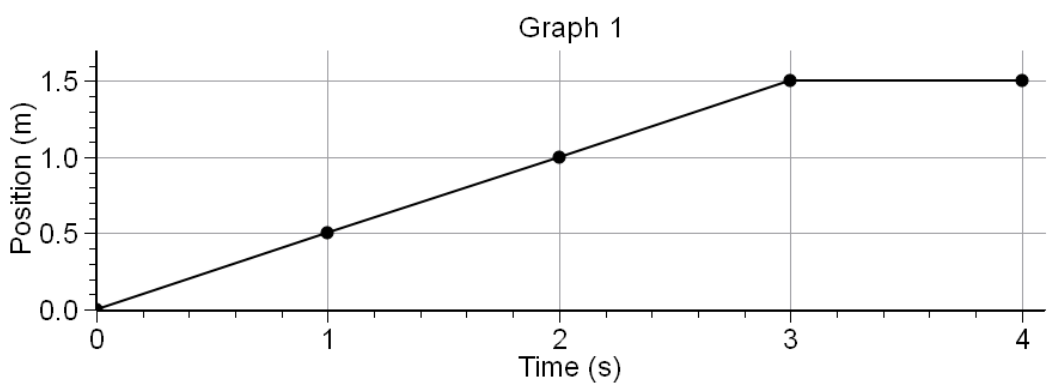
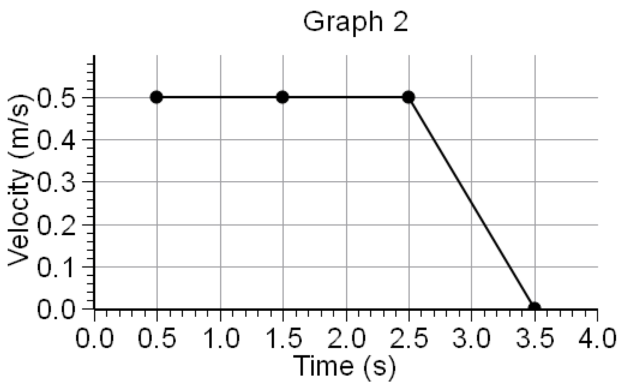


Table 2: Velocity–walking

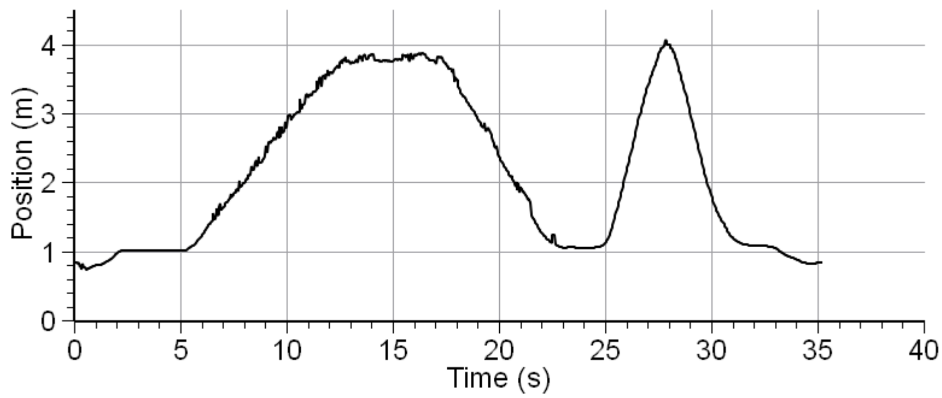
Velocity (m/s)	Time (s)
0.5	0.5
0.5	1.5
0.5	2.5
0.0	3.5

CALCULATION

$$\text{Velocity} = \frac{\text{Change in Position}}{\text{Change in Time}} = \frac{0.5\ \text{m} - 0.0\ \text{m}}{1.0\ \text{s}} = 0.5\ \text{m/s}$$



Graph 3: Graph from Procedure – Reading Electronic Graphs



Answer Key

Below are sample responses to the questions found in the Reading Graphs activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions found in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE READING GRAPHS ACTIVITY HANDOUT

Procedure	Sample Response
3	0.0 m
4	1.5 m
5	2 s
6	Average position = (0.0 m + 0.5 m + 1.0 m + 1.5 m + 1.5 m)/5 = 0.9 m
9	Minimum velocity = 0 m/s at 3.5 s; Maximum velocity = 0.5 m/s between 0.5 s and 2.5 s
10	Average velocity = (0.5 m/s + 0.5 m/s + 0.5 m/s + 0.0 m/s)/4 = 0.4 m/s
11	Starting height = 0.67 m
12	Δt = 3.1 s – 0.9 s = 2.2 s
13	Bounce heights from first to last: 0.36 m, 0.20 m, 0.12 m, 0.07 m, 0.04 m, 0.03 m, 0.02 m
19a, S6	The responses for 19a through 19e are based on the graph shown in the Sample Data section, Reading Electronic Graphs: Minimum = 0.73 m; Maximum = 4.06 m; Mean = 2.14 m.
19b, S7	Minimum = 0.73 m; Maximum = 3.87 m; Mean = 2.64 m.
19c, S8, S9	Minimum = 1.05 m; Maximum = 4.06 m; Mean = 2.15 m. The average positions were different between the first and second trips.
19d, S10	Δt (first trip) = 18.6 s.
19e, S11, S12	Δt (second trip) = 6.4 s. The second trip took less time.

Connecting the Activity to the Challenge

Students will use the skills outlined in this activity throughout the other Research activities when analyzing data and graph trends. Building a good graphing skill set will allow students to focus on the analysis results rather than analysis techniques throughout the module.

SAMPLE RESPONSES TO THE READING GRAPHS RESEARCH QUESTIONS

Question	Sample Response
1	The process for determining the maximum value of a data set from a graph begins by identifying the data point on the graph that is above all other data points in the y-axis direction, then finding the value of that data point using the scale on the y-axis of the graph.
2	The process for determining the minimum value of a data set from a graph begins by identifying the data point on the graph that is below all other data points in the y-axis direction, then finding the value of that data point using the scale on the y-axis of the graph.
3	To determine the average (mean) value of a data set, add all of the data points together and divide that sum by the number of data points in the data set.

Activity: Acceleration and Gravity

Objective

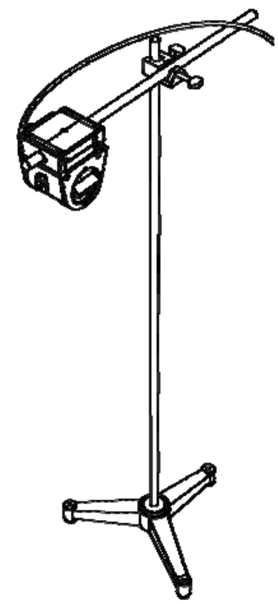
Analyze how gravity affects the motion of falling objects of different size and mass.

Materials and Equipment

- Data collection system
- Motion sensor
- Large base and support rod
- Right angle clamp
- Small rod
- Balance, 1-g resolution (1 per class)
- No-bounce pad
- Three objects of different size and similar mass
- Three objects of different mass and similar size
- Meter stick

Procedure – Similar Mass but Different Size

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



☐ 1. Set up the motion sensor, rods, rod stand, and right angle clamp like the picture to the right. Slide the setup to the edge of your lab table with the motion sensor pointed toward the floor.

NOTE: *The motion sensor should be as high above the floor as possible.*

☐ 2. Point the motion sensor straight down, toward the floor, and then place the no-bounce pad on the floor directly under the sensor.

☐ 3. Start a new experiment on the data collection system and connect the motion sensor to it. �(2.1) �(1.2)

☐ 4. Create a graph of velocity versus time �(7.1.1)

☐ 5. Set the switch on the top of the motion sensor to the stick figure (long range setting), and then set the data collection system to record 50 samples per second (50 Hz). �(5.1)

☐ 6. Copy Table 1 into your notebook and then measure the mass of the three objects of different size and similar mass. Record the values in the table in your notebook.

Table 1: Determine the velocity and acceleration caused by the force of gravity on objects of different size

Object	Mass (kg)	Initial Velocity (m/s)	Final Velocity (m/s)	Time of Fall (s)	Acceleration (m/s^2)
Large size					
Medium size					
Small size					

RECORD ALL DATA IN YOUR NOTEBOOK.

☐ 7. You will use your data to calculate the acceleration of each of the three objects with different size but similar mass in free fall, but before recording any data, predict (in your notebook) which object (large, medium, or small size) will have the greatest acceleration. Explain your prediction.

☐ 8. Hold the large object under the motion sensor so the bottom of the object is 40 cm below it. Begin recording a run of velocity versus time data just before you drop the object. �(6.2)

☐ 9. Stop recording data after the object hits the no-bounce pad. � (6.2)

NOTE: *The object must hit the no-bounce pad on the floor. If the object misses the pad, slide the pad to the spot where the object landed and re-record a run of data.*

☐ 10. Repeat the same procedure for the medium and small objects.

☐ 11. Use your graph to determine the initial velocity (just before you dropped it), final velocity (just before it hit the ground), and time of fall (time from when it is dropped to when it hits the ground) for each different-sized object. Record the results in Table 1. � (9.1) (9.2)

Procedure – Similar Size but Different Mass

☐ 12. Next, you will drop the objects with similar size but different mass. Copy Table 2 into your notebook and then measure the mass of the three objects. Record the values in the table in your notebook.

Table 2: Determine the velocity and acceleration caused by the force of gravity on objects of different mass

Object	Mass (kg)	Initial Velocity (m/s)	Final Velocity (m/s)	Time of Fall (s)	Acceleration (m/s^2)
Large mass					
Medium mass		RECORD ALL DATA IN YOUR NOTEBOOK.			
Small mass					

☐ 13. You will use your data to determine the acceleration of each object, but before recording more data, predict (in your notebook) which object (large, medium, or small mass) will have the greatest acceleration. Explain your choice.

☐ 14. Hold the object with the greatest mass under the motion sensor so the bottom of the object is 40 cm below it and begin recording a run of velocity versus time data, in the same graph as the first three runs, just before you drop the object. �(6.2), (7.1.1)

☐ 15. Stop recording data after the object hits the no-bounce pad. � (6.2)

☐ 16. Repeat the same procedure for the medium and small mass objects.

☐ 17. Use your graph to determine the initial velocity (just before you dropped it), final velocity (just before it hit the ground), and time of fall (time from when it is dropped to when it hits the ground) for each object. Record the results into Table 2 in your notebook. � (9.1) (9.2)

Questions

NOTE*: Record all work, including calculations and answers, into your notebook.*

1. If nobody was touching the object as it was falling in each trial, what was causing it to fall toward the ground?
2. After the object was dropped in each trial, did it change direction as it fell? Was it speeding up or slowing down? What evidence do you have to support your answers?
3. An object is accelerating when it is speeding up, slowing down, or changing direction. Based on your response to the previous question, was the object in each trial accelerating? Why or why not?
4. Acceleration describes the rate at which the velocity of an object changes. To calculate the acceleration of an object, you use the equation:

   $$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$$

   Use this equation to calculate the acceleration of each object in Table 1 and Table 2, and then enter the acceleration values into the last column of each table in your notebook.
5. Do the acceleration values support your predictions? Explain your answer.
6. Is it correct to say that falling objects accelerate the same no matter what size or mass the objects are? How does your data support or not support your answer?
7. Based on your answers to the previous question, do you think an apple and a bowling ball will hit the ground at the same time if they are dropped from the same height at the same time? Answer using complete sentences.
8. Complete the questions in the Challenge: Egg Drop handout for this activity.

Teacher Notes: Acceleration and Gravity

Learning Objectives

Analyze how gravity affects the motion of falling objects with different size and mass.

Activity Preparation

The materials and equipment list for this activity calls for six distinct objects, three with similar mass and different size (spatial), and three with similar size and different mass. These objects need to be prepared prior to the lab and made available for students when the lab begins. Although you can choose the objects students will use, below are several recommendations as to the type of object to use to produce the best data. For the best results, the objects to be dropped should:

- Be large enough to allow the motion sensor to report data (larger than 5 cm across)
- Have mostly smooth surfaces
- Be uniform in shape (no sharp edges)
- Have a mass great enough (relative to size) to negate any force from air drag
- Be made of material that will not break on impact

Some suggested objects include:

- Different sports balls (volleyball, baseball, racquet ball, bocce ball)
- Balled tin foil or other paper or plastic material
- Hollow plastic container (hollow holiday eggs work well) with a lid, in which you can put different masses.

Adding mass to any of the objects may be necessary to satisfy the materials requirements. There are many different ways to add mass to an object, but one of the easiest is to tape a mass to the outside of the object or, if possible, place a mass inside the object.

Activity Introduction

One of the most prevalent misconceptions regarding gravitational acceleration is that objects of different size and mass, dropped from the same height, will fall at different rates. The Acceleration and Gravity activity should empirically show students how objects of different size and mass all obey earth's gravitational acceleration.

A good way to introduce students to this activity topic is to provide a short demonstration that calls out this misconception. For this demonstration you will need two rubber balls, one much larger than the other (a basketball and a tennis ball or racquetball, for example).

Start by asking students what they know about gravity and how it affects objects that are dropped, like a basketball or egg-drop apparatus. Students will hopefully understand that gravity is the reason things like basketballs and other objects fall to the ground if we drop them or throw them. Show your students the two different sized balls. Ask them what will happen to either ball if it is dropped. Students should state that both balls will fall to the ground if dropped. Follow by asking which of the two balls, if dropped, will fall to the ground faster. Have students explain their guesses.

If it hasn't already been mentioned by students, ask them how the different sizes of the two balls will affect how fast they fall, and why. Some students will already understand that gravity is constant for all objects regardless of size, but many students will believe that the greater size of the larger ball will cause it to fall faster; or that the heavier ball will fall faster.

Tell students that a way to support or not support their guesses is to drop the two balls from the same height, at the same time, and listen for the sounds the balls make when they hit the ground. If the sound made by each ball happens at the same time, then the balls hit the ground at the same time, and thus, fell at the same rate. If the students hear two distinct sounds, the balls didn't hit at the same time, and thus, didn't fall at the same rate.

Next, stand on a desk or lab table holding the two balls at the same height (measure to the bottom of the ball), and have the class listen carefully. Simultaneously drop both balls and have the class report what they heard. If done correctly, both balls should hit the ground at the same time producing one sound.

Ask students if this test is an accurate way to support their hypothesis and have them identify possible sources of error (for example, human error in hearing and not dropping the balls at the same time or from the same height).

This demonstration is a good qualitative analysis and provides an excellent segue into the activity, which uses a much more accurate and quantitative method of determining the rate at which objects of different sizes fall after being dropped.

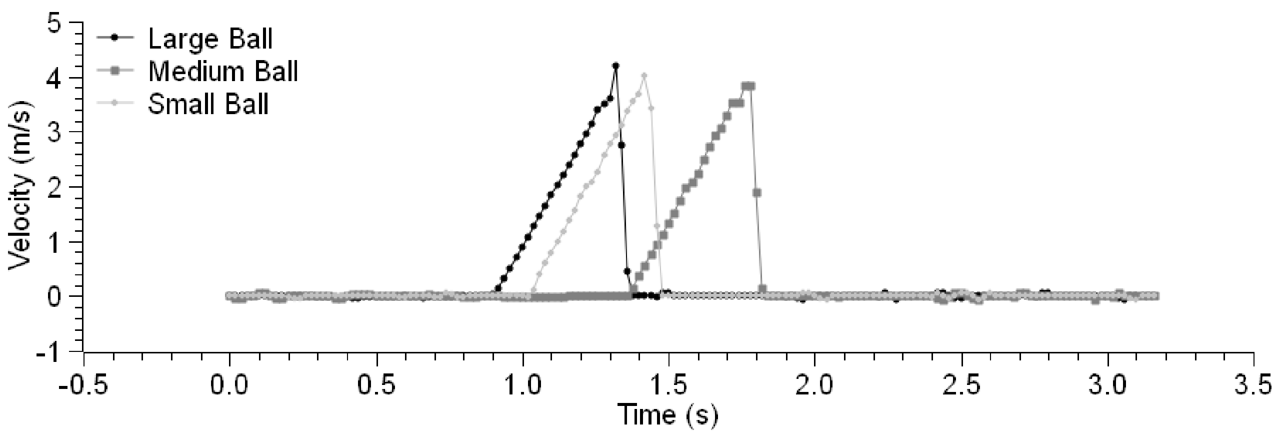
Teacher Tips

The height at which each ball is dropped is an important variable that must be held constant. Emphasize to your students that each ball must be dropped from the same height in each trial.

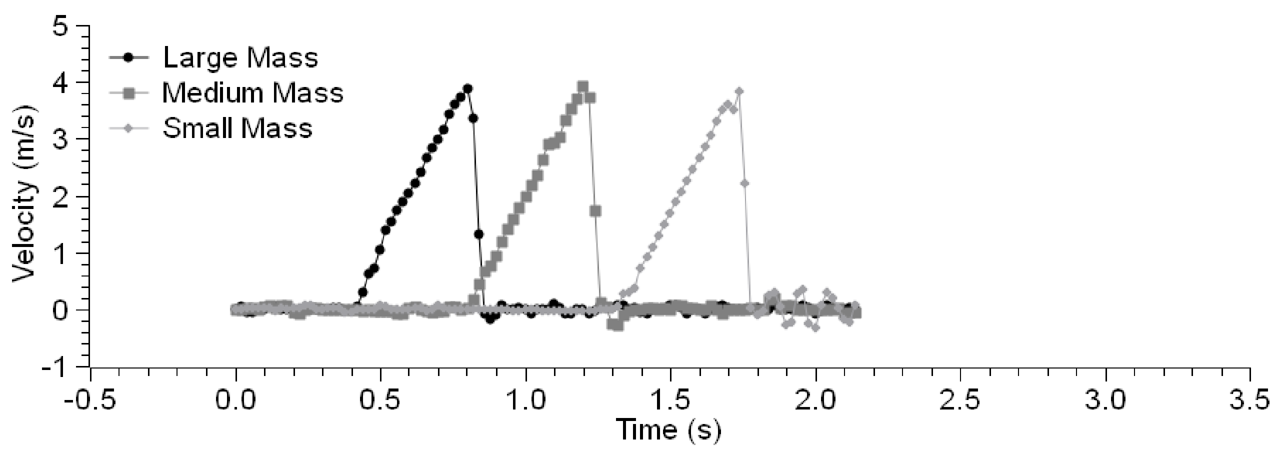
Also, have students make certain that the ball lands on the no-bounce pad. Students should only be concerned with the data corresponding to the time between when the ball is dropped and immediately before it hits the ground. If the ball bounces, the extra data can be confusing for students, showing negative velocity as the ball bounces upward. Making certain the ball hits the no-bounce pad will eliminate this problem.

Sample Data

Graph 1: Velocity caused by the force of gravity on objects of different size



Graph 2: Velocity caused by the force of gravity on objects of different mass



Answer Key

Below are sample responses to the questions found in the Acceleration and Gravity activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions found in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE ACCELERATION AND GRAVITY ACTIVITY HANDOUT

Procedure	Sample Response
7, S5	I think all three balls will have the same acceleration because earth's gravity is constant regardless of the size of the object.
13, S12	I think all three balls will have the same acceleration because earth's gravity is constant regardless of the mass of the object.
Questions	**Sample Response**
1, S1	Earth's gravity was causing the balls to fall after they were dropped.
2, S2	After each ball was dropped it was not changing direction. We watched each ball drop and each dropped straight down without changing direction. However, it was speeding up. The graph showed an increase in velocity.
3, S3	Based on the answers to the previous questions, we can say that the ball was accelerating. Although its direction wasn't changing, the ball's velocity was increasing (speeding up).
4, S5, S6	See tables and calculation below.

Table 1: Velocity and acceleration caused by the force of gravity on objects of different size

Object	Mass (kg)	Initial Velocity (m/s)	Final Velocity (m/s)	Time of Fall (s)	Acceleration (m/s^2)
Large Ball	0.356 kg	0.0 m/s	4.19 m/s	0.43 s	9.7 m/s^2
Medium Ball	0.354 kg	0.0 m/s	3.84 m/s	0.41 s	9.4 m/s^2
Small Ball	0.354 kg	0.0 m/s	4.01 m/s	0.41 s	9.8 m/s^2

Table 2: Velocity and acceleration caused by the force of gravity on objects of different size

Object	Mass (kg)	Initial Velocity (m/s)	Final Velocity (m/s)	Time of Fall (s)	Acceleration (m/s^2)
Large mass	0.667 kg	0.0 m/s	3.84 m/s	0.40 s	9.6 m/s^2
Medium mass	0.411 kg	0.0 m/s	3.92 m/s	0.40 s	9.8 m/s^2
Small mass	0.151 kg	0.0 m/s	3.88 m/s	0.40 s	9.7 m/s^2

CALCULATION

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}} = \frac{4.19\ \text{m/s} - 0.0\ \text{m/s}}{0.43\ \text{s}}$$

$$\text{Acceleration} = 9.7\ \text{m/s}^2$$

Questions	Sample Response
5, S7	The acceleration values generally support our predictions. The acceleration for the large ball and small ball are the same, although the acceleration of the medium ball is lower than we expected. Our data for the objects with different mass support our prediction, because all of the acceleration values are nearly the same.
6, S8	Considering that the calculated accelerations were about the same, and three objects were very different in size, and the other three were very different in mass, we believe it is safe to say that falling objects accelerate the same no matter what size the objects are.
7, S9	Based on the answers to the previous question, we believe that an apple and a bowling ball will hit the ground at the same time if dropped from the same height at the same time.

Connecting the Activity to the Challenge

The main goal of this activity is to introduce students to the idea that heavier objects fall at the same rate as lighter objects, and that larger objects (volume) will fall at the same rate as smaller object. Understanding this will inform students' designs in terms of their size, showing students that a larger volume will not affect the velocity of the apparatus at impact. All apparatuses dropped from the same height will have the same final velocity regardless of their size and mass.

A secondary goal of this activity is to give students experience using an equation to calculate acceleration based on changes in velocity and time, an equation that will be manipulated to calculate the final velocity of their egg-drop apparatus. Also, the final velocity calculated here will be used later in the module (for the Force activity) to determine the force at impact, which will also help to inform design decisions.

SAMPLE RESPONSES TO THE ACCELERATION AND GRAVITY RESEARCH QUESTIONS

Question	Sample Response
1	Our data from the Acceleration and Gravity activity showed that objects fall at the same rate regardless of their size and mass. Based on this I think that the egg-drop apparatus will fall at the same rate with the egg in or out of it.
2	$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$ $\text{Final velocity} - \text{Initial velocity} = \text{Time} \times \text{Acceleration}$ $\text{Final velocity} = (\text{Time} \times \text{Acceleration}) + \text{Initial velocity}$
3	$\text{Final velocity} = (\text{Time} \times \text{Acceleration}) + \text{Initial velocity}$ $\text{Final velocity} = (1.1\ \text{s} \times 9.8\ \text{m/s}^2) + 0\ \text{m/s}$ $\text{Final velocity} = 10.8\ \text{m/s}$
4	Because objects of different size fall at the same rate when dropped, a bowling ball dropped from 6 meters would have the same final velocity as an egg-drop apparatus dropped from 6 meters: 10.8 m/s.

Activity: Force

Objective

Analyze how the acceleration of a cart changes as more mass is added to the cart while the force pulling the cart doesn't change. Then show how force, mass, and acceleration are mathematically related.

Materials and Equipment

- Data collection system
- Motion sensor
- Force sensor with hook
- Compact cart mass (2), 250-g
- Dynamics cart
- Balance (1 per class), 1-kg
- Dynamics track
- Super pulley with clamp
- Hanging mass, 40-g
- Adjustable end stop
- String, 85 cm

Procedure

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

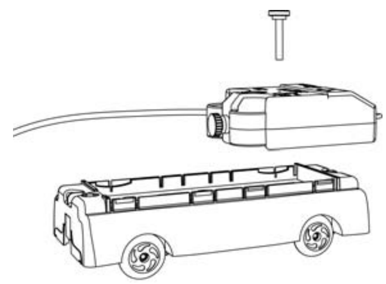


Figure 1

☐ 1. Place the track level on the lab table and then attach the motion sensor to one end of the track, the adjustable end stop to the other end of the track, and clamp the pulley to the track just behind the end stop (see Figure 2). Adjust the pulley to its highest position.

☐ 2. Mount the force sensor to the top of the cart as shown in Figure 1. Attach the hook to the front of the force sensor.

☐ 3. Copy Table 1 into your notebook and then measure the mass of the force sensor and cart. Record the value, to 3 decimal places, in the table for Trial 1.

Table 1: Affect of mass on acceleration and force due to gravity

Trial	Mass (kg)	Average Acceleration (m/s^2)	Average Force (N)	Mass × Acceleration
1				
2	RECORD YOUR ANSWERS IN YOUR NOTEBOOK.			
3				

☐ 4. Tie a piece of string, 85 cm long, from the hook on the force sensor to the hanging mass.

☐ 5. Move the track so the end with the pulley is barely hanging over the edge of the lab table. Place the cart onto the track with the string around the pulley and the hanging mass over the edge of the table.

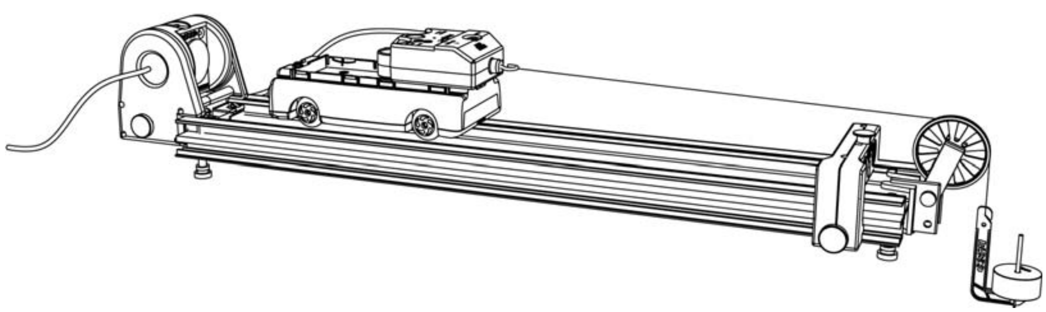


Figure 2

☐ 6. Start a new experiment on the data collection system �(1.2) and connect the force and motion sensors to it. �(2.2)

☐ 7. Create a graph of force (pull positive) versus time and a graph of acceleration versus time. �(7.1.1)

☐ 8. Set the sample rate to 25 samples per second (25 Hz) �(5.1) and then adjust the display resolutions for both force and acceleration measurements to show two digits to the right of the decimal. � (5.4)

☐ 9. Lift the hanging mass up slightly so nothing is pulling on the force sensor hook and press the Zero button on the top of the force sensor.

☐ 10. Have one group member slide the cart up the track so it is about 15 cm in front of the sensor and hold it in place.

NOTE: *For every trial, make certain the string is running over the pulley and the mass is hanging freely and not swinging. Remove any object the mass might hit as it descends.*

☐ 11. The cord on the force sensor will affect your data if it pulls on the cart as it rolls freely down the track. Have a group member hold the force sensor cord up as the cart rolls down the track to avoid this.

☐ 12. Have another group member start recording data �(6.2) just before the first group member releases the cart, allowing it to accelerate down the track.

☐ 13. Stop recording �(6.2) data just before the cart hits the end stop.

☐ 14. Repeat the same procedure for two more trials, each time adding a compact cart mass to the tray on the top of the cart behind the force sensor. For each trial, record the new mass of the cart-sensor-mass combination in Table 1.

☐ 15. Draw or attach a copy of your force versus time and acceleration versus time graphs into your notebook.

☐ 16. After you have finished recording data, use your graphs to determine the following quantities for each trial and enter them into Table 1:

- The average (mean) force pulling on the cart while the cart was moving. �(9.4)
- The average acceleration the cart experienced while it was moving. �(9.4)

Questions

NOTE*: Record all work, including calculations and answers, into your notebook.*

1. Does your force versus time data show that the force applied to the sensor was constant in each run? Write your answer in your notebook and explain why you think it was or was not constant.
2. What do you notice is different about the acceleration values between trials?
3. Write a list of the variables in this experiment that were held constant and a list of the variables that were changed.
4. Based on your data, describe how the acceleration of an object changes as the mass of the object changes, if force is held constant. Use complete sentences.
5. Based on your description from the previous question, would a trailer being pulled by a truck with constant force accelerate more or less with you sitting in it compared to if you were not sitting in it?
6. Complete the last column in Table 1 by multiplying the mass by the average acceleration in each trial. Is the result similar to another value that was measured in each trial?
7. What are the units associated with the results of the mass × acceleration calculations? Do the units match those of any of the other measurements?
8. Based on your response to the previous questions, what is mass × acceleration equal to? First write your response in words and then write it as a mathematical formula.
9. Use your formula from the previous question to calculate the force needed to accelerate a 2,000 kg car at a rate of 5 m/s^2.
10. How fast does a 0.14 kg baseball accelerate if it is hit by a bat with a force of 510 N?
11. Complete the questions in the Challenge: Egg Drop handout for this activity.

Teacher Notes: Force

Learning Objectives

Show that the acceleration of an object is proportional to the force pushing or pulling it and inversely proportional to the mass of the object. Mathematically verify Newton's 2nd Law and use it as a tool to determine the force experienced by a falling egg upon impact.

Activity Introduction

We recommend that teachers avoid showing students the mathematical relationship describing Newton's 2nd Law prior to this activity and use this activity as a discovery-based approach. Before beginning this activity, students simply need to understand acceleration and know that force is either a push or a pull and can be measured using a force sensor.

Quickly demonstrate Newton's 2nd Law with a skateboard, two volunteers, a 10-ft section of strong rope, and a stack of heavy books. Tie one end of the rope to one end of the skateboard and place the skateboard on the floor. Have one volunteer hold the opposite end of the rope and ask the class to pay close attention to the acceleration of the skateboard as the volunteer slowly pulls the rope. When the rope is pulled, the skateboard begins to move quickly because its mass is small and requires little force to accelerate.

Have the second volunteer stack several heavy books on top of the skateboard and ask the class what they believe will happen to the acceleration if the first volunteer pulls with the same force again. Make certain to have students explain their reasoning and guide them to the fact that the mass has changed and not the "weight" on the skateboard. Have the first volunteer pull again with the same force and direct the class to pay attention to how the acceleration changes. Because the mass of the books is so much greater, the acceleration of the skateboard and books should be much less, given the same applied force.

Finally have the second volunteer remove the books and sit on the skateboard. Ask the class to once again guess what will happen to the acceleration now, if the first volunteer pulls with the same force. Have students guess how much different the acceleration will be and why. Remember to guide students to focus on the changes in mass rather than changes in weight. Good guesses will be based on the relative difference between the mass of the books and the mass of the second volunteer, "The acceleration will be five times less because the mass of the volunteer is five times more." Have the first volunteer pull again with the same force and direct the class to pay attention to how the acceleration changes. Because the mass of the volunteer is so much greater, the acceleration of the skateboard and volunteer should be much less, given the same applied force.

Teacher Tips

Some tips for using the sensors and other equipment:

- The face on the motion sensor can be adjusted and "aimed." Make sure the screen face on the motion sensor is aimed at the back of the cart and no objects, like books or book bags, are near the track obstructing the sensor's line of sight.
- The force sensor has a Zero button on its top that will erase any offset that may cause errors in the data. Before recording data using the force sensor, students should press the zero button on the sensor.
- The cord on the force sensor may inhibit the motion of the cart as it rolls down the track. A good practice for groups is to have one member hold the cord up off the lab table and follow the cart with it as the cart rolls down the track in each run, minimizing its interference.

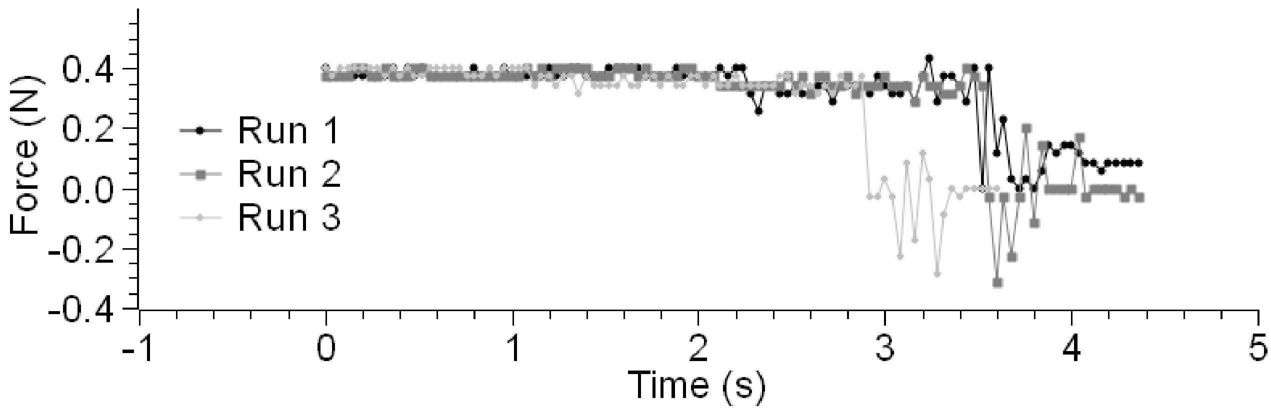
Sample Data

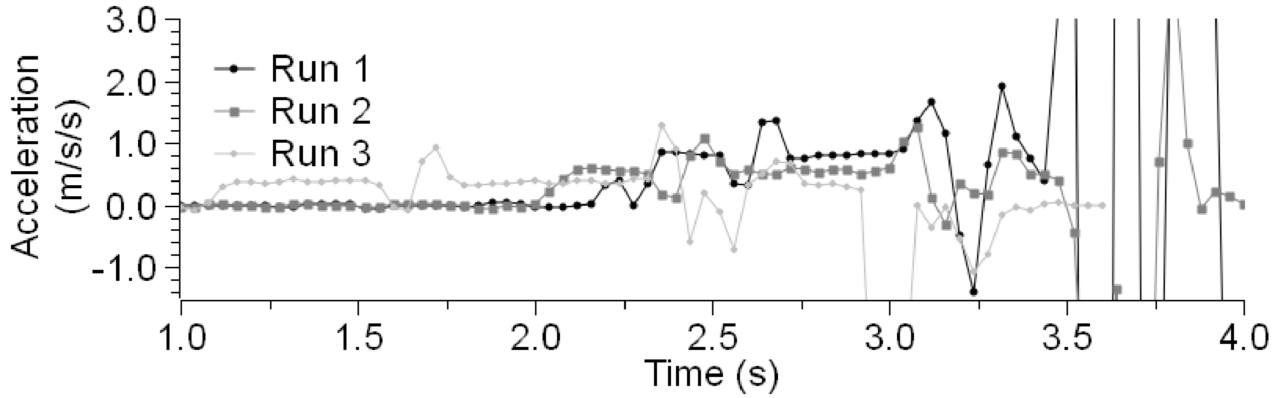
Table 1: Affect of mass on acceleration and force due to gravity

Trial	Mass (kg)	Average Acceleration (m/s^2)	Average Force (N)	Mass × Acceleration ($kg \cdot m/s^2$)
1	0.355	0.905	0.382	0.321
2	0.615	0.542	0.368	0.333
3	0.875	0.369	0.374	0.322

CALCULATION

$$\text{Force} = \text{Mass} \times \text{Acceleration} = 0.355\ \text{kg} \times 0.905\ \text{m/s}^2 = 0.321\ \text{kg} \cdot \text{m/s}^2$$


Force (N)
0.4
0.2
0.0
-0.2
-0.4
Run 1
Run 2
Run 3
-1
0
1
2
3
4
5
Time (s)


Acceleration (m/s/s)
3.0
2.0
1.0
0.0
-1.0
Run 1
Run 2
Run 3
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (s)

Answer Key

Below are sample responses to the questions found in the Force activity handout. Responses numbered under the "Questions" heading in the first column are responses to questions found in the "Questions" section in the handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE FORCE ACTIVITY HANDOUT

Questions	Sample Response
1, S1	The force was constant because it was caused by gravity and we did not change the amount of mass hanging.
2, S2	The acceleration values decrease in Runs 2 and 3.
3, S3	Variables held constant: Hanging mass or applied force. Variables changed: Mass of cart and acceleration.
4, S4	If the force applied to an object is constant, the acceleration of the object increases if its mass decreases, and decreases if its mass increases.
5, S5	Based on the description from the previous question, the trailer would accelerate less if I sat in it because it would increase its mass.
6, S6	See sample data column 5 for calculation results. The results are similar to our measured values for average force.
7, S8	The units are kg·m/s^2, or Newtons (N), which match the units for force.
8, S9	Based on our responses to the previous questions, we believe that mass × acceleration is equal to force. Force = Mass × Acceleration
9, S10	$\text{Force} = \text{Mass} \times \text{Acceleration}$ $\text{Force} = 2{,}000\ \text{kg} \times 5\ \text{m/s}^2$ $\text{Force} = 10{,}000\ \text{N}$
10, S11	$\text{Force} = \text{Mass} \times \text{Acceleration}$ $\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}$ $\text{Acceleration} = \frac{510\ \text{N}}{0.14\ \text{kg}}$ $\text{Acceleration} = 3{,}600\ \text{m/s}^2$

Connecting the Activity to the Challenge

The Force activity introduces students to the mathematical relationship between force, mass, and acceleration (Newton's 2nd Law) which they will use to calculate the force experienced by an egg at impact after being dropped from a height of 6 meters. Understanding the amount of force at impact will help influence students' design decisions related to cushioning, which will be described in greater detail in the Impact Force activity. Students will use information and results from the Acceleration and Gravity activity in their force calculations.

SAMPLE RESPONSES TO THE FORCE RESEARCH QUESTIONS

Question	Sample Response
1	After the egg hits the ground, its velocity, the final velocity, is zero.
2	$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$ $\text{Acceleration} = \frac{0.00\ \text{m/s} - 10.8\ \text{m/s}}{0.011\ \text{s}}$ $\text{Acceleration} = -980\ \text{m/s}^2$
3	$\text{Force} = \text{Mass} \times \text{Acceleration}$ $\text{Force} = 0.064\ \text{kg} \times \left(-980\ \text{m/s}^2\right)$ $\text{Force} = -63\ \text{N}$

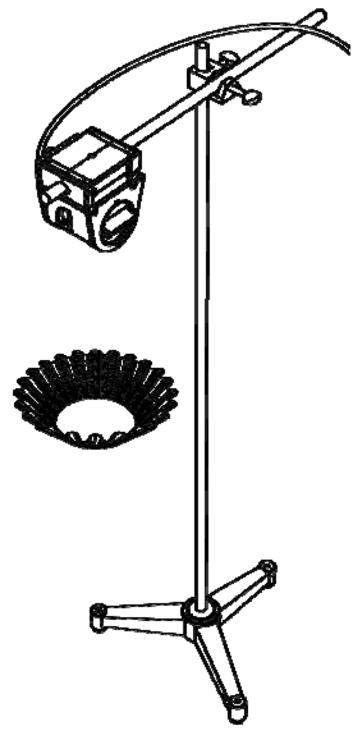
Activity: Air Drag

Objective

Analyze how the velocity of an object in free fall is related to the net force on the object. Show that air drag produces a force opposite the direction of fall.

Materials and Equipment

- Data collection system
- Motion sensor
- Large base and support rod
- Small rod
- Right angle clamp
- Centigram balance, one per class
- Coffee filters (4)
- Meter stick



Procedure

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

☐ 1. Set up the motion sensor, small rod, rod stand, and right angle clamp as shown in the picture to the right. Slide the setup to the edge of your lab table with the motion sensor pointed toward the floor.

***NOTE:** The motion sensor should be as high above the floor as possible.*

☐ 2. Start a new experiment on your data collection system �(1.2) and connect the motion sensor to it. �(2.1)

☐ 3. Create a graph of velocity versus time. �(7.1.1)

☐ 4. Set the switch on the top of the motion sensor to the stick figure (long range setting), and then set the data collection system to record 25 samples per second (25 Hz). �(5.1)

☐ 5. Copy Table 1 into your notebook. Stack the 4 coffee filters together and then measure and record the total mass of the stack.

Table 1: Forces acting on free-falling coffee filters

Number of Filters	Mass (kg)	Final Velocity (m/s)	Time of Fall (s)	Average Acceleration (m/s^2)	Average Net Force (N)	Force From Gravity (N)
4						
3						
2						
1						

☐ 6. Hold the stack, with the crimped end upward, under the motion sensor so the bottom of the stack is about 40 cm below it.

***NOTE:** Drop the stack from the same height each time.*

☐ 7. Record a run of velocity versus time as you drop the stack, letting it fall until it hits the floor. �(6.2)

☐ 8. From your graph, determine the final velocity of the 4 coffee filters just before they hit the floor and record the value in Table 1. �(9.1)

☐ 9. From your graph, determine the time of the fall from the point when the coffee filters were released to just before they hit the floor. �(9.1) Record the value in Table 1.

☐ 10. Repeat the same procedure three more times, each time removing one of the coffee filters from the stack and recording the mass of the stack, the final velocity of the stack (just before it hits the floor), and the time of fall in Table 1.

Questions

***NOTE**: Record all work, including calculations and answers, into your notebook.*

1. Copy the following statement and describe, using complete sentences, how your data supports it:

   "During its free fall, the stack of coffee filters in each run was accelerating."

2. What do you notice about the final velocity of each run? Based on what you notice, explain how the acceleration of the stack in each run was different.

3. Calculate the average acceleration of the stack in each run using the equation below and enter the results into Table 1. Assume that the initial velocity in each run is equal to zero.

   $$\text{Average acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time of fall}}$$

4. Newton's 2nd Law states that the net force on an object is equal to the mass of the object multiplied by the object's acceleration. Calculate the average net force on the stack in each trial using the equation below and enter the results into Table 1.

   $$\text{Average net force} = \text{Mass} \times \text{Average acceleration}$$

5. Is the average net force changing in each run? Why do you think the net force is changing or not changing for the different runs?

6. Earth's gravity produces a force pointing downward, causing falling objects to accelerate toward the earth at a rate of 9.8 m/s^2. Calculate the force from earth's gravity on the stack in each trial using the following equation and enter the results into Table 1.

   $$\text{Force from gravity} = \text{Mass} \times 9.8\ \text{m/s}^2$$

7. For each run, is the net force equal to the earth's gravitational force? Explain what your answer tells you about the number of forces acting on the stack.

8. Assume that the only forces acting on the stack in each trial are due to gravity and air drag. Based on your data, have you shown that the force from air drag opposes the earth's gravitational force? If so, explain how.

9. Look at your data. Do you see a pattern between the mass of the stack and the net force on the stack between trials? If so, what is that pattern?

10. Complete the questions in the Challenge: Egg Drop handout for this activity.

Teacher Notes: Air Drag

Learning Objectives

This activity explores the concepts of air drag and net force during free fall. Free-falling objects traveling at a high speed just before hitting the ground will have a greater force associated with that collision than free-falling objects traveling at a slower speed. One way to reduce a falling object's speed is to counteract earth's gravitational force using the force of air drag.

Activity Introduction

Up to this point, students have assumed that forces from air drag are negligible as they have explored how dissimilar objects fall at the same rate regardless of their masses and sizes. Now students will explore the concept of net force and how falling objects like skydivers can help slow themselves using a force that opposes gravity: air drag.

Teacher Tips

Students will use a stack of coffee filters as their falling object (an object with high drag and small mass). Although the motion sensor should return good data, there may be times where the data looks slightly jumpy. This is caused by the crimped end of the coffee filter as it falls. To minimize these effects, have students flatten the filters slightly to create a more uniform surface while still maintaining its shape.

The height at which the stack of filters is dropped is an important variable that must be held constant. Emphasize to your students that the stack must be dropped from the same height in each trial.

Sample Data

Table 1: Forces acting on free-falling coffee filters

Number of Filters	Mass (kg)	Final Velocity (m/s)	Time of Fall (s)	Average Acceleration (m/s^2)	Average Net Force (N)	Force from Gravity (N)
4	0.0063	2.34	0.92	2.54	0.016	0.062
3	0.0047	1.89	1.00	1.89	0.009	0.046
2	0.0031	1.46	1.20	1.22	0.004	0.030
1	0.0016	1.10	1.44	0.76	0.001	0.016

CALCULATIONS

Average Acceleration:

$$\text{Average Acceleration} = \frac{\text{Final Velocity} - \text{Initial Velocity}}{\text{Time of Fall}} = \frac{2.34\text{ m/s} - 0.00\text{ m/s}}{0.92\text{ s}}$$

$$\text{Average Acceleration} = 2.54\text{ m/s}^2$$

Average Net Force:

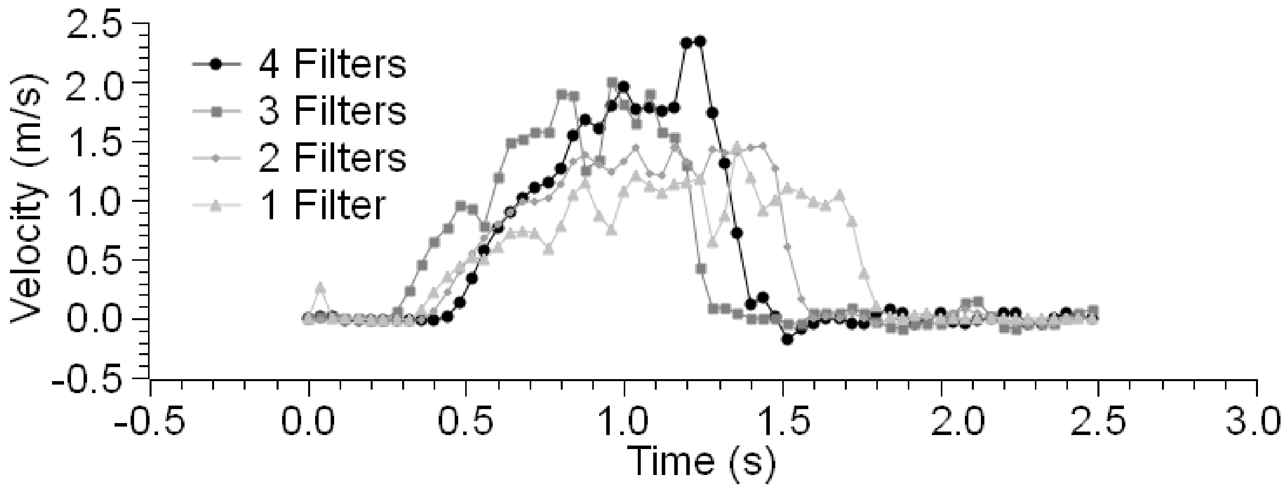
$$\text{Average Net Force} = \text{Mass} \times \text{Average Acceleration} = 0.0063\text{ kg} \times 2.54\text{ m/s}^2$$

$$\text{Average Net Force} = 0.016\text{ N}$$

Force From Gravity:

$$\text{Force From Gravity} = \text{Mass} \times 9.8\text{ m/s}^2 = 0.0063\text{ kg} \times 9.8\text{ m/s}^2$$

$$\text{Force From Gravity} = 0.062\text{ N}$$



Answer Key

Below are sample responses to the questions found in the Air Drag activity handout. Responses numbered under the "Questions" heading in the first column are responses to questions found in the "Questions" section in the handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

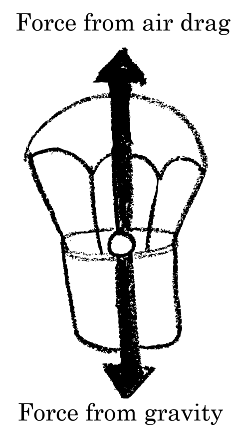
SAMPLE RESPONSES TO THE QUESTIONS IN THE AIR DRAG ACTIVITY HANDOUT

Questions	Sample Response
1, S1	"During its free fall, the stack of coffee filters in each run was accelerating." Our data supports this statement because an object is accelerating when it is speeding up, slowing down, or changing direction. Each run showed that the velocity of the stack of filters increased as it fell, so it was speeding up.
2, S2	We notice that the final velocities are not the same, which indicates that each stack had a different acceleration. The stack with the most filters had the greatest acceleration and the stack with the fewest filters had the least acceleration.
3, S3	See sample data column 5 for calculation results.
4, S4	See sample data column 6 for calculation results.
5, S5	The average net force is changing because the mass of the falling stack changed as filters were taken away.
6, S6	See sample data column 7 for calculation results.
7, S7	For each run, the net force is not equal to the earth's gravitational force, which implies that there are more forces than gravity acting on the stack.
8, S8	Yes, because the net force is less than the earth's gravitational force, the other force (air drag) must push up, opposing gravity.
9, S9	We do see a pattern between the mass of the stack and the net force between trials: the net force downward decreases as the mass of the stack decreases.

Connecting the Activity to the Challenge

Air drag will produce a force that counteracts gravity for falling objects; however, if the force from gravity is far greater than the force from air drag, the effects of air drag will be unnoticeable. Students can use this information to influence their design such that the force from gravity is minimum (low mass) allowing the force from air drag to play a role in counteracting gravity.

SAMPLE RESPONSES TO THE AIR DRAG RESEARCH QUESTIONS

Question	Sample Response
1	
2	The net force downward can be decreased by reducing the mass of the falling object.
3	One way to increase the force from air drag is to increase the surface area of the falling object. This can be done by adding a parachute, which we can implement in our design using a plastic bag.

Activity: Impact Force

Objective

Analyze force during a collision and use the resulting data to determine the best material to cushion and protect fragile objects during a collision.

Materials and Equipment

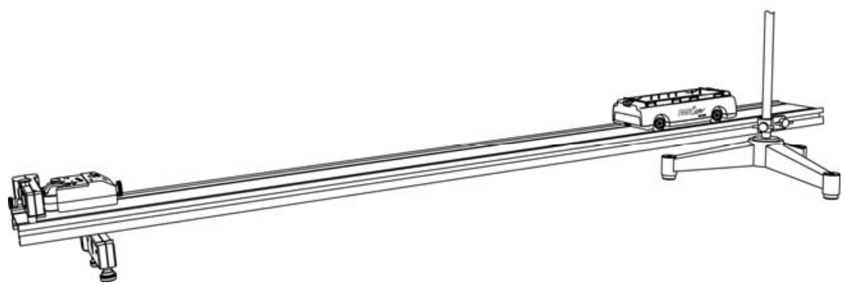
- Data collection system
- Force sensor with rubber bumper
- Discover Collision Bracket
- Light spring bumper [1]
- Heavy spring bumper[1]
- Force sensor cup
- Different bumper materials (4)
- Large base and support rod
- Dynamics cart
- Dynamics track with feet
- Track rod clamp
- Tape

[1]The spring bumpers are included with the Discover Collision Bracket.

Procedure – Same Impact, Different Force

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

☐ 1. Set up the track, track rod clamp, rod stand, force sensor, and collision bracket as shown in the picture. The track should be angled upward very slightly.



☐ 2. Start a new experiment on the data collection system �(1.2) and then connect the force sensor to the data collection system.

☐ 3. Screw the small rubber bumper into the front of the force sensor and press the Zero button on the sensor.

☐ 4. Create a graph of force (push positive) versus time �(7.1.1), and then set the data collection system to record 500 samples per second (500 Hz). �(5.1)

☐ 5. Set the cart on the track near the top of the incline and then start recording a run of force versus time data just before you release the cart. Stop recording data after it collides with the bumper. �(6.2)

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

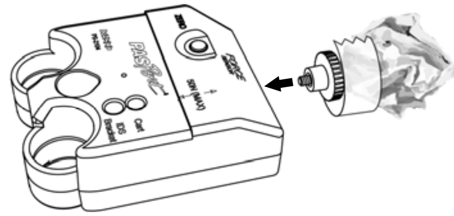
☐ 6. Switch the rubber bumper on the force sensor to the heavy spring bumper and repeat the procedure, recording one run of data. �(6.2)

☐ 7. Switch the heavy spring bumper to the light spring bumper and record one more run of data. �(6.2)

☐ 8. Draw or attach a copy of your graph in your notebook. Indicate what the maximum force was for each run and which spring bumper was used. Label this graph in your notebook, “Graph 1: Same Impact, Different Force”.

☐ 9. Both spring bumpers are softer than the rubber bumper, and the light spring bumper is softer than the heavy spring bumper. Do you think that if you used an even softer bumper material, the force versus time graph would look different for the same collision? How would it look different, and why?

Procedure – Same Impact, Different Material



☐ 10. Use one of the materials provided by your teacher and the empty force sensor cup to create a bumper that will mount to the force sensor like the one shown here.

☐ 11. Once you have mounted your bumper to the force sensor, set the cart on the track near the top of the incline and then record a run of force versus time data: start collecting data just before you release the cart and stop collecting data after it collides into the bumper. �(6.2)

☐ 12. Repeat the same procedure once for each of the remaining bumper materials.

☐ 13. Show the runs from each new bumper on the same graph �(7.1.3), and then draw or attach a copy of your graph in your notebook. Indicate the maximum force for each run and which bumper material was used. Label this graph in your notebook, "Graph 2: Same Impact, Different Material".

☐ 14. Which bumper material cushioned the best, and how does your data support your answer?

☐ 15. Try to create a "better" bumper to cushion the collision using more than one material, or perhaps using a more creative design. Use the materials your teacher has provided to create a bumper you think will better cushion the collision and then test your bumper using the same procedure as above.

☐ 16. Show the run from your new bumper on a graph �(7.1.3) and then draw or attach a copy of your graph into your notebook. Indicate the maximum force and describe how your bumper was constructed. Label this graph in your notebook, "Graph 3: Custom Bumper".

Questions

***NOTE**: Record all work, including calculations and answers, into your notebook.*

1. In Graph 1, what is different between the maximum force values from each bumper?
2. If the cart was released from the same position on the track for every trial, the cart should have the same speed just before it hits the bumper. Why do you think the maximum force is different between the runs on Graph 1 even though the cart was going the same speed just before impact in every run?
3. Is there a difference between the shapes of the runs on Graph 1? If so, what is the difference?
4. "Collision time" is measured from the point at which the force begins to increase during the collision to the point at which the force returns to zero. In Graph 1, is there a difference between the collision times using the light spring bumper and the collision times using the heavy spring bumper? If so, why?
5. In your own words, describe how the maximum force in a collision changes when a softer bumper is used, and explain what else changes as a result of using a softer bumper.
6. In Graph 2, which bumper material resulted in the smallest maximum force and which material resulted in the greatest maximum force?
7. Describe some of the physical differences between the bumper material that resulted in the greatest maximum force and the bumper material that resulted in the smallest maximum force (softer, rougher, lighter, etc.).
8. Describe how you constructed the custom bumper used in Graph 3, noting the materials used and the construction method.
9. If the effectiveness of a bumper is based on its ability to minimize the maximum force in a collision, was your new bumper in Graph 3 more effective or less effective than the bumpers in Graph 2? Explain why you think it was more effective, less effective, or had no change.
10. Complete the questions in the Challenge: Egg Drop handout for this activity.

Teacher Notes: Impact Force

Learning Objectives

Analyze force during a collision and use the resulting data to determine the best material to cushion and protect fragile objects during a collision.

Activity Preparation

This activity requires no setup prior to the day of the lab. However, even though the Impact Force activity handout includes a picture of the equipment setup, a demonstration setup at the teacher station may be helpful for students to models theirs after.

In the activity, students choose 4 different materials to test as cushioning material, and possibly use along with other materials to construct a bumper of their design. Providing a large range of materials will allow students to be creative and diverse in their designs. Some suggested materials are:

- Cotton balls
- Small balloons
- Facial tissue
- Construction paper
- Toothpicks
- Popsicle sticks
- Rubber cement
- Tin foil
- Newspaper
- Cardboard
- Plastic bags
- String
- Duct tape
- Masking tape

Activity Introduction

This activity focuses on force during a collision and how cushions help to decrease the amount of force imparted to colliding objects. Students should stay focused on minimizing the force in a collision to help understand how a cushion will help their engineering design.

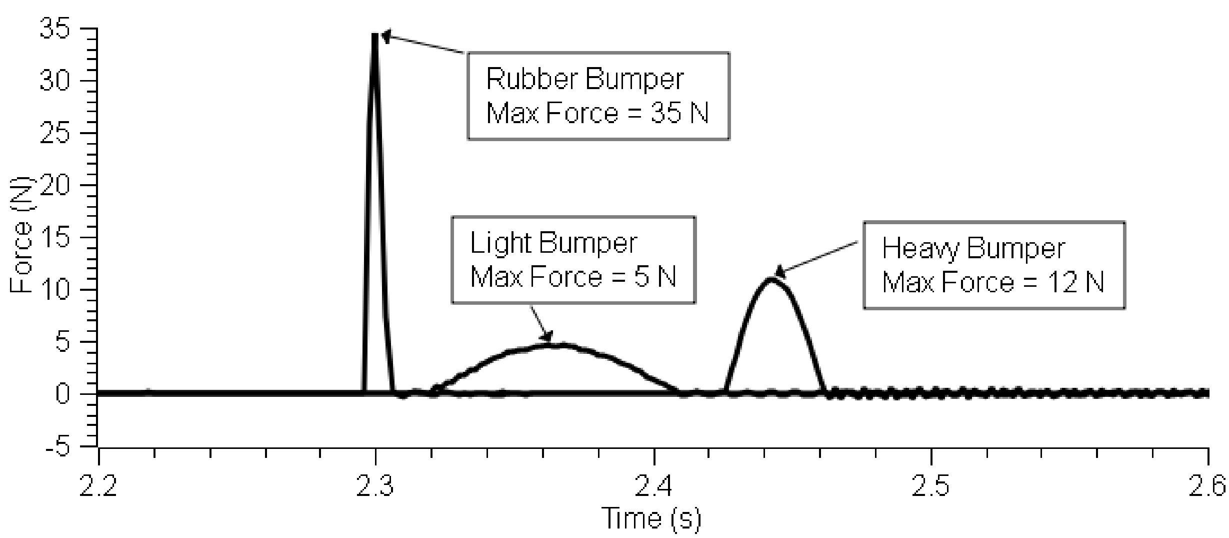
Teacher Tips

The setup includes a slightly inclined track to produce the same velocity at impact in each run. Also to maintain the same velocity for each run, students should release their cart from the same location on the track. Additionally, it is important that the cart not hit the force sensor with too much force (50 N or less) to prevent damage to the sensor. To avoid this, the incline in the track should be very small (between 2° and 5°).

In the second part of the activity, students test other bumper materials as well as construct a bumper of their own design. To make certain that the data collected during these trials is representative of the force imparted to the cart during a collision, the bumper material must be fully mounted to the force sensor cup and should not be resting on the track. Tape is included in the materials list so students can secure their bumpers to the force sensor cup, but other adhesives should be used if necessary.

Sample Data

GRAPH 1: SAME IMPACT, DIFFERENT FORCE



Answer Key

Below are sample responses to the questions found in the Impact Force activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions found in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE IMPACT FORCE ACTIVITY HANDOUT

Procedure	Sample Response
9, S11	If we used a softer bumper, the maximum force on the force versus time graph would be less than in the other three runs because the softer material would cushion better.
14, S19	Answers will vary depending on the cushioning material provided, but students should specify the bumper material that corresponds to the collision with the lowest maximum force.
Questions	**Sample Response**
1, S1	The magnitude of the maximum force values for each bumper is different. As the bumper gets softer, the maximum force of the collision decreases.
2, S2	Even though the cart had the same velocity before each collision, the maximum force in the collisions decreased because the bumpers got softer.
3, S3	Yes, there is a difference in the shapes of the three graphs in Graph 1: the shape of the graph got wider and shorter as the bumper got softer.
4, S4	The collision time in each collision in Graph 1 increased as the bumper material got softer. The collision time is longer for the light spring bumper compared to that from the heavy spring bumper. This is because the soft bumper compresses more and takes longer to rebound.
5, S5	The maximum force in a collision decreases when a softer bumper is used, but the collision time increases.
6, S6	Cotton balls produced the smallest maximum force, while crumpled newspaper resulted in the highest maximum force.
7, S7	Some of the physical differences between the cotton ball bumper and the crumpled newspaper bumper are: the cotton balls are much softer than the newspaper, the cotton balls kept their shape after the collision and the newspaper did not, the crumpled newspaper bumper was smaller than the cotton ball bumper, and the newspaper bumper was lighter (had less mass) than the cotton ball bumper.
8, S8	Our bumper was constructed by taping a wad of cotton balls to a slightly inflated balloon which was then taped to the force sensor cup.
9, S9	The new bumper in Graph 3 (Custom Bumper) had a maximum force of 4 N and was more effective than the bumpers in Graph 2 (Same Impact, Different Material), with the lowest maximum force of 5 N. We think the new bumper was more effective because the slightly inflated balloon made the bumper larger, which helped lower the maximum force by increasing the collision time.

Connecting the Activity to the Challenge

This activity demonstrates how forces are different in a collision when different cushioning materials are used and that large amounts of softer cushioning material help reduce the maximum force experienced by an object during a collision. If students choose to use cushioning in their design, this activity will help them determine which materials and designs work best.

SAMPLE RESPONSES TO THE IMPACT FORCE RESEARCH QUESTIONS

Question	Sample Response
1	A bumper made of cotton balls taped to a slightly inflated balloon made the best cushion. Our data supported this by showing the smallest maximum force for that bumper out of all the materials we tested using the same collision parameters.
2	The same amount of material used in the activity may not be sufficient given that our egg will experience a maximum force of 63 N and our greatest maximum force in the collision was only 35 N. NOTE: Students calculate the maximum force the egg will experience in response to the Challenge: Egg Drop Research Question #3 in the Force activity.
3	To help decrease the maximum force experienced by our egg at impact, we would use the same cushioning material but much more of it. We noticed in the activity that the maximum force decreased as the amount of material increased, for the same material.

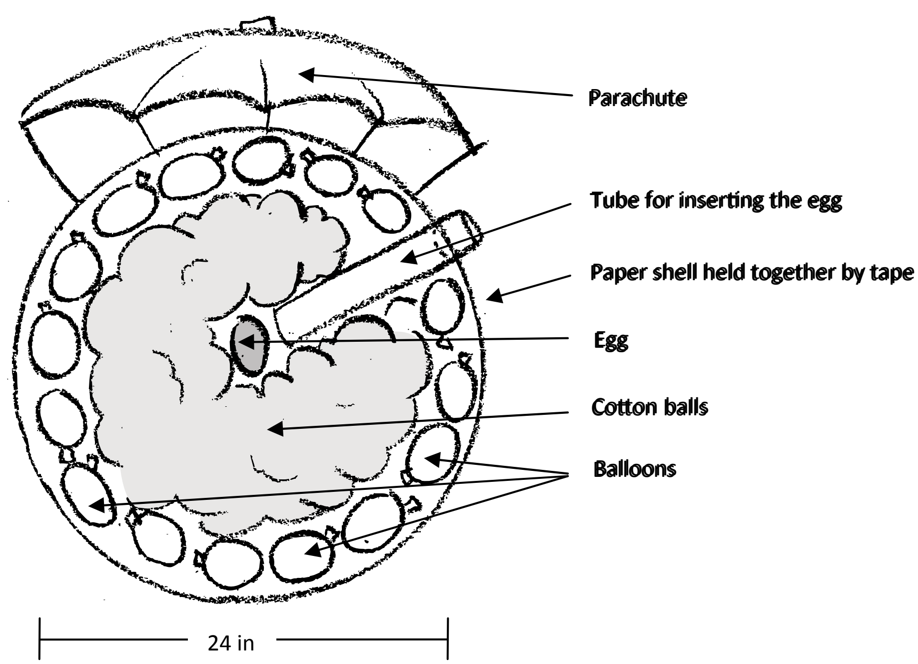
3 Revise Design

During the Revise Design process students are expected to work individually to review their initial designs and incorporate the concepts and ideas contained in the research activities. The Initial Design Ideas stage provided an opportunity to identify some of the misconceptions that students had prior to the research activities:

- Heavier objects will fall faster than lighter objects.
- The amount of force experience by the egg at impact will be the same regardless of how the apparatus is designed.
- Only larger designs will work.

Now that students are revising their designs, it would be useful to discuss, as a class, how those misconceptions were addressed within the research activities. Students should use the Revise Design questions to explain how those concepts will influence their revisions. Below are sample responses to these questions.

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

Question	Sample Response
1	Based on the information I learned in the research activities, some of my design ideas still work, like the cushioning inside the apparatus around the egg and the parachute attached to the top of the apparatus. The parachute may change, though, to be bigger and the cushioning may be a softer material.
2	My revised design will use a combination of cotton balls and slightly inflated balloons as cushion because our data showed that this combination helped reduce the maximum force of the impact.
3	Yes, I will change the outer structure. My revised design will have a thinner outer shell to help reduce the mass of the apparatus so the force from gravity is less and the air drag force will stay the same, thus reducing the net force downward.
4	
5	Materials list: ▪ Cotton balls ▪ Balloons ▪ Plastic bag ▪ String ▪ Paper ▪ Tape Safety concerns: none

4 Develop Group Design

During the Develop Group Design stage, students work together to develop a final design for their egg-drop apparatus, one from which they will construct their prototype. Groups should spend time discussing the different designs created by each group member and agree on a collaborative design that will be most effective. Group members should have a picture of the final design in their notebooks and outline the important design ideas and explain why they were chosen.

The role of the teacher in this stage is a facilitative one that keeps students focused on the concepts covered in the research activities and how they apply to each group's final design. Each group design must be approved by the teacher before it can be considered ready for building. When approving designs, make certain that each design conforms to the design requirements and constraints (the total mass of the device plus the egg cannot be greater than 0.4 kg) and passes a "sanity" check—ensuring the design can be constructed from the proposed materials. If the design fails to pass the sanity check, students should present design changes or material replacements, or both, without completely changing the original group design.

Remind students that engineering research is not necessarily a linear process and that there are many different and equally valid ways to solve the same problem. Every engineering project benefits from a variety of proposed solutions. Below are sample responses to the questions found in the Develop Group Design section of the Challenge document.

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

Question	Sample Response
1	Important Design Points: ▪ Very light materials were used to keep the total mass of the apparatus as small as possible, allowing air drag to help decrease impact force. ▪ The distance from the egg to the outside shell is large, allowing the collision time to be as long as possible, which will help lower the impact force. ▪ A tube was inserted into the apparatus so we could build the apparatus first, and then insert the egg after it was built. The tube will be removed before testing and the hole will be filled with cotton balls.
2	Materials list: ▪ Cotton balls ▪ Balloons ▪ Paper ▪ Duct tape Safety concerns: none

5 Build a Prototype

After finalizing their group designs (with teacher approval), students build a prototype based on that design. This stage of the Challenge can be done in class or at home. If you choose to have groups build their prototypes in class, it is recommended that students be given more than one class period to construct their prototypes.

Again, the role of the teacher in this stage is a facilitative one, helping students complete their prototypes and mitigating unseen issues with their group designs. Make it clear to students that their prototypes should be test-ready before the next stage.

Students have the option to either build their apparatus around the raw egg during prototype construction or to insert the egg once the prototype has been constructed, on the day of testing. If groups choose to have the egg built into their apparatus, make them aware that a broken egg at any point (including before testing or during construction) will affect their grade. Groups choosing to insert the egg just before testing must have some method for inserting the egg into their finished prototype.

Below are sample responses to the questions found in the Build a Prototype section of the Challenge document.

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

Question	Sample Response
1	Group Member Responsibilities: ▪ John – find tube for inserting egg into apparatus, as well as balloons and cotton balls ▪ Jane – build outer shell made of paper ▪ Jackie – inflate all of the balloons half-way ▪ Everybody – fill shell with balloons and cotton balls
2	The total weight of our apparatus was too great in our original prototype, so we decided to keep the same design but scale it down until it was under 400 g. The final prototype was much smaller, but was also 100 g less massive.
3	Mass = 389 g

6 Test and Evaluate

Each egg-drop apparatus has been designed and built to protect a raw egg from breaking after being dropped from a height of 6 meters. A second story school room balcony, if there is one, is usually about 6 meters above the ground, so it is recommended to have students drop their apparatuses from the second story balcony, aligning the bottoms of each apparatus with the 6-meter mark.

Although every group's apparatus is expected to succeed, those that don't can make quite a mess when the raw egg inside explodes. To help minimize the egg splatter, each egg should be placed in a small fold-top bag or sealable plastic bag before it is inserted into the prototype. After each apparatus is dropped, the egg inside (whether cracked or not) should be disposed of, and students should wash their hands immediately following.

When dropping an apparatus, have one member from each group drop the prototype, while the other members observe the apparatus as it hits the ground, paying close attention to how the apparatus is affected by the impact and whether the egg cracks or breaks. Observers should record their observations in their notebooks and keep in mind that these notes will be used to help them answer the questions in the Design Review section in the Challenge handout.

7 Design Review

In this stage, students use the observations recorded during the Test and Evaluate step to determine where their apparatus succeeded and where it failed, and to answer the questions in the Design Review section in the Challenge handout. Below are sample responses to these questions:

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

Question	Sample Response
1	The egg was undamaged.
2	Where the design failed: The parachute didn't open as the apparatus dropped because the time it took for the apparatus to hit the ground was too short for the parachute to open. The outer shell broke open and some of the cushioning fell out because the outer shell was too thin. Where the design succeeded: The cushioning, cotton balls and balloons, was soft enough to keep the egg from breaking.
3	Another group used sticks to hold their parachute open, which would have helped ours stay open as well.
4	If we were to redesign our apparatus we would use more tape to hold the shell together and we would leave the parachute out.

Concluding the Module

To conclude the STEM Egg Drop Module, have a class discussion about what worked and what didn't work, focusing on how the features that worked obeyed the laws and concepts explored in the research activities. Have students work together in their groups to create a list of components that worked well in their design and components that didn't work well. For those that worked, have students identify the physical laws that applied to that function. Call out once again some of the misconceptions that students had before the research activities and have them discuss how this project affected those ideas.

After the individual groups have created their lists, 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

Answer each question to the best of your knowledge.

1. Below is a graph of position versus time data. Draw lines from each term, on the left, to its location(s) in the graph on the right.

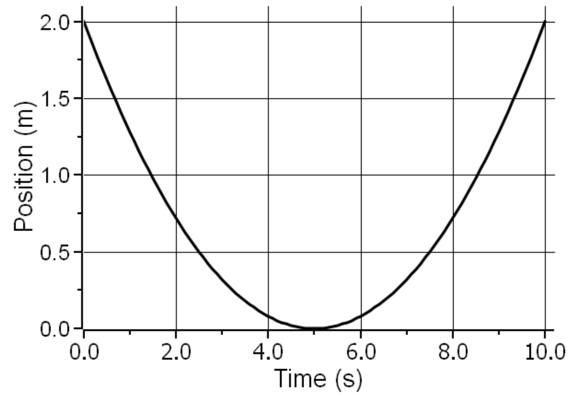
Terms

a. *x*-axis

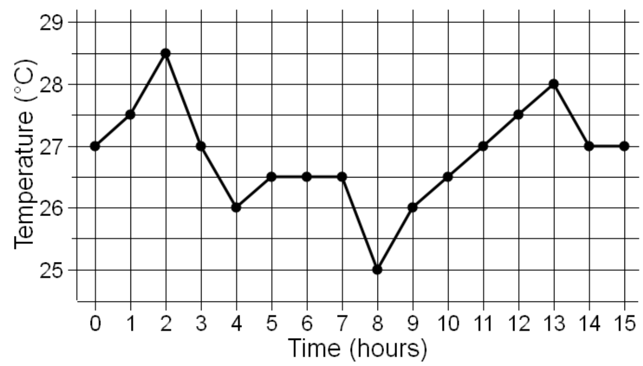
b. *y*-axis

c. Maximum position

d. Minimum position



2. This graph shows the temperature in a room throughout a day. How long did it take for the temperature to reach its minimum value? What was the average (mean) temperature during that time? Circle the best answer combination.
   A. 4 hours; 27.2 °C
   B. 4 hours; 27.3 °C
   C. 8 hours; 26.7 °C
   D. 8 hours; 26.8 °C



3. When Amy drops a bowling ball on the ground she hears one loud thud, and when she does the same with a golf ball she hears one soft thud. What sort of a sound will Amy hear if she drops both balls from the same height at the same time? Choose the best answer below.
   A. Amy will hear one loud thud.
   B. Amy will hear one soft thud.
   C. Amy will hear one loud thud and then one soft thud just after the loud thud.
   D. Amy will hear one soft thud and then one loud thud just after the soft thud.

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

4. Ignoring forces from friction and air drag, what is the acceleration of a 680 kg airplane (before it takes off) if the propeller on the airplane is producing a constant force of 2,000.0 N?
   A. 2.9 m/s^2
   B. 1.9 m/s^2
   C. 0.34 m/s^2
   D. 1.5 m/s^2

5. A car traveling with a velocity of 20.0 m/s suddenly slams on its brakes and begins to skid. If the skidding tires produce a constant acceleration equal to $-8.0\ m/s^2$, how long does it take the car to finally come to a stop?
   A. 4.0 s
   B. 3.5 s
   C. 3.0 s
   D. 2.5 s
6. A baseball pitcher accelerates a baseball at a constant rate of $70.0\ m/s^2$ when he pitches. If the baseball has a mass of 0.145 kg, what is the force applied to the ball by the pitcher when he pitches?
   A. 483 N
   B. 10.2 N
   C. 5.50 N
   D. 0.002 N
7. If an egg dropped from 6.0 m takes 1.1 s to hit the ground, what is its final velocity just before it hits the ground, assuming that acceleration from gravity is constant and equal to $9.8\ m/s^2$?
   A. 11 m/s
   B. 1.1 m/s.
   C. 110 m/s.
   D. Not enough information.
8. Jackie's egg-drop apparatus uses a parachute to help lessen the force on the egg at impact. Before Jackie drops the apparatus she decides to remove some excess mass from it, thinking it will help keep the egg from breaking. Is Jackie's thinking correct? Circle your answer and explain why her thinking is correct or incorrect.
   A. Yes, Jackie's thinking is correct.
   B. No, Jackie's thinking is not correct.

Explain why Jackie's thinking is correct or incorrect?

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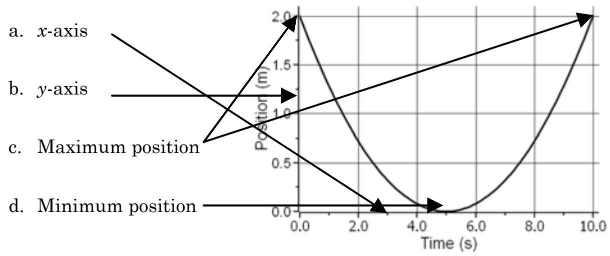
9. A skydiver experiences a 670 N force downward from gravity in free fall. At one point in the free fall, the force from air drag on the skydiver is 550 N. What is the net force on the skydiver at that point?
   A. 1220 N downward
   B. 0 N downward
   C. 670 N downward
   D. 120 N downward
10. Airbags are used in most vehicles as a cushion for drivers and passengers in a collision. Circle the answer below that best explains why a cushion like an airbag is used to help protect drivers and passengers in a collision.
   A. When a person in a collision hits an airbag, the air pushes the person away from the hard parts of a car.
   B. An airbag eliminates all of the impact force experienced by a person in a collision.
   C. An airbag lowers the impact force experienced by a person in a collision by increasing the collision time.
   D. An airbag pushes back on a person in a collision, making the net force equal to zero.

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. If a question requires more than a multiple choice response, refer to the third column for a more detailed description of the question's assessment information.

Question	Correct Answer	Assessment Information
1	See Assessment Information	 Related to graphing and graphical analysis techniques. A correct answer shows good understanding of the pieces of a graph, and an excellent understanding of how to identify maximum and minimum values within a graph.
2	C	Related to graphing and graphical analysis techniques: Students who chose A failed to identify the time at which the lowest temperature value occurred, however, the value for the mean temperature is correct for the time frame chosen. Those who chose B failed to identify the minimum time and calculated the mean as the temperature half way between the minimum and maximum for that time range. Those who chose D identified the minimum temperature correctly but failed to calculate the average temperature.
3	A	When two objects are dropped at the same height and time they will hit the ground at the same time. Acceleration from gravity is constant and equal for all objects on earth's surface. If both balls hit the ground at the same time, both thuds will occur at the same time, but because the loud thud would mask the soft thud, the only sound that would be heard is the loud thud.
4	A	$\text{Force} = \text{Mass} \times \text{Acceleration}$ $\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}$ $\text{Acceleration} = \frac{2{,}000.0\ \text{N}}{680\ \text{kg}}$ $\text{Acceleration} = 2.9\ \text{m/s}^2$
5	D	$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initialvelocity}}{\text{Time}}$ $\text{Time} = \frac{\text{Final velocity} - \text{Initialvelocity}}{\text{Acceleration}}$ $\text{Time} = \frac{0\ \text{m/s} - 20.0\ \text{m/s}}{-8.0\ \text{m/s}^2}$ $\text{Time} = 2.5\ \text{s}$
6	B	$\text{Force} = \text{Mass} \times \text{Acceleration}$ $\text{Force} = 0.145\ \text{kg} \times 70.0\ \text{m/s}^2$ $\text{Force} = 10.2\ \text{N}$
7	A	$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$ $\text{Time} \times \text{Acceleration} = \text{Final velocity} - \text{Initialvelocity}$ $\text{Final velocity} = \text{Time} \times \text{Acceleration} + \text{Initialvelocity}$ $\text{Final velocity} = 1.1\ \text{s} \times 9.8\ \text{m/s}^2 + 0\ \text{m/s}$ $\text{Final velocity} = 11\ \text{m/s}$
8	A	The net force downward of a falling object subject to air drag will be smaller if the mass of the object is smaller, thus lessening the acceleration of the object and its final velocity before it hits the ground. With a smaller final velocity, the egg will experience less force on impact and be less likely to break.
9	D	$\text{Net force} = \text{Gravitational force down} - \text{Air drag force up}$ $\text{Net force} = 670\ \text{N downward} - 550\ \text{N upward}$ $\text{Net force} = 120\ \text{N downward}$
10	C	Cushions are responsible for lowering the force associated with collisions and lengthening the collision time, thus conserving the impulse in a collision. Larger, softer objects will have a longer collision time than smaller, harder objects, and thus have a lesser maximum force.

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	**Reading Graphs (p.21)** Use a motion sensor to generate graph data for practice in interpreting graphs.	Data Collection System	1
		PASPORT Motion Sensor	1
		Meter stick	1
		Pencils	2
2	**Acceleration and Gravity (p.29)** Use a motion sensor to analyze how gravity affects the motion of falling objects of different size and mass.	Data Collection System	1
		PASPORT Motion Sensor	1
		Large base and support rod	1
		Right angle clamp	1
		Small rod	1
		Balance, 1-g resolution	1 per class
		No-bounce pad	1
		Three objects of different size and similar mass	1
		Three objects of different mass and similar size	1
		Meter stick	1
3	**Force (p.35)** Use a motion sensor and force sensor to analyze the relationships between force, mass, and acceleration.	Data Collection System	1
		PASPORT Motion Sensor	1
		PASPORT Force Sensor with hook	1
		Compact cart mass, 250-g	2
		Dynamics cart	1
		Dynamics track	1
		Super pulley with clamp	1
		Adjustable end stop	1
		Hanging mass, 40-g	1
		Balance, 1-g resolution	1 per class
		String	85 cm
4	**Air Drag (p.41)** Use a motion sensor to analyze how the velocity of an object in free fall is related to the net force on the object and that air drag produces a force opposite the direction of fall.	Data Collection System	1
		PASPORT Motion Sensor	1
		Large base and support rod	1
		Small rod	1
		Right angle clamp	1
		Balance, 0.01-g resolution	1 per class
		Coffee filters	4
		Meter stick	1
5	**Impact Force (p.47)** Use a force sensor to analyze force during a collision and determine the best material to cushion and protect fragile objects during a collision.	Data Collection System	1
		PASPORT Force Sensor with rubber bumper	1
		Discover Collision Bracket with spring bumpers	1
		Force sensor cup	1
		Large base and support rod	4
		Dynamics cart	1
		Dynamics track with feet	1
		Track rod clamp	1
		Different bumper materials	4
		Tape	1 roll

Activity by Equipment

The numbers in the "Activity Where Used" column refer to the activities listed in the Equipment by Activity table above.

Items Available from PASCO	Qty	Activity Where Used
Data Collection System	1	1, 2, 3, 4, 5
Motion sensor	1	1, 2, 3, 4
Force sensor	1	3, 5