Soft Landing

Day 2: Reduce Force Applied on a Spacecraft on Impact with Earth

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Middle School</th>
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<tr>
<td>Lesson Length</td>
<td>One 50-minute session (If possible, consider adding another day)</td>
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Lesson Overview

In this lesson, students build on ideas developed during Day 1. Students conduct an investigation to determine how an impact graph changes when objects with different masses are dropped from different heights. Students develop an explanation relating the height and mass of the falling object to the force on impact. Next, students conduct an investigation to determine what happens when an egg, rather than a medicine ball, is dropped. Students engage in a class consensus discussion to explain why the egg, and not the medicine ball or force plate, breaks. Finally, students determine the maximum impact force an egg can survive and the maximum height from which an egg can be dropped without breaking. Students use these ideas to further define the criteria and constraints of the design problem. At the end of the lesson, students relate the science ideas developed through the lesson to the design challenge.

Connecting to the Next Generation Science Standards

On Day 2, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices:** Asking Questions and Defining Problems, Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions
- **Disciplinary Core Ideas:** PS2.A Forces and Motion, PS3.A Definitions of Energy
- **Crosscutting Concepts:** Cause and Effect, Systems and System Models

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations

This lesson contributes toward building understanding of the following **physical science** performance expectations:

- **MS-PS2-1.** Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.
- **MS-PS3-1.** Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

Specific Connections to Classroom Activity

In this lesson, students compare data from ball-drop tests to determine similarities and differences among impact graphs. Students conclude that the peak of the impact graph increases when the falling object is heavier or dropped from a higher height. Students then consider what happens when the falling object is made of a different material (such as an egg rather than a medicine ball). After calculating the maximum impact force an egg can withstand and the maximum height from which it can be dropped, students use these figures to inform
their design criteria. Finally, students consider ways to either reduce the force upon impact or strengthen the material being dropped in order to design a safe spacecraft capsule.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
<th>Connections to Classroom Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking Questions and Defining Problems</td>
<td>• Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.</td>
<td>By determining the maximum impact force an egg can withstand and the maximum height from which an egg can be dropped without breaking, students define additional criteria and constraints for the design problem. Students must create a drop capsule that withstands any force greater than the force identified as the maximum impact force. In addition, students double the maximum height to determine the height of their drop tower. Students compare impact graphs from a variety of drop tests to determine similarities and differences. Students develop an explanation for why the shape and the peak of impact graphs change when the mass of the object falling or the height from which it is dropped changes. Students also develop an explanation for why the egg (and not the force plate or the medicine ball) breaks when it falls. Students use these ideas to inform their design decisions in later lessons.</td>
</tr>
<tr>
<td>Analyzing and Interpreting Data</td>
<td>• Analyze and interpret data to determine similarities and differences in findings</td>
<td>Students continue to develop the idea that the force plate “pushes back” against the falling object. Students work with the idea that the material of the falling object matters in determining the momentum of the object upon impact. After conducting two investigations involving drop heights, impact force, and the mass of the object dropped, students develop the idea that when objects fall from a greater height, they have more kinetic energy, which causes greater force on the force plate.</td>
</tr>
<tr>
<td>Constructing Explanations and Designing Solutions</td>
<td>• Apply scientific ideas or principles to design an object, tool, process, or system.</td>
<td>Students consider the different materials of falling objects and the ways by which materials can lead to different outcomes. Students brainstorm ways to prevent a spacecraft (or egg) from breaking when it falls. Students work with the egg model and the force plate/medicine model to explain the phenomenon of the spacecraft falling to Earth.</td>
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**Science and Engineering Practices**

**Disciplinary Core Ideas**

PS2.A: Forces and Motion

• For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton’s Third Law).

PS3.A: Definitions of Energy

• Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

**Crosscutting Concepts**

Cause and Effect

• Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Systems and System Models

• Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems.
Basic Teacher Preparation

Refer to the Soft Landing Student Handbook ahead of time. All Day 2 documents are on pages 2–7 and 9–11 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (pages 2 and 3)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Investigation: How Mass and Drop Height Relate to Impact Force (page 9)
- Investigation: The Maximum Impact Force an Egg Can Survive (pages 10 and 11)

Find a variety of objects with different masses for students to use when investigating the relationships among mass, drop height, and impact force. Weigh each object, and label it with its mass. This also provides practice using the force plate, interface, and software with the medicine ball and egg. To prepare for the consensus discussion, review the Talk Science Primer (see the Suggested Teacher Resources at the end of this lesson).

<table>
<thead>
<tr>
<th>Required Preparation</th>
<th>Links/Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Gather or purchase the required materials for the lesson</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>□ Find objects for the investigation, and label each object with its mass</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>□ Set up access to force plates and the associated interface for all teams</td>
<td>Refer to the Materials List below</td>
</tr>
</tbody>
</table>

Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Landing Student Handbook</td>
<td>Download, print, and copy for students</td>
<td>1 per student</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Force Plate</td>
<td></td>
<td>1 per team</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Force Plate Interface and Software</td>
<td></td>
<td>1 per team</td>
<td>Various platforms available [Web Link]</td>
</tr>
<tr>
<td>4 lb medicine ball</td>
<td>Must bounce when dropped</td>
<td>1 per class</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Objects of various sizes and weights</td>
<td>For investigations—label each object with its mass</td>
<td>Several per team</td>
<td>Available in schools or grocery stores</td>
</tr>
<tr>
<td>Measuring tape</td>
<td>To measure drop heights</td>
<td>1 per team</td>
<td>Available in most hardware stores</td>
</tr>
<tr>
<td>Raw eggs</td>
<td>Place in a plastic bag to avoid a mess</td>
<td>1 per class and 2 per team</td>
<td>Available in most grocery stores</td>
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</table>
Day 2: Reduce Force Applied on a Spacecraft on Impact with Earth

Introduction (5 minutes)

Have students take out their homework from the previous lesson. Students were asked to consider what might happen to the shape of the impact graph if a 4 pound ball was dropped on a force plate from 8 feet or 80 feet rather than 4 feet. Students also considered what might happen to the shape of the impact graph if an 8 pound ball was dropped rather than a 4 pound ball. Instruct students to share their ideas with their design team. As students share their ideas, remind them to support their ideas with reasoning.

After students have shared their ideas, set up the force plate and the medicine ball to test their hypotheses. Stand on a chair, approximately 8 feet above the force plate. Drop the ball. Zoom in on the output interface so students can read the data. Students will likely see that when the ball is dropped from a greater height, it exerts more force on the force plate. This causes the impact graph to have a higher peak and to increase and decrease more quickly.

Investigation: How Mass and Drop Height Relates to Impact Force (10 minutes)

Have students turn to Investigation: How Mass and Drop Height Relate to Impact Force on page 9 in the Soft Landing Student Handbook. Tell students they are going to investigate how mass and drop height relate to impact force. Prompt students to work in their teams to develop an investigation to figure out how mass and drop height relate to impact force. Students should record their investigation steps on page 9.

Provide students with the equipment needed to carry out their investigations. Each team should have access to a force plate and interface, measuring tape, and several objects with different masses (objects should be labeled with their masses). Allow students time to conduct their investigations, record data (page 9), and draw conclusions.

Whole Group Discussion: Conclusions about the Relationships among Mass, Drop Height, and Impact Force (5 minutes)

Lead a class discussion about the patterns among mass, drop height, and impact force. Have students share their conclusions from their investigations with the rest of the class. Encourage students to support all claims with evidence and reasoning. Students should begin to realize that dropping an object of greater mass or from a greater height will lead to greater force on the plate.

NGSS Key Moment

To draw conclusions regarding the relationship among mass, drop height, and impact force (PS3.A), students must analyze and interpret data from their investigation.

NGSS Key Moment

Students should connect PS3.A, cause and effect, systems and system models, analyzing and interpreting data, and constructing explanations.
Investigation: What Happens When a Falling Object Does Not Bounce (5 minutes)

Lead the class to the question, *What happens when the falling object does not bounce?* In this investigation, students consider what might happen if the object that falls does not rebound or change momentum.

Set up the force plate again, but this time, take out an egg (in a plastic bag). Drop the egg on the force plate. The egg will break when it falls. Zoom in on the impact graph so students can interpret the data. Ask students, *Why do you think the egg broke when it hit the force plate? Why didn’t the force plate or the medicine ball break?*

Lead a short discussion in which students consider the reasons why the egg broke instead of the force plate. By the end of the discussion, students should generally agree that the force plate must have “pushed back” against the egg, but instead of changing the momentum of the egg, the egg broke. The egg broke because the material making up the egg was not strong enough to handle the force.

Important Note

To avoid a mess, use a raw egg in a plastic bag. Using a raw egg adds to the “wow” factor for students.

NGSS Key Moment

Through this discussion, students develop a deeper understanding of Newton’s Third Law of Motion. Students consider the ways by which the materials that make up the object change the forces acting on objects in a collision.

Investigation: The Maximum Impact Force an Egg Can Survive (10 minutes)

Tell students their goal in the design challenge is to prevent the egg (astronaut) from breaking (astronaut fatality). To do this, they need to determine the maximum impact force. Students use their knowledge of the maximum impact force in their design solutions. In addition, they need to determine the maximum height the egg can survive. Students double this height to determine the criteria for their drop tower height.

Instruct students to follow the directions on pages 10 and 11 in the *Soft Landing Student Handbook* to determine the maximum impact force (astronaut fatality) and height (doubled for the drop tower height) an egg can survive. Direct students to drop the egg on the sensor plate from a low and then ever-increasing height until it breaks. Students should record their data on page 10.

Students should conduct two trials and average their results. Instruct them to record their data as part of the class data set. Students should calculate the average height and impact force for the class. After calculating the maximum height, have students double it. This gives them the required height for their drop towers.

Helpful Tip

Most Internet sources indicate that the average chicken egg breaks at an impact of 25N (kg • m/s²).
Whole Group Discussion: Returning to the Spacecraft Design Challenge (10 minutes)

Using a fishbowl style discussion (see Appendix C), engage the class in a discussion to relate today’s investigations to the overall design challenge. Begin by prompting students to discuss the systems model. Have students explain why dropping the egg from a greater height leads to greater force on the plate.

Students should begin to develop the idea that greater height means greater kinetic energy leading to greater force on the plate. Students may not initially know to use the term kinetic energy. Introduce the term to the discussion after students sufficiently develop the concept.

Next, have students discuss what the data from their investigation means to their engineering design decisions. Students should realize that to protect their astronauts, they must design a capsule that can withstand greater than \(-25\text{N (kg \cdot m/s^2)}\) of force. Students should also realize they need to either make the materials of the spacecraft strong enough to withstand the impact or decrease the force upon impact (to lower the peak of the impact graph).

Finally, have students discuss potential ways to protect their astronauts. Some students may talk about slowing down the astronaut (parachute) while others may talk about spreading out the force (cushion).

Student Reflection (5 minutes)

Refer students to the KLEWS Chart, and ask them to add to the L, E, W, and S columns. Have students write a reflection in their science notebooks or on Day 2 in Student Reflections and New Questions (page 2) in the Soft Landing Student Handbook. Some questions to address:

- Why did the egg, and not the force plate, break?
- What are your ideas for reducing the amount of force upon impact (of the spacecraft on Earth)?
- How does today’s investigation relate to your design challenge?
Assessment

Several opportunities for formative assessment exist in this lesson:

- Use the KLEWS Chart to gather data to determine student progress.
- Use the fishbowl discussion and associated rubric to reinforce students’ skills in discourse and accountability for using evidence, and to monitor developing science ideas.
- Soft Landing Student Handbook entries and reflections can always be used to monitor student progress during the module. Specifically, the teacher can look at students’ conclusions from both investigations to determine understandings of the connections among mass, drop height, and impact force.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Ask students to engage in a discussion with adults about examples of objects colliding. Examples may include two cars, a foot and a soccer ball, or a baseball and a bat. Have students think carefully about the impact graph and talk about ways to change the impact graph (such as padding on a car dashboard).
## Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Resource</th>
<th>Notes</th>
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<tbody>
<tr>
<td>KLEWS Chart</td>
<td>Ongoing from earlier lessons</td>
</tr>
<tr>
<td>Meeting the Needs of All Learners</td>
<td>Soft Landing Teacher Handbook, Appendix B</td>
</tr>
<tr>
<td>Talk Science Primer</td>
<td>[Web Link]</td>
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<tr>
<td>Engineer Profile: Tony Castilleja</td>
<td>[Web Link]</td>
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<tr>
<td>Engineer Profile: Victoria Wilk</td>
<td>[Web Link]</td>
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<tr>
<td>Engineer Profile: Myron Fletcher</td>
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<tr>
<td>Engineer Profile: Dylon Rockwell</td>
<td>[Web Link]</td>
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<tr>
<td>Engineer Profile: Simon Bahr</td>
<td>[Web Link]</td>
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<tr>
<td>Engineer Profile: Tricia Hevers</td>
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