Lesson Overview

On the first day of the module, students are introduced to Soft Landing Systems, a fictitious company involved in space travel. Soft Landing Systems wants to design a spacecraft capable of transporting an entire crew (six people) back to Earth. Before designing a large-scale drop tower and spacecraft capsule, Soft Landing Systems wants to test prototypes of the drop tower and spacecraft capsule. By optimizing the prototype drop tower and capsule on a smaller scale prior to testing on a large scale, Soft Landing Systems will save valuable time and resources. Soft Landing Systems has asked students to work as a team of engineers to:

- Design a prototype drop tower to drop the spacecraft (simulating the return of the spacecraft to Earth)
- Design a control circuit to hold the spacecraft at the top of the drop tower until the start of the test (to prevent accidental drops that can be very costly with large-scale equipment)
- Design a capsule to protect the spacecraft

For the prototype, Soft Landing Systems requested that students use an egg to simulate the astronauts in the spacecraft. The task is to design a drop tower, control circuit drop system, and capsule that will protect the spacecraft on impact with Earth.

After being introduced to the design problem, students learn to use a KLEWS (Know, Learn, Evidence, Wonder, and Scientific Principles) Chart. The KLEWS Chart is also used later in the module when students are introduced to the key parts of the project “build.”

The remainder of this lesson focuses on developing an understanding of what happens when a spacecraft returns to earth. Students observe a demonstration of a medicine ball falling on a force plate and interpret the graphical display of data collected by a force plate. Using the medicine ball and a force plate model, students reason about the collision between the medicine ball and the force plate and develop an understanding of the forces involved in the impact.

Connecting to the Next Generation Science Standards

On Day 1, 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 investigate what happens when a spacecraft (or ball) drops to Earth (or a force plate). Students interpret graphical displays of data to support the claim that when a ball drops, it exerts force on Earth and Earth exerts equal and opposite force on the ball. Students engage in a whole class discussion to develop an explanation for why the impact graph of a ball dropping on a force plate increases, reaches a peak, and decreases. In later lessons, students explore the relationships among the kinetic energy, mass, and speed of falling objects.

<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>• <em>Ask questions that can be investigated within the scope of the classroom,</em> outdoor environment, and museums and other public facilitates with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.</td>
<td>Students develop a KLEWS chart, in which they record what they already know about the design problem and what they still need to know. Throughout the module, students record their questions on the KLEWS chart and investigate their questions as part of the science investigations included in the module. As a class, students interpret graphical output readings from a force plate when the teacher drops a medicine ball on the force plate. Students explain the shape of the graph produced by the ball falling on the force plate. Students develop an explanation of the forces involved in dropping a ball on a force plate. Students conclude that the force the ball exerts on the force plate increases, reaches a peak, and decreases because of the change in momentum. Later, students use this idea to design a capsule that allows astronauts to drop safely on land.</td>
</tr>
<tr>
<td>Analyzing and Interpreting Data</td>
<td>• <em>Analyze and interpret data</em> to determine similarities and differences in findings. • Construct and interpret graphical displays of data to identify linear and nonlinear relationships.</td>
<td></td>
</tr>
<tr>
<td>Constructing Explanations and Designing Solutions</td>
<td>• <em>Apply scientific ideas or principles</em> to design an object, tool, process, or system.</td>
<td></td>
</tr>
<tr>
<td>PS2.A: Forces and Motion</td>
<td>• <em>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).</em></td>
<td>In a whole class investigation, the teacher drops a medicine ball on a force plate. Students examine the impact graph from the force plate and notice that during impact, the force reading on the force plate increases, reaches a peak, and decreases. Students engage in a whole group discussion to consider the forces exerted on the force plate and the ball. Students conclude that when the ball drops, it exerts force on the plate, but the plate also exerts force back on the ball in the opposite direction. The change in force changes the momentum of the ball. In the homework, students consider ways to change the amount of force exerted by the ball on the plate.</td>
</tr>
<tr>
<td>PS3.A: Definitions of Energy</td>
<td>• Motion energy is properly called kinetic energy; it is <em>proportional to the mass of the moving object and grows with the square of its speed.</em></td>
<td></td>
</tr>
</tbody>
</table>
In the demonstration with the falling ball, students observe that the force of the ground pushing back on the ball at the point of impact is a function of the velocity and the mass of the falling object. This concept is not explicitly named in this lesson. Rather, students are exposed to the general idea and build on the idea in subsequent lessons.

In the homework, students work with the concept of cause and effect by considering ways to change the amount of force exerted by a medicine ball on a force plate. Students also begin to reason about slowing down the ball so it exerts less force on the plate. Students work with the force plate and medicine ball model to explain the phenomenon of the spacecraft falling back to Earth.

### 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

In this module, students are organized into groups of four and work in their groups throughout the module. Prior to beginning the lesson, assign student groups based on individual student needs.

Refer to the [Soft Landing Student Handbook](#) ahead of time so you can address any questions students might have. All Day 1 documents can be found on pages 1 through 8 in the [Soft Landing Student Handbook](#). The documents used in this lesson are:

- Engineering Design Process (page 1)
- Student Reflections and New Questions (pages 2 and 3)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Fishbowl Rubric (page 8)

If possible, practice using the force plate, interface, and software. A less expensive alternative to the force plate from Vernier is the dual-force sensor. It requires some modification and a piece of hardware from Vernier to facilitate using the sensor to build a force table. The sensor is meant for less force than the force plate, so a smaller alternative to the medicine ball will be required.

To prepare for the consensus discussion, review the [Talk Science Primer](#) (see the Suggested Teacher Resources at the end of this lesson).
### Required Preparation

<table>
<thead>
<tr>
<th>Task</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>Download, print, and prepare the Soft Landing Student Handbook packets for students</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>Review suggested teacher preparation resources and recommended websites</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson</td>
</tr>
<tr>
<td>Assign student groups</td>
<td>Assign groups based on student needs</td>
</tr>
<tr>
<td>Practice with the force plate</td>
<td>Refer to the lesson description</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 to use throughout the module</td>
<td>1 per student</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Chart paper or small white boards</td>
<td></td>
<td>1 per team</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Force plate</td>
<td></td>
<td>1 per class</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Force plate interface and software</td>
<td></td>
<td>1 per class</td>
<td>Various platforms available [Web Link]</td>
</tr>
<tr>
<td>4 pound medicine ball</td>
<td>The ball must be able to bounce when it is dropped</td>
<td>1 per class</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>
Day 1: What Happens When a Spacecraft Lands on Earth?

Introduction (5 minutes)

Begin the module by explaining that students will assume the roles of engineers who have been hired by Soft Landing Systems, a company involved in space travel. Soft Landing Systems is interested in designing a spacecraft capable of transporting an entire crew (six people) from the International Space Station back to Earth. Before designing a large-scale drop tower and spacecraft capsule, Soft Landing Systems wants to test prototypes of the drop tower and spacecraft capsule. By optimizing the prototype drop tower and capsule on a small scale prior to testing on a large scale, Soft Landing Systems will save valuable resources and money. Soft Landing Systems has asked student engineers to work as a team of engineers to:

- Design a prototype drop tower to drop the spacecraft (simulating the return of the spacecraft to Earth)
- Design a control circuit to hold the spacecraft at the top of the drop tower until the start of the test (to prevent accidental drops that can be very costly with large-scale equipment)
- Design a capsule to protect the spacecraft

Tell students that the design problem for this module is, How can we develop a capsule and test system that ensures astronauts return to Earth safely? As you introduce the design challenge, reference pages 4 through 6 in the Soft Landing Student Handbook. Be sure to introduce students to the International Space Station and the Soyuz Spacecraft.

Assign students to design teams. Have students meet in design teams to establish group norms. Students should record group norms on page 4 in the Soft Landing Student Handbook. Some possible examples include:

- We will share our ideas.
- We will ask clarifying questions.
- We will ask for help.

Tell students they will work through the engineering design process as they design their spacecraft capsule and drop tower. Reference and review the Engineering Design Process graphic on page 1 in the Soft Landing Student Handbook (or Appendix A).

Web Resources

During the design challenge introduction, the teacher may want to reference information about the International Space Station (ISS) and the Soyuz Spacecraft.

- NASA Overview of the ISS [Web Link]
- Soyuz Spacecraft [Web Link]

NGSS Key Moment

Engineers often refer to the engineering design process when they discuss their work. In NGSS, the Science and Engineering Practices are used in place of the engineering design process. Students should understand that the engineering design process is not linear in practice. Rather, engineers engage in all of the steps, often jumping between steps. Students may want to think of the engineering design process as a web of practices.
After introducing the design challenge, show students the 1 minute [Orion Parachute Drop Test video](#), which shows a real-life space capsule drop test. The video will engage the students and get them excited to start planning their models and engage in the real design work of the module.

**Whole Group Discussion: KLEWS Chart (5 minutes)**

Throughout the module, students work with a [KLEWS](#) chart. A KLEWS chart helps students keep track of their thinking throughout an investigation of a phenomenon.

- **K**—What do we already know? This step draws out students’ developing conceptions about the phenomenon and gives the teacher an idea of where each student may fall on the learning progression.
- **L**—What are we learning? Students use this column to record their developing explanations and reasoning while investigating the phenomenon.
- **E**—What is our evidence? In this step, students list observations or data that they feel substantiate their claims and reasoning.
- **W**—What do we still wonder about? Students pose new questions about the phenomenon or new phenomena.
- **S**—What science ideas help explain the phenomenon? In this step, students work in collaboration with their teacher and classmates to develop a final explanation for the phenomenon. This last step is crucial because students develop an understanding of the science ideas that explain the phenomenon throughout the investigation. Students should be the ones to articulate the science ideas.

On the board or chart paper, prepare a KLEWS chart as shown on the next page. You may opt to align the KLEWS chart vertically (as illustrated in the [Soft Landing Student Handbook](#) on page 7) or horizontally (as shown here).

Remind students that the design problem for this module is, *How can we develop a capsule and test system that ensures astronauts return to Earth safely?*

Post the design problem across the top of the KLEWS chart. Remind students that they will be developing a prototype drop tower to drop the spacecraft capsule, a control circuit to hold the spacecraft at the top of the drop tower until the start of the test, and a capsule to protect the spacecraft. Introduce students to the two sub-questions for the module, *How can we design a capsule that allows astronauts to drop safely on land?* and *How can we create a test system...*
for our capsule that can be used repeatedly? Post both sub-questions to the KLEWS chart below the design problem.

Instruct students to think individually about what they already know about the design problem and what they still need to learn. Students should record their thoughts in the K column and the L column.

Invite students to share their ideas with each other in small groups. Begin a class KLEWS chart by prompting students to record their ideas on sticky notes. Ask students to post their own KLEWS questions on the class board as they share their ideas and questions with their classmates.

Prompt the class to answer, What problems do we anticipate? What do we need to investigate? Record student ideas on the class KLEWS chart.

Students will likely know that when something falls to Earth, it hits hard. To keep the astronaut safe, the spacecraft will need to be cushioned. Students may wonder how to cushion the spacecraft and how to design a test stand and a switch.

<table>
<thead>
<tr>
<th>K: Know</th>
<th>L: Learn</th>
<th>E: Evidence</th>
<th>W: Wonder</th>
<th>S: Science Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>What do we already know about the design problem?</td>
<td>What do we want to learn about the problem? What do we still need to know?</td>
<td>What evidence have we gathered?</td>
<td>What do we still wonder about?</td>
<td>What science ideas helped us with the design solution?</td>
</tr>
</tbody>
</table>

Investigation: What Happens When a Spacecraft Lands on Earth? (10 minutes)

Remind students that one part of the design problem is to protect the spacecraft and the astronauts in the spacecraft upon impact with the Earth’s surface. On Day 1, students consider what happens to a spacecraft when it returns to Earth. Tell students that when a spacecraft returns from the International Space Station, it leaves the orbit of the Earth and falls to Earth’s surface. In this investigation, students think more deeply about happens when the spacecraft collides with the Earth. Students experiment with a force plate and a medicine ball to model what happens when a spacecraft falls to Earth.

Set up a force plate at the front of the room. Project the interface and software so that all students can see the data collection. Tell

Helpful Tip

Use the KLEWS Chart to gather data regarding student progress on the key 3rd- and 4th-grade performance expectations. If students need additional support, consider reviewing the concepts or spending additional time on the second half of this lesson.

Helpful Tip

Consider viewing Vernier’s informational video about using force plates for more information.

[Force Plates–Vernier Web Link]
students that the force plate records the force applied to the plate. To demonstrate, push down on the force plate with your hand. Students should observe a change in the graph on the interface output. They should notice that the number of Newtons (kg • m/s²) increases as you push down with your hand.

Next, take out the 4 pound medicine ball. Tell students that the medicine ball is a model of the spacecraft and the force plate is a model of the Earth. Hold the ball approximately 4 feet above the force plate.

Ask students what they think will happen if you drop the ball. Lead a whole group discussion to draw out initial ideas. Encourage all students to share their ideas and to support their thoughts with evidence. Many students will likely suggest that the force reading on the plate will go up. Push students to consider whether the force reading will go up instantaneously or if it will increase, reach a peak, and decrease.

After all students have had the opportunity to share their ideas, drop the ball on the force plate. Zoom in on the interface output so students can see the graph. Students should notice that the force increases, reaches a peak, and decreases.

For your reference, the graph to the right is a screen shot from the Vernier website for the force plate. It shows the force of someone stepping onto the plate, jumping, standing, and stepping off.

Developing Models: When a Spacecraft Lands on Earth (10 minutes)

Have teams develop a model of what they think is happening. Student teams should sketch their thinking on whiteboards or chart paper for display during the following discussion. Students should use some analysis of the available data as they construct their explanations.
Whole Group Discussion: Why Force Increases, Reaches a Peak, and Decreases When a Ball Is Dropped (15 minutes)

With their initial models in hand, gather students in a Scientists Circle. Remind students that in the investigation, they observed a ball hitting the force plate. The output readings showed that the ball hit with a certain amount of Newtons (kg • m/s²) of force and that the impact graph showed the force increased, reached a peak, and then decreased.

Ask students, *Why do you think the force reading increased, reached a peak, and decreased?* Encourage students to think about this phenomenon by slowing time.

Lead a consensus discussion in which students consider the reasons why the force readings increased, peaked, and decreased. During the discussion, students should revise or modify their initial models. Creating a class consensus model may be helpful.

By the end of the discussion, students should generally agree that the ball exerts force on the force plate and the force plate must have “pushed back” against the ball, changing the ball’s momentum (and direction). Guide students to the idea that the force plate does not “feel” the full impact of the ball until the ball reaches its lowest point. The ball then rebounds, which redirects the force in a different direction.

At the end of the discussion, relate the investigation back to the design challenge. When a spacecraft falls to Earth, it falls from a much higher height. Ask students to think about how the impact graph from a spacecraft falling to Earth might compare to the impact graph generated from dropping the medicine ball on the force plate.

NGSS Key Moment

Whole group discussions, particularly consensus discussions, can be an effective way to engage students in the science practices of argumentation and explanation. Leading whole group discussions requires proper preparation. See Talk Science Primer for strategies.

Helpful Tip

Hold a class discussion in a fishbowl format. This involves some students participating in the discussion and the rest observing. This reinforces the discourse and importance of using evidence and reasoning to explain the cause and effect of the phenomenon (ball dropping).

Have students evaluate their classmates using the Fishbowl Rubric on page 8 in the Soft Landing Student Handbook and Appendix C.

NGSS Key Moment

This discussion is key for helping students develop a deep understanding of MS-PS2-1. Students should develop the idea that when the ball lands on the force plate, the plate exerts an opposite force on the ball. The opposite force changes the direction of the ball.
Student Reflection (5 minutes)

Have students write in Day 1 on the Student Reflections and New Questions page in the Soft Landing Student Handbook (page 2). Possible questions to address should include:

- What caused the shape of the impact graph?
- What do you think you would have to do to change the shape of the impact graph?
- How does the investigation relate to the design challenge?

Homework

Have students explain what they think will happen to the shape of the impact graph if you dropped the ball from 8 or 80 feet rather than 4 feet. What about an 8 pound ball instead of a 4 pound ball? Students should back up their claims with reasoning.

Meeting the Needs of All Learners

During this unit, students take on the role of an engineer. Choose at least two of the identified videos to show students what engineering is about and what engineers do on a daily basis.

- What Is Engineering? (2:46) [YouTube Link]
- Boeing Engineer Profile: Tony Castilleja (4:08) [Web Link]
- Celebrating Engineering at Boeing (3:46) [Web Link]
- Job Show for Teens: Engineering Careers (3:26) [YouTube Link]

Assessment

Several opportunities for formative assessment exist in this lesson:

- Use the KLEWS Chart to gather data to determine student progress on 3rd- and 4th-grade performance expectations. Provide appropriate supports or extensions as necessary.
- Use initial and revised student models of the ball hitting the force plate to determine student progress on MS-PS2-1.
- Hold the class discussion in a fishbowl format to reinforce the claim-evidence-reasoning mode of discourse and to evaluate student progress on the disciplinary core ideas, science and engineering practice, and crosscutting concepts identified for this lesson. During the discussion, students should also provide feedback to their classmates using the Fishbowl Rubric.
- Soft Landing Student Handbook entries and reflections can be used to monitor student progress during the module.
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**

As students take on their roles as engineers, it may be helpful for students to meet engineers in the community. Provide some examples of engineering companies, activities, or individuals in your community that represent engineering in action. By sharing local examples, students can better understand the important impact of engineering in their community.

**Suggested Teacher Resources**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Design Process</td>
<td>Soft Landing Teacher Handbook, Appendix A</td>
</tr>
<tr>
<td>Meeting the Needs of All Learners</td>
<td>Soft Landing Teacher Handbook, Appendix B</td>
</tr>
<tr>
<td>Fishbowl Discussion Rubric</td>
<td>Soft Landing Teacher Handbook, Appendix C</td>
</tr>
<tr>
<td>Soft Landing Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Talk Science Primer</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>NSTA Article on the KLEWS Process or Methods and Strategies: KLEWS to Explanation-Building in Science</td>
<td>[Web Link 1] [Web Link 2]</td>
</tr>
<tr>
<td>NASA Overview of the International Space Station</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Soyuz Spacecraft</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Drop Test Video</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Vernier’s Force Plates</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Video—What Is Engineering</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Video—Job Show for Teens: Engineering Careers</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Video—PBS Learning Media Engineer Profile: Tony Castilleja</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Video—Celebrating Engineering at Boeing</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>