Science and Innovation

A Boeing/Teaching Channel Partnership

SOFT LANDING

Teacher Handbook

Teaching Channel

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The Boeing Company and Teaching Channel teamed in 2014 to create problem-based curricula inspired by science and engineering innovations at Boeing and informed by globally competitive science, math, and literacy standards. This two-week curriculum module and the companion video series are designed to help teachers in grades 4–8 integrate the engineering design process, aligned to science standards, into their classrooms. The collection of Teaching Channel curricula is one part of a collection of K–12 education resources intended to mark Boeing's centennial anniversary and prepare the next generation of innovators.

The materials created by this collaboration were taught by the authoring teachers in Puget Sound and Houston, and in 2015, a second group of teachers taught the lessons and provided feedback to improve the modules. As part of a second iteration of the modules, the senior science editor at Teaching Channel worked with Achieve to integrate the teachers' feedback while more closely aligning the modules to The Next Generation Science Standards (NGSS) call for significant shifts in the way science is taught and learned. In 2016, a panel of science experts from around the country convened for a two-day training with Achieve to learn how to incorporate the Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Science. As part of the iterative process of improvement, the expert reviewers then completed an EQuIP Rubric for each module. Teaching Channel's senior science editor combined the reviewers input to create a third iteration of the modules that promotes a close alignment to standards while honoring the original expertise of the authoring teachers and engineers.

Partners at both the University of Washington's Institute for Science and Math as well as Educate Texas were instrumental in teacher recruitment for this project. Teachers and engineers in the project received training from learning scientists at the University of Washington's Institute for Science and Math Education, led by Dr. Philip Bell. He and his team also created a design template to support curricula development to promote alignment to standards and research on science learning and teaching.

Please note that the resource links provided in these lessons are intended as helpful illustrations to teachers adapting the unit for their classrooms and are not an endorsement of specific products or organizations.

Soft Landing

Background and Overview

In this middle school module, students devise a way to protect an astronaut during a landing by designing and testing a capsule for a spacecraft. As part of the design challenge, students design a drop tower and control circuit to test their spacecraft capsule designs.

As students work to solve the design problem, they develop a deep understanding of the forces involved in safely landing a spacecraft. Students also develop an initial understanding of electricity and magnetism as they design and test an electromagnetic release system for the drop tower. Students test their ideas and assumptions, and consider alternative approaches to optimize their spacecraft capsule and drop tower designs. This egg-drop challenge enhances the traditional focus of the egg drop by incorporating an electromagnetic release system that is built into a drop tower fixture.

Unit Overview

At the beginning of the module, students are presented with the challenge of designing a prototype drop tower, control circuit, and protective capsule to keep astronauts safe during a landing. On Days 1 and 2, students consider the forces involved in landing a spacecraft on Earth by experimenting with dropping a medicine ball on a force plate.

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Students determine the maximum impact force an egg can withstand and the maximum height from which an egg can be dropped without breaking. The capsule designs must be able to protect an egg from forces greater than the maximum impact force, and the drop tower must be twice the maximum height from which a dropped egg can survive. Throughout the investigations on Days 1 and 2, students interpret graphical displays of data comparing mass, drop height, and impact force to develop a conceptual understanding of Newton's Third Law of Motion.

On Day 3, students experiment with electrical circuits and electromagnets. Students figure out how to wire series and parallel circuits, draw schematic diagrams, and build electromagnets. In addition, students develop ways to make electromagnets strong enough to hold the drop capsule. Students use the electromagnets and circuits to design their drop tower.

On Days 4 through 10, students plan, build, test, and present their spacecraft capsules, drop towers, and circuit controls. Students use evidence from previous investigations to support their design decisions. Finally, students present their progress in the engineering design process and their optimization plans.

Soft Landing
Background and Overview

Engineering Design in the Module

Throughout the module, student engineers have many opportunities to explore various parts of the engineering design process. Early on, students learn about the overall design challenge: how to design a capsule drop tower that uses an electromagnetic release switch—triggering a capsule release where the egg inside survives impact on landing. Students create blueprints of their egg capsule, electromagnet drop switch, and drop tower. They then manufacture their "builds" from the blueprints, test their physical models, and record data. Students consider ways to optimize their design solutions. Near the end of the module, students write final research reports of their engineering findings and arguments justifying their design decisions.

Sequencing

Soft Landing is intended as a middle school engineering and physical science module. This module was designed to help students make progress on four performance expectations: MS-ETS1-4, MS-PS2-1, MS-PS2-3, and MS-PS3-1. The performance expectations address the engineering design process, motion and stability, electricity and magnetism, and energy.

This module can be used at any point throughout the development of MS-PS2-1 and MS-PS3-1, but is best placed toward the end of middle school as a preview for HS-PS2-3 (forces and motion) and HS-PS2-5 (electricity and magnetism). It is most appropriately placed after students have developed an understanding that the change in an objects' motion depends on the sum of the forces on the object and the mass of the object (MS-PS2-2), but before students have considered gravitational interactions (MS-PS2-4).

Students should have already mastered the *performance expectations*, *disciplinary core ideas*, *science and engineering practices*, *and crosscutting concepts* included in 3rd through 5th grade Engineering Design and 3rd and 4th grade Physical Science.

- Students should have mastered 3-PS2-1, 3-PS2-2, 3-PS2-3, 3-PS2-4, 4-PS3-1, 4-PS3-3, and 4-PS3-4, which address Forces and Motion (PS2.A), Types of Interactions (PS2.B), and Energy (PS3.A). Ideally, students should have already been exposed to MS-PS2-2 and figured out that the change in an object's motion depends on the sum of the forces acting on the object and the mass of the object.
- Beyond the Physical Science performance expectations, students should have already demonstrated deep conceptual understanding for all of the 3-5 Engineering Design performance expectations and associated science and engineering practices, disciplinary core ideas, and crosscutting concepts.
- Students should have made grade-appropriate progress on the following *science and engineering practices*: Asking Questions and Defining Problems, Developing and Using Models, Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions, and Engaging in Argument from Evidence.
- Students should also have made grade-appropriate progress on the following *crosscutting concepts*: Cause and Effect, Systems and Models, and Structure and Function.

Performance Expectations

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electrical and magnetic forces.

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.

Soft Landing

Connecting to the Next Generation Science Standards

The lessons and activities outlined in this module are one step in the learning progression toward reaching the performance expectations listed below. Additional supporting lessons and activities will be required. Specific connections between the performance expectations, three dimensions, and classroom activities are articulated at the beginning of every lesson.

Important Note

The grade level and associated performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts identified throughout the unit were selected to align with the Next Generation Science Standards. In classrooms using local or state standards, this unit may fall within a different grade band and may address different standards. Teachers should adapt this unit to meet local and state needs.

Furthermore, teachers should adapt the unit to extend student learning to additional grade levels, performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts to meet student needs.

Performance Expectations

The lessons and activities in this module contribute toward building understanding of the following *engineering* performance expectations:

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

The lessons and activities in this module contribute 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-PS2-3. Ask questions about data to determine the factors that affect the strength of electrical and magnetic forces.

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.

Dimension	NGSS Element
Science and Engineering Practices	**Asking Questions and Defining Problems** • Ask questions that can be investigated within the scope of the classroom, outdoor environment, museums, and other public facilitates with available resources, and, when appropriate, frame a hypothesis based on observations and scientific principles. • 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. **Developing and Using Models** • Develop a model to generate data to test ideas about design systems, including those representing inputs and outputs. **Analyzing and Interpreting Data** • Analyze and interpret data to determine similarities and differences in findings. • Construct and interpret graphical displays of data to identify linear and nonlinear relationships. • Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success. **Constructing Explanations and Designing Solutions** • Apply scientific ideas or principles to design an object, tool, process, or system. **Engaging in Argument from Evidence** **Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.**
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Models of all kinds are important for testing solutions. **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). **PS2.B: Types of Interactions** • Electrical and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. **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. **Structure and Function** • Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Connections to the Common Core State Standards

In addition to connecting to the *Next Generation Science Standards*, this unit can support student growth in multiple *Common Core State Standards.* This unit can be easily adapted to support growth in the following standards:

English Language Arts

- CCSS.ELA-Literacy.W.8.1: Write arguments to support claims with clear reasons and relevant evidence.
- CCSS.ELA-Literacy.SL.8.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
- CCSS.ELA-Literacy.SL.8.3: Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and relevance and sufficiency of the evidence and identifying when irrelevant evidence is introduced.
- CCSS.ELA-Literacy.SL.8.4: Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

Soft Landing
Module Storyline

This module is designed as a coherent set of learning experiences that motivate a progressive building of understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts. The following storyline demonstrates how ideas are built across the lessons. You may find it helpful to continually reference the storyline to help frame lessons.

Driving Question:
How can we develop a capsule and test system that ensures astronauts return to Earth safely?

Question/Problem	What Students Are Doing	What Students Figure Out
What happens when a spacecraft lands on Earth?	Students interpret the graphical display of data generated by a force plate when a medicine ball is dropped on a force plate.	When a ball drops on a force plate, the force reading increases, reaches a peak, and decreases because the momentum of the ball changes.
How can we reduce the force applied on a spacecraft upon impact with Earth?	Students explore what happens when an egg is dropped on a force plate and consider ways to prevent the egg from cracking.	If the falling object is not strong enough or falls with enough force, it might break. Reducing the force or strengthening the material can prevent the object from breaking.
How can we design a drop tower to test our spacecraft capsules?	Students experiment with circuits and electromagnets to design the strongest electromagnet to hold the drop capsule prior to launch.	Different arrangements of circuits and electromagnets lead to electromagnets with different strengths.
How do we design and build our drop tower, circuit controls, and capsule to test our design?	Students draft blueprints and build their drop tower, circuit controls, and capsule.	Prototypes can be used for iterative testing and modification of a proposed technology such that an optimal design can be reached.

Soft Landing

Day 1: What Happens When a Spacecraft Lands on Earth?

Grade Level	Middle School
Lesson Length	One 50-minute session (If possible, consider adding another day)

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.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Asking Questions and Defining Problems** • *Ask questions that can be investigated within the scope of the classroom*, outdoor environment, and museums and other public facilitates with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles. **Analyzing and Interpreting Data** • *Analyze and interpret data* to determine similarities and differences in findings. • Construct and interpret graphical displays of data to identify linear and nonlinear relationships. **Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles* to design an object, tool, process, or system.	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.
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.*	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.

		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.
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.	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.

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	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Download, print, and prepare the Soft Landing Student Handbook packets for students	Refer to the Materials List below
❑ Review suggested teacher preparation resources and recommended websites	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Assign student groups	Assign groups based on student needs
❑ Practice with the force plate	Refer to the lesson description

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Soft Landing Student Handbook	Download, print, and copy for students to use throughout the module	1 per student	[Resource Link]
Chart paper or small white boards		1 per team	Available in most schools
Force plate		1 per class	[Web Link]
Force plate interface and software		1 per class	Various platforms available [Web Link]
4 pound medicine ball	The ball must be able to bounce when it is dropped	1 per class	[Web Link]

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

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]

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.

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.

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).

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.

NGSS Key Moment

Taking time to introduce the design challenge is essential because it familiarizes students with the anchoring phenomenon for the unit.

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?*

Important Note

The class KLEWS chart should be maintained throughout the unit. Be sure to keep it on the board or displayed so it can be easily accessed. Refer to the KLEWS chart whenever appropriate.

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.

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.

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.

K: Know	L: Learn	E: Evidence	W: Wonder	S: Science Ideas
What do we already know about the design problem?	*What do we want to learn about the problem? What do we still need to know?*	*What evidence have we gathered?*	*What do we still wonder about?*	*What science ideas helped us with the design solution?*

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

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/s^2) 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.

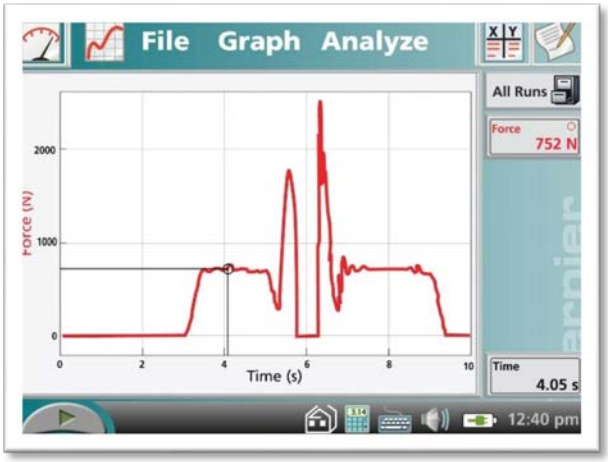
Important Note

The force plate will measure the force of the impact in Newtons (kg • m/s^2). At this point in the unit, students should recognize that a Newton (kg • m/s^2) is a unit of force. They develop a more detailed idea of a Newton (kg • m/s^2) in

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.



Source: Vernier (www.vernier.com/products/sensors/force-sensors/fp-bta)

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/s^2) 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

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

Soft Landing

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

Grade Level	Middle School
Lesson Length	One 50-minute session (If possible, consider adding another day)

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.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	Asking Questions and Defining Problems • *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.* Analyzing and Interpreting Data • *Analyze and interpret data to determine similarities and differences in findings* Constructing Explanations and Designing Solutions • *Apply scientific ideas or principles to design an object, tool, process, or system.*	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.
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.*	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.
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.	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.

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).

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Find objects for the investigation, and label each object with its mass	Refer to the Materials List below
❑ Set up access to force plates and the associated interface for all teams	Refer to the Materials List below

Materials List

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

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.

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.

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

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/s^2).

Meeting the Needs of All Learners

To make the design problem more challenging, instruct students to triple or quadruple the maximum drop height for the egg to determine the criteria for tower drop height.

To add an additional math extension, consider incorporating the idea of central tendencies in statistics to arrive at a class number for egg-break force and height.

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 todays 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 ~25N ((kg • 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).

NGSS Key Moment

This discussion is key in that it connects the design challenge to key science ideas. Students should continually work with the physical science key ideas throughout the remainder of the design challenge.

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?*

Homework

Have students continue to brainstorm ways to reduce the amount of force upon impact for when the spacecraft (egg) hits the Earth (force plate). Students should record their ideas.

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

KLEWS Chart	Ongoing from earlier lessons
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Talk Science Primer	[Web Link]
Engineer Profile: Tony Castilleja	[Web Link]
Engineer Profile: Victoria Wilk	[Web Link]
Engineer Profile: Myron Fletcher	[Web Link]
Engineer Profile: Dylon Rockwell	[Web Link]
Engineer Profile: Simon Bahr	[Web Link]
Engineer Profile: Tricia Hevers	[Web Link]

Soft Landing

Day 3: Design a Drop Tower to Test Spacecraft Capsules

Grade Level	Middle School
Lesson Length	One 50-minute session (If possible, consider adding another day)

Lesson Overview

In today's lesson, students consider the science ideas involved in designing the circuit control and drop tower—circuits (series and parallel), electromagnets, and schematic diagram. Students create circuits and electromagnets. Students experiment with ways to make an electromagnet stronger. The strength of the electromagnet either adds a criterion for the magnet or a constraint on the drop capsule. This lesson connects to the overall module in that students eventually build test capsules (containing an egg) and a testing fixture that uses electromagnets to release the capsule for testing.

Connecting to the Next Generation Science Standards

On Day 3, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Developing and Using Models, Analyzing and Interpreting Data
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions, PS2.B Types of Interactions
- 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-PS2-3. *Ask questions* about data *to determine the factors that affect the strength of electrical and magnetic forces.*
Specific Connections to Classroom Activity In this lesson, students build, test, and create schematic diagrams of circuits. Although the NGSS do not specifically discuss circuits, using a circuit in the engineering design problem contributes to an understanding of engineering design by reinforcing fair testing. Students also build and test electromagnets. Students are challenged to make an electromagnet stronger. The test tower's magnet needs sufficient strength to hold the capsule. This adds either a criterion for the magnet or a constraint on the capsule.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	Developing and Using Models • *Develop a model to generate data to test ideas about design systems, including those representing inputs and outputs.* Analyzing and Interpreting Data • *Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.*	In the design challenge, students develop a model of the drop tower and use it to test their spacecraft capsule. This lesson prepares students to develop their drop tower model. Students experiment with making their electromagnets stronger. To test the strength of their electromagnets, students either use a dual-force sensor or add washers to a string hanging from a can lid. Students use data from their tests to determine the maximum weight the electromagnet can hold. This adds either a criterion for the magnet or a constraint on the capsule.
Disciplinary Core Ideas	ETS1.B: Developing Possible Solutions • *Models of all kinds are important for testing solutions.* PS2.B: Types of Interactions • *Electrical and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.*	In this lesson, students prepare to use electricity and magnetism to develop a drop tower model to test their spacecraft capsule. Students experiment with electrical circuits and electromagnets to determine what makes an electromagnet stronger. The strength of the electromagnet determines a criterion for the drop tower and a constraint on the capsule design. Students formulate questions and gather data relative to the cause-and-effect relationships that affect magnetic forces due to (1) the magnitude of any electric current present in the interaction or other factors related to the effect of the electric current (such as the number of turns of wire in a coil), (2) the distance between the interacting objects, (3) the relative orientation of the interacting objects, and (4) the magnitude of the magnetic strength of the interacting objects.
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.*	Students recognize that designing circuits and electromagnets in different ways can have different effects on the load (the light, buzzer, and so forth). Students also recognize that they can manipulate electromagnets in various ways to make them stronger. In this lesson, students prepare to build a prototype model for the drop tower.

NGSS Key Moment

In this lesson, students prepare to build circuits to control their drop tower. Although the NGSS do not include specific examples of circuits, such as parallel and series circuits, the use of circuits in this lesson helps contribute to MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. The inclusion of circuits in this lesson builds heavily on 4-PS3-4. Students should have a solid foundation in 4th grade energy prior to engaging in Day 3. Including circuits also serves as a content extension. However, when discussing circuits, the focus should be on understanding the core concept of energy transfer.

Basic Teacher Preparation

This lesson is designed to prepare students to build their circuit controls and drop tower. To fully prepare for this lesson, review the Suggested Teacher Resources and experiment with circuits and electromagnets. Content background notes are embedded throughout this lesson for added teacher assistance.

Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All Day 3 documents can be found on pages 2, 7, 8, and 12 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (page 2)
- KLEWS Chart (page 7)
- Fishbowl Rubric (page 8)
- Investigation: How to Make and Electromagnet Stronger (page 12)

To prepare for the consensus discussion, review the Talk Science Primer (refer to the Suggested Teacher Resources at the end of this lesson).

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources at the end of this lesson
❑ If you are using the tin can lid with string and washers, prepare the tin can lids	Refer to the Materials List below

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Soft Landing Student Handbook	Download, print, and copy for students to use throughout the module.	1 per student	[Resource Link]
Switch samples	Consider purchasing two different colored switches so it is easy to tell which switch is which. For safety purposes, have the switches in parallel so both have to be off in order to drop the egg. Alternatively, switches can be constructed from nails, wire, and metal strips cut from cans.	1 per group	Switch samples [Web Link]
Electromagnet	If time permits, build the electromagnet. See the information in the Suggested Teacher Resources at the end of this lesson.	1 per group	Electromagnet [Web Link] Or make your own
Wire	Many wire options are available. One possibility is to use zip cord and split it. Old or damaged extension cords can be raided for this kind of wire. (Also, this wire is much bigger than necessary.) You could also use 18 or 24 gauge wire. One suggestion is to use stranded wire. Solid wire tends to break. For example, the wire for speakers would work fine. If making an electromagnet, *magnet wire* is easier to work with, because it's solid and has a thin insulation layer. Do not use bare wire for anything—only use insulated wire. The wire should be thin enough to work with but not so thin as to be unable to handle the current. Typical batteries and magnets are within the AWG24—AWG18 range, which is adequate for connections. Magnet wire is usually AWG 22-30.	1 roll per group	Wire [Web Link]
Scissors		1 per group	Scissors [Web Link]
Small lightbulbs		1 per group	Lightbulbs [Web Link]
Batteries		1 per group	Batteries [Web Link]

Nails		1 box	Bring from home or buy at local hardware store
Electrical tape (optional)	Handy to have to wrap connections.	1 roll per group or class	Electrical tape [Web Link]
Wire cutters	May be able to use certain scissors. Ideally, purchase a pair of diagonal cutters suitable for the wire being used. They can also be used to strip wires, making separate wire strippers unnecessary.	1 per group or class	Wire cutters [Web Link]
Dual force sensor	Used to measure the strength of the electromagnet	1 per group	[Web Link]
Tin can lid with string attached	Alternative to the dual force sensor	1 per group	Bring from home or buy at local hardware store
Washers	To add to the tin can lid	Several per group	Bring from home or buy at local hardware store
Balance with large capacity	To measure the mass of the tin can lid and washers	1 or 2 per class	[Web Link]

Day 3: Design a Drop Tower to Test Spacecraft Capsules

Introduction (5 minutes)

Refer students to the design challenge and the KLEWS Chart. Remind students their task is 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

So far in the module, students already explored the ideas related to designing a capsule to protect the spacecraft (forces and motion). Students haven't yet considered ways to design the circuit control and drop tower. Tell students the circuit control and drop tower are essential to the engineering design process because they allow for controlled testing.

Ask students to think back to their 4th-grade module on energy. In Grade 4, students should have built an understanding of 4-PS3-4. Likely, students engaged in creating a device, perhaps an electrical circuit, to convert electrical energy into a different form of energy. Day 3 builds heavily on the ideas developed in 4th grade. Instruct students to record what they already know about electricity and circuits in the KLEWS Chart.

Some possible class discussion questions to activate students' background knowledge include:

- *How does electricity travel?*
- *What forms of energy can electricity be converted to?*

NGSS Key Moment

The link to 4th-grade physical sciences included in this lesson demonstrates the importance of cohesion of science ideas across grade levels, which is central to the NGSS. Although this lesson is not intended to help students develop an understanding of circuits, using circuits helps students develop fair tests for their engineering design solution.

Mini-Lesson: Electricity and Circuits (5 minutes)

Tell students they are going to build circuits as part of their drop tower circuit controls. In high school, students further explore electricity and magnetism (HS-PS2-5). For now, students build on their understanding of electricity in magnetism. To design the drop tower, students build an electrical circuit with an electromagnet.

Show students the Circuits Video. Lead a short discussion on circuits, drawing on familiar examples, such as Christmas lights, circuit breakers, and so forth.

Video Link

▶ Circuits Video [YouTube Link]

Investigation: How to Build a Circuit (10 minutes)

After watching the video, students can use wire, batteries, a lightbulb, and a switch to construct several types of circuits. Allow students to tinker with the materials to build a variety of circuits.

Based on the information in the video, have students draw a schematic diagram of the circuits they build. The diagrams should include symbols and labels. Check on the teams while they work, ask probing questions, and provide support as needed.

NGSS Key Moment

Students should have the opportunity to experiment, or tinker, with circuit designs to figure out how circuits work. Allow students to continue to tinker with circuit designs as they design their drop tower circuit controls.

Investigation: How to Make an Electromagnet Stronger (15 minutes)

Show students the 5-minute video on electromagnets. Have students pay close attention to the experiments the narrator suggests at the end of the video.

Then, have students use wire, a battery, and a nail to make an electromagnet. Ask students, *How can you make your electromagnet stronger?* Encourage students to experiment with some of the suggestions in the video.

Students should test how adding coils or batteries makes the magnetic field stronger. Students should also check how the nail's orientation affects the strength of the field.

After tinkering with their electromagnets, instruct students to select three setups they think will yield the strongest electromagnet. Direct students to test each setup's strength, using the dual force sensor. Alternatively, have students hang a string from a tin can lid and then add washers one by one. The lid's mass plus the washers gives a relative strength of the magnet. Have students draw a schematic diagram of each setup and record their data from each test. Students should explain how they think they made their electromagnet stronger. Check on the teams while they work, ask probing questions, and provide support as needed. Conclude the investigation by telling students the test tower's magnet needs sufficient strength to hold the capsule. The strength of the electromagnet either adds a criterion for the magnet or a constraint on the capsule. Students use the data from today's investigation in their design solution.

Video Link

- Electromagnets [YouTube Link]

NGSS Key Moment

As students tinker with electromagnets, they develop an understanding of the factors that affect the strength of magnetic and electrical forces (MS-PS2-3).

Whole Group Discussion: How to Make Electromagnets Stronger (10 minutes)

At the end of the investigation, have students meet in a Scientists Circle to discuss their electromagnet models. Use the fishbowl structure and the Fishbowl Rubric on page 8 in the Soft Landing Student Handbook (see Appendix C). Have students share their experiments and results with the class. Work to develop class consensus about what makes an electromagnet stronger.

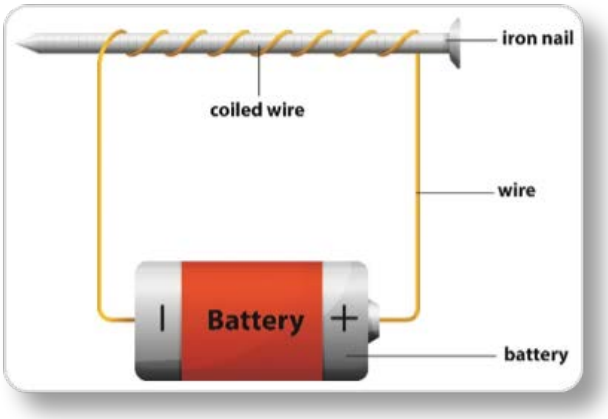
At the end of the discussion, remind students that the test tower's electromagnet needs sufficient strength to hold the capsule. The strength of the electromagnet either adds a criterion for the magnet or a constraint on the capsule. Have students discuss the design implications of their findings from today's lesson.

How to Create an Electromagnet

Use the nails from the electrical boxes along with a magnet wire, although any small wire will do (small because you need to use a lot of it to wrap around the nail).

Magnet wire is hard to strip. You need a razor or maybe a flame in order to strip it. If you want to have a finished look to your electromagnet, then get some 1/4" nuts and bolts (or larger) at the local hardware store (use steel) and matching washers. The result should look similar to the image on the right. However, the image does not have the nuts and bolts at each end.

You can also use nails and whatever wire you can scrounge up. Simply wrap the wire around the nails. Additional ideas for making your own electromagnets can be found at [Web Link].



▲ Electromagnet example

Source: Purple Trail (www.purpletrail.com/partytrail/types-of-magnets)

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to the L, E, W, and S columns.

Remind students that they are going to build an electromagnet and a circuit as part of the drop tower in their engineering challenge.

Have students write their reflections on page 2 in the Soft Landing Student Handbook, Day 3 Student Reflections and New Questions.

Possible questions to address include:

- *How can you make an electromagnet stronger?*
- *How could you draw a schematic diagram for a circuit for your drop tower?*

Homework

Have students brainstorm schematic diagrams for their drop towers.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Gather data from the KLEWS Chart 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 be used to monitor student progress. Look at students' conclusions from the electromagnet investigation to monitor progress on PS2.B, cause and effect, and analyzing and interpreting data.

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

Community Connections

Some students' parents, guardians, or family members may work as electricians or in careers involving electrical systems, energy, or magnets. If so, ask those students to share insights or information they have learned based on their conversations with their family members.

Suggested Teacher Resources

KLEWS Chart	Ongoing from Day 1
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Fishbowl Discussion Rubric	Soft Landing Teacher Handbook, Appendix C
Talk Science Primer	[Web Link]
Circuits Video	[YouTube Link]
Video on Electromagnets	[YouTube Link]
Resource for Working with Circuitry	[Web Link]
Resource for Magnetic Fields	[Web Link]

Background Information for Teachers: Schematic Diagrams

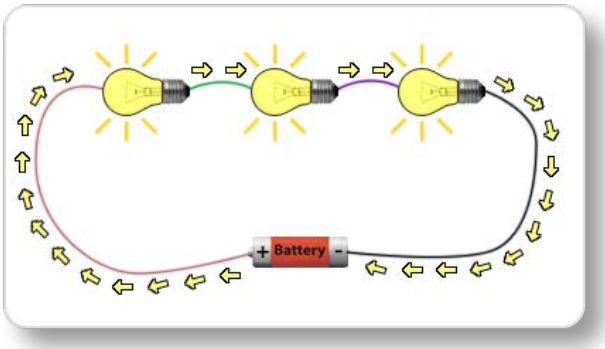
The key idea is that in a *series circuit*, all the current flows through the one "loop" and because of that, the current is the same in each piece. That's a great application (and example) of conservation of energy. If the current going in is X, then the current going out also has to be X. So if you know the current in one spot, you know it in every part of the series circuit.

In a *parallel circuit*, the current is divided, with the path of least resistance getting the most current. However, the voltage across the elements is the same. So if you know the voltage on one parallel branch, you know the voltage on all of them. If you have advanced students who enjoy electronics, challenge them to look up Kirchoff's laws, which are pertinent to analyzing circuits like this.

Another key idea is the concept of what happens when one element is removed from a circuit. For example, what happens if one element (a lightbulb) is removed or burns out in a series circuit? (The circuit is broken and no current flows.) What happens in a parallel circuit? (The current flows through the remaining elements.)

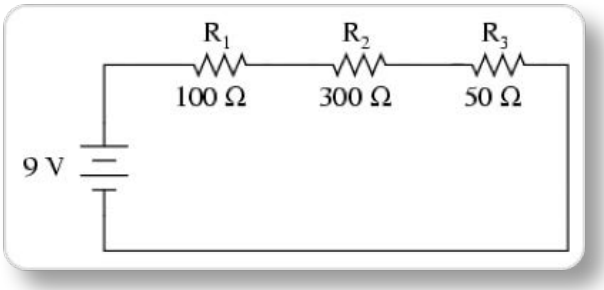
If these were switches, they would act like the Boolean operators AND and OR. That is, a lightbulb in series with three switches would be like saying, "Turn on the lightbulb when switch 1 AND switch 2 AND switch 3 are all on." If the three switches were in parallel and the lightbulb was in the series, it would be like saying, "Turn on the lightbulb when switch 1 OR switch 2 OR switch 3 is on."

This is important for an upcoming lesson, because the students use switches to operate their egg drop test stand.



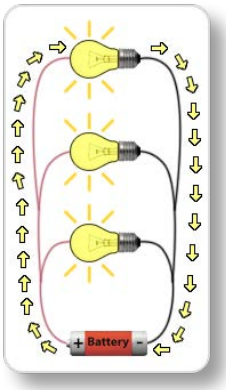
▲ Representation of a series circuit

Source: Science Buddies (www.sciencebuddies.org/science-fair-projects/project-ideas/Elec_p074/electricity-electronics/squishy-circuits-project-2#background)



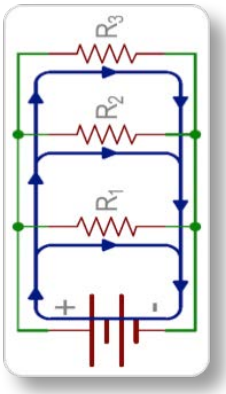
▲ Schematic diagram of a series circuit

Source: Lessons in Electric Circuits (www.malayalam.net/howto/LessonsInElectricCircuits/DC/DC_5.html)



▲ Representation of a parallel circuit

Source: Science Buddies (www.cdn.sciencebuddies.org/Files/4889/7/parallel-circuit-diagram_img.jpg)



▲ Schematic diagram of a parallel circuit

Source: SparkFun Electronics (learn.sparkfun.com/tutorials/series-and-parallel-circuits/all?print=1)

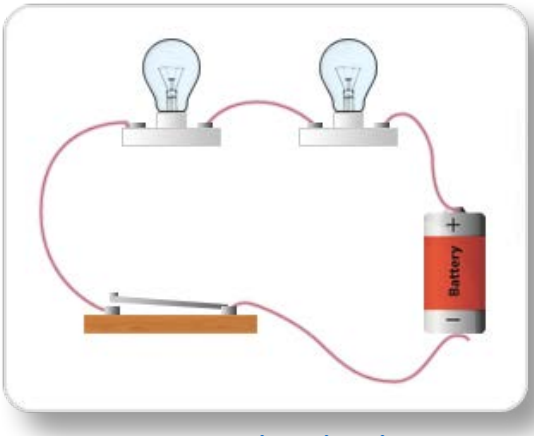
Background Information for Teachers: Series and Parallel Circuits

Understanding the difference between open and closed electrical circuits, and how electrical energy can be changed into light, heat, and sound energy are essential concepts in physical science. Most 4th-grade students can differentiate between conductors and insulators. Most have also learned electricity travels in a closed path, creating an electrical circuit, and they have explored electromagnetic fields. If necessary, conduct a review.

Electricity is a form of energy produced when electrons move along a path called a *circuit*. An atom's nucleus contains protons and neutrons. The nucleus is surrounded by an electron cloud. Metals, such as copper, have loosely attached electrons in their outer orbits, which roam randomly around other atoms. When the free electrons are charged and move between atoms, an electrical current is created.

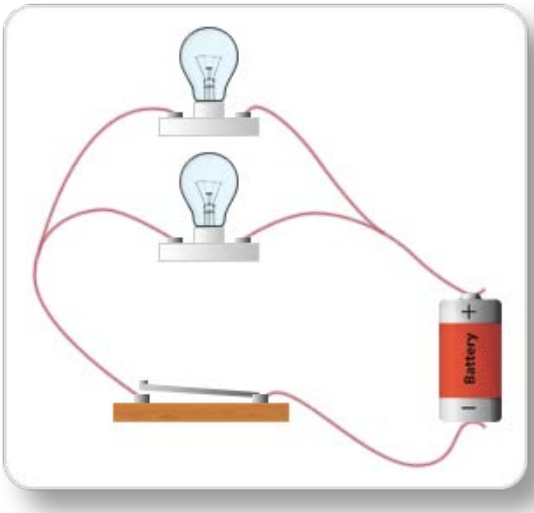
Electricity is conducted through some materials better than others. *Conductors* are materials with loosely held electrons that allow electrons to flow, such as copper, aluminum, and steel. *Insulators* are materials that hold their electrons tightly and do not allow them to flow, such as rubber, plastic, glass, wood, and cloth.

A completed path, or *closed*, circuit can conduct electricity, while an incomplete path, or *open*, circuit prevents electricity from flowing. In a *closed circuit*, a switch is flipped on and a piece of metal closes the pathway so the electrical current flows. In an *open circuit*, a switch is flipped off, which makes the path incomplete, and the electricity ceases to flow. A battery or a generator produces the pressure, or *force* (measured in *volts*), that pushes the current through wires. Circuits can be large or small. Some circuits involve huge power plants that generate electricity at one end and send megawatts of electricity along power lines to homes or businesses hundreds of miles away at the other end. Other circuits can be incredibly small, such as those in electronics that send information using tiny microchips.



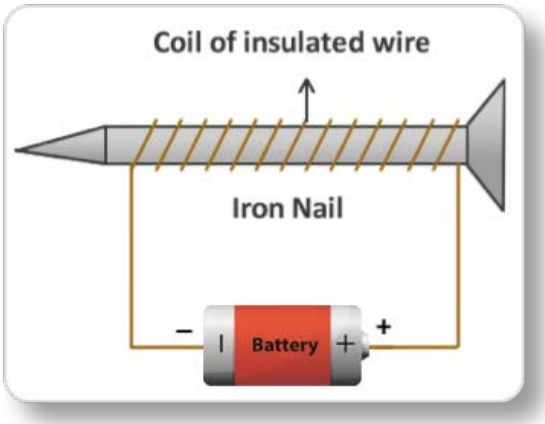
▲ Series circuit

Source: The Science Classroom (thescienceclassroom.wikispaces.com/Electric+Circuits)



▲ Parallel circuit

Source: The Science Classroom (thescienceclassroom.wikispaces.com/Electric+Circuits)



▲ Electromagnet

Source: Our EDU Blog (blog.oureducation.in/some-concepts-of-electromagnetic-field/#!prettyPhoto)

Soft Landing
Day 4: The Blueprint

Grade Level	Middle School
Lesson Length	50-minute lesson (If possible, consider adding another day)

Lesson Overview

On Day 4, students work on the design phase of their model's three components—the circuit (an electromagnetic switch), the spacecraft, and the test hardware box. Students are required to complete a blueprint of their model with dimensions, labels, and justifications for design decisions. All justifications must be grounded in evidence collected during previous investigations and should include an explanation of the physical laws at play.

In subsequent lessons, students build and use the capsules (containing an egg "astronaut") and a testing fixture that uses electromagnets to release the capsule. A successful test protects the egg from being broken on impact. To maximize a successful prototype, teams need to be able to visualize and design, on paper, what their model will look like and provide specific dimensions and labels that can facilitate construction.

Connecting to the Next Generation Science Standards

On Day 4, students make progress toward developing an understanding across the following three dimensions:

- Science and Engineering Practices: Asking Questions and Defining Problems, Developing and Using Models, Constructing Explanations and Designing Solutions, Engaging in Argument from Evidence
- Disciplinary Core Ideas: ETS1.B: Developing Possible Solutions, PS2.A: Forces and Motion, PS2.B: Types of Interactions
- Crosscutting Concepts: Systems and System Models, Structure and Function

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 engineering performance expectations:
MS-ETS1-4. *Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.*
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-PS2-3. Ask questions about data to *determine the factors that affect the strength of electrical and magnetic forces.*

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
On Day 4, students use their developing understanding of MS-PS2-1, MS-PS2-3, and MS-PS3-1 to develop draft plans for a design solution to the design problem. In an effort to design a spacecraft that can safely return astronauts to Earth from the International Space Station, students design prototype models to test space capsules. The prototype models are on a smaller scale to save cost and resources. Using prototype models helps students develop an understanding of MS-ETS1-4. Students develop and test the models on Days 5 through 10 in order to propose modifications and optimal designs. All design decisions must be justified using evidence from previous investigations related to MS-PS2-1, MS-PS2-3, and MS-PS3-1.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Asking Questions and Defining Problems** • *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.* **Developing and Using Models** • *Develop a model to generate data to test ideas about design systems, including those representing inputs and outputs.* **Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles to design an object, tool, process, or system.* **Engaging in Argument from Evidence** • *Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute* an explanation or a model for a phenomenon or *a solution to a problem*.	At the beginning of the lesson, students look through notes from previous investigations to define the criteria and constraints for the design problem. Students add the criteria and constraints to the scoring guide for use in assessing a successful design solution. Students develop draft plans for a prototype model for a drop tower, circuit control system, and spacecraft capsule. Students develop an understanding that the models can be used to generate data and to test designs. Students take the first step in designing a solution to the design problem by creating blueprints for their design solution. Students justify all design decisions using data and science ideas developed in previous investigations. Students record their arguments for their design decisions on the blueprint.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* • *Models of all kinds are important for testing solutions.* **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).* **PS2.B: Types of Interactions** • Electrical and magnetic (electromagnetic) forces can be attractive or repulsive, and *their sizes depend on the magnitudes of*	In this lesson, students develop blueprints for their design solutions. They work with ideas included in PS2.A and PS2.B to make decisions about their design solutions. Students recognize that after creating blueprints, they will build, test, and modify their design solutions, thus building an understanding of ETS1.B. In this lesson, students develop blueprints for their design solutions. They work with ideas included in PS2.A and PS2.B to make decisions about their design solutions. Students recognize that after creating blueprints, they will build, test, and modify their design solutions, thus building an understanding of ETS1.B.

	the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.	
Crosscutting Concepts	**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. **Structure and Function** • *Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.*	Students work with the small-scale prototype model to design and optimize a solution to a problem. Working with the model keeps costs low. Students take into account the purposes for each structure included in the drop tower and capsule, and design each structure accordingly, justifying design decisions with evidence from previous investigations.

Basic Teacher Preparation

This lesson is important because students learn the value of creating a blueprint that addresses all the characteristics (criteria, constraints, tradeoffs, and so forth) for their eventual build. In addition, students incorporate ideas developed during Days 1 through 3 into their design solutions by justifying design decisions with evidence from previous investigations.

This lesson provides background information and notes that can be used to help convey key concepts and directions to students. Before the lesson, read through the Suggested Teacher Resources listed at the end of the lesson.

Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All Day 4 documents can be found on pages 2, 4–7, and 13–16 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (page 2)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Egg Engineering Workspace Blueprints (pages 13–15)
- Blueprint Feedback Reflection (page 16)

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List that follows
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Soft Landing Student Handbook	Download, print, and copy for students to use throughout the module	1 per student	[Resource Link]
Chart paper or graph paper	Chart paper can be used as an alternative to the student handbook to draw blueprints	Plenty for every group	Available at most schools
Cardboard boxes	The larger, the better	Many per class or team	Bring from home or grocery store
Eggs		1 per group	Grocery store
Tin snips (optional)		1 per group	Tin snips [Web Link]
Scissors		1 per group	Available at most schools
Box cutters	Make sure only the teacher or adult assistant has access to these	1 per teacher	Hardware store
Switches	Purchase or make switches using nails, wire, strips cut from cans, paper clips, and so forth	1 per group	Can be recycled from previous lessons
Battery/source	A 6V lantern battery works well	1 per group	Battery [Web Link]
Alligator clips	To attach to the terminals	1 per group	Clips [Web Link]
Electromagnets	Purchase or make electromagnets using nails, wire, cylindrical form like a cardboard or plastic tube (such as a pill bottle, thread spool, toilet paper tube)	1 per group	Can be recycled from previous lessons
Wire	Stranded wire is easiest to work with for connections. If making an electromagnet, *magnet wire* is the easiest to work with. It's solid and has a thin insulation layer. Do not use bare wire for anything (always use insulated wire). The wire size should be thin enough to work with but not too thin to handle the current. With typical	1 roll per group	Can be recycled from previous lessons

	batteries and magnets, the AWG24–AWG18 range is good. Magnet wire is usually AWG 22–30		
Glue		6 bottles per class	Available in most schools
Newspaper		Many	Bring from home
Plastic zip bags	If using for entire spacecraft, suggest a larger bag. If just using it for the inner egg holder, a smaller bag can be used.	1 box per class	Grocery store
Hot glue gun	May not need this if you are using duct tape and regular glue	1 per group	Office supply or craft store
Glue sticks for hot glue gun	If using a hot glue gun	1 bag per group	Office supply or craft store
Plain white paper	Needed for blueprint work	1 sheet per student	Available in most schools
Wire cutters/ strippers	Purchase a pair of diagonal cutters suitable for the wire being used	1 per group or class	Wire cutters [Web Link]
Wire nuts	Or some other means of connecting wires. You may not need this (yet) if you are building your own electromagnet and don't mind running the wires straight to the battery or have a way to connect a commercial electromagnet to the battery with one length of wire. These should be sized to match your wire.	2-6 per group	Wire nuts [Web Link]
Electrical tape (optional)	Handy for wrapping connections	1 roll per group	Hardware store, or bring from home
Duct tape (optional)	Useful for sticking things together. May substitute masking tape.	1 roll per group	Hardware store, or bring from home
Miscellaneous tools and supplies	Depending on switches, batteries, and electromagnets used, you may need screwdrivers, battery holders, and other similar items to facilitate building.	As needed for sharing	Hardware store, or bring from home

Day 4: The Blueprint

Introduction (5 minutes)

Refer students to the growing KLEWS Chart they have been updating for the past three lessons. Also refer students to the design problem (pages 4–6 in the Soft Landing Student Handbook). Give them time to review the information, and then lead a class discussion about the design problem and the progress thus far.

Design Work: Defining Criteria and Constraints (10 minutes)

Refer to pages 5–6 in the Soft Landing Student Handbook. Students will find a scoring guide that partially outlines the criteria and constraints of the design problem.

Instruct students to look through their notes from Days 1–3, data, and the price list. Have student teams add their own criteria and constraints to each box in the scoring guide. For example, students should add to the *Space Craft* criteria that the capsule must be able to withstand greater than 25N (kg • m/s^2) of force. Students should also add the required height of the drop tower.

After student teams have added their criteria and constraints, have groups share. Incorporate student ideas into a class scoring guide and instruct students to do the same. Contribute to the discussion concerns about test integrity, safety, redundancy, and dimensions.

As a class, set the design trade-offs against each other to determine a "Goldilocks" score: 5 points for 'just right' and fewer points for going too far one way or the other.

NGSS Key Moment

By adding their own criteria and constraints, students build on the science ideas developed on Days 1 through 3 to more clearly define the design problem.

Helpful Tip

You might need to provide specific examples for students to understand the notion of design tradeoffs. For example, ask students, "I need to haul a lot of something to another state. What kind of truck is best?" Student answers might be a pickup truck, a semi-truck, or perhaps, a dump truck. Then, reveal that you are trying to move, say, water or gasoline.

For water, a tank trunk is probably best, but that would not be the best for moving furniture or chickens, for example. An engineer would have answered the "What kind of truck is best" question with more questions, such as, "What is it you have to move? How far is it going?" Getting specific criteria is important!

Design Work: Designing a Blueprint (20 minutes)

In today's lesson, students begin the design phase of their design solution, which includes three components—the circuit (an electromagnetic switch), the spacecraft, and the test hardware box. Teams work together to create their blueprints for their design solution. As teams work, walk around and monitor students while they are working, ask probing questions, and provide support if needed.

Important Note

Provide students with a box of materials that they can use to build. That way students can see what they are able to use once they start to create their models.

Explain to students that in order to build a test capsule containing an egg and a testing fixture that uses an electromagnet to release the capsules for testing, teams need to be able to visualize and design, on paper, how their model will look.

Students need to create a blueprint of their models with dimensions and labels. On page 13 in the Soft Landing Student Handbook, students can see the Blueprint Criteria for Success that they need to use when they create their blueprint. Review the Blueprint Criteria for Success and give students the opportunity to ask clarifying questions before they begin drawing their blueprints.

Make sure students know today's work will contribute to their team presentations as well as individual reports in the final lessons.

NGSS Key Moment

The most important **Blueprint Criteria for Success** is the justification. By including justifications, students build on science ideas developed during Days 1 through 3. Push students to dig deeply into their data and science knowledge to incorporate rich justifications grounded in evidence.

Blueprint Criteria for Success

- You must include measurements for all three models—circuit, spacecraft, and test hardware box.
- You must label each part of all three models.
- You must have sufficient detail on your blueprint so that someone could build what is on your blueprint without having to ask you questions.
- You must incorporate data from Days 1 through3 to justify your design decisions. Labels should show how certain design features contribute to meeting criteria. For instance, if you label the kinetic energy and force that would squash an unprotected astronaut, what features mitigate the disaster? What is the estimated mass of the capsule? Does your planned magnet have enough strength, plus a little excess? Justifications should include data collected in previous lessons or during testing, science ideas developed in previous lessons, and physical laws at play.

Introduce students to various Blueprint Examples found on this website. If desired, print the pictures for students to use as a reference, or project pictures onto the board from the links. Students should create their blueprints on pages 13, 14, and 15 in the Soft Landing Student Handbook or on chart paper or graph paper.

Web Resource

- Blueprint Examples [Web Link]

Important Notes

You can change the focus (and complexity) of this lesson by supplying objects you don't want to emphasize. For example, you could provide students with preassembled components, including the test box, circuit, or spacecraft. You can also provide students with ready-made switches or electromagnets, or have students build their own switches or electromagnets. Consider these possibilities to help you control the amount of time you want to devote to the design and build process.

The dimensions in the constraints can also be adjusted for your particular situation. However, a couple general requirements include:

- Eggs should fall a reasonable distance (at least 1 meter) so they have a chance of breaking.
- Eggs should have astronauts drawn on them.

[Optional] Mini Lesson: Resources for Design Work

If time permits, review some background information with students before they begin their design process. Essential background information is provided in this resource.

Important Background Information about the Design Components

Use this information during lesson planning, and share the information about the components of the build with students.

Spacecraft

The spacecraft should hold the egg in a plastic zip bag to prevent a mess in case of breakage. The student drawing should show how the egg is inserted and secured. The magnets are going to have to be strong enough to hold the spacecraft, so be careful they are not too heavy. A minimal spacecraft can be a plastic zip bag along with a tin can lid taped or glued to one side. You might also consider a small cardboard box with a tin can lid attached. An entire tin can will be too heavy.

If you use the minimal plastic zip bag design, you may want to use two bags—one to hold the egg and one to hold the shock-absorbing material so if the egg breaks it doesn't make a big mess inside the spacecraft.

Test Hardware Box

The box provides a way to hold the spacecraft until testing. The electromagnet from the electronics should mount to the top of the box so the spacecraft will stay put until the release button. Typically, a removable shelf will hold the egg until the magnet is engaged and then be removed prior to the test.

This entire structure can be as simple as a large cardboard box with window and access holes, a slot for the shelf, and the shelf (perhaps from the part cut out to make a window) along with a mounting hole for the electromagnet. The box should be tall or have provisions for putting the box up on two closely spaced tables or chairs so the egg has as much distance as possible to drop.

For something even more minimal, use some other way to hold the magnet assembly and the spacecraft. For example, two yard sticks across a gap between two tables could hold the electromagnet. A variety of towers could also be built with construction toys.

More Information about Design Tradeoffs

The idea behind a design tradeoff is that you want to balance goodness with badness. Let's use a car as an example. You want a car that costs $1, gets 1,000 miles to the gallon, drives 500 miles per hour, and prevents injuries to all passengers during an accident. However, the reality is you may not be able to have all of those things. So, *tradeoffs* will have to be made. For instance, the car will cost more than $1. It is going to cost $20,000. At that price, one can put enough protection on it that it will be safe in a 15-mph crash and provide a 60% survivable rate in an 80-mph crash. What if we want 65% survivability? That will drive the cost up to $25,000.

So, there's an example of a tradeoff. Do we keep costs low and be less safe? Or, do we increase safety and raise the cost?

Here's another example related to the design project in this module. You could wire four switches to keep the electromagnet energized. One could be a lockout that stays closed until the safety officer opens it. It would be parallel with the other three wired in the series. Once the lockout is open, the magnet would stay energized until any one of the three drop switches are opened. But there is a cost to having four switches and a risk in four places for a potential failure. Do you use one switch, two switches, or more?

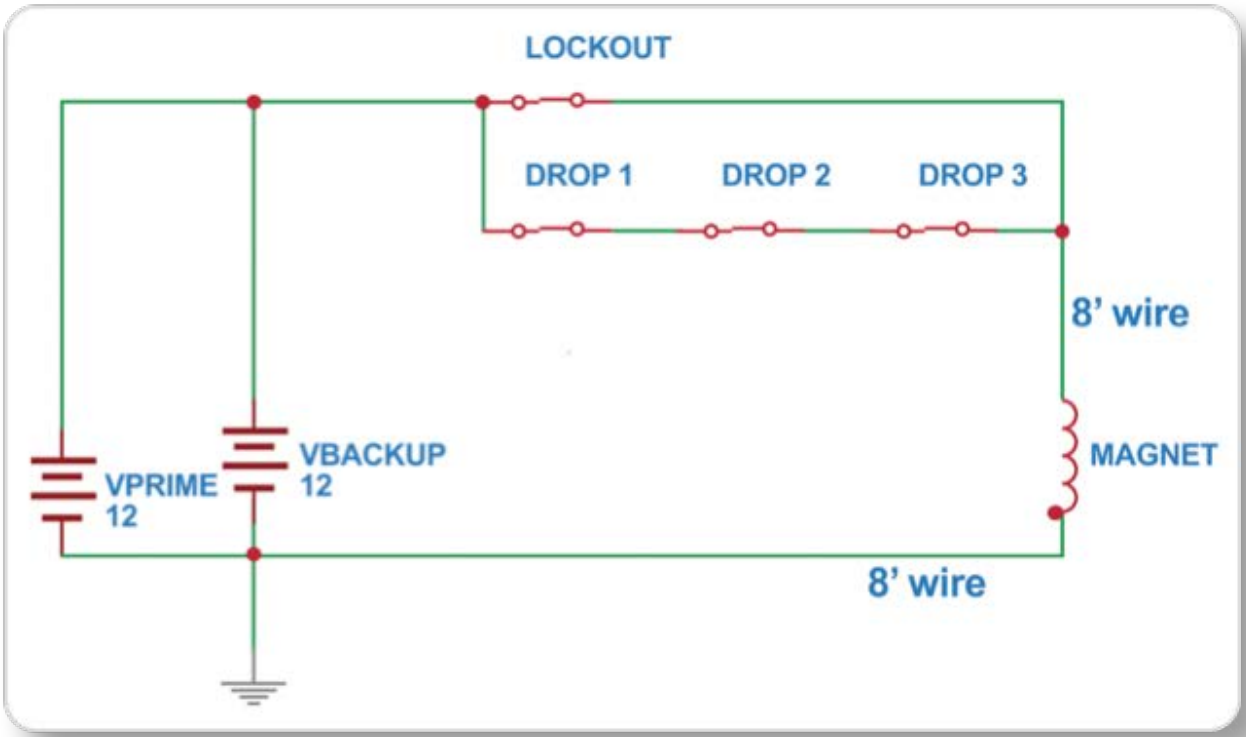
Exemplars of Blueprints

Circuit

For electrical projects, you would usually draw a circuit diagram as a schematic with no actual dimensions, except maybe for the wire going to the magnet. Students need to draw a schematic if they are building their own switches. If they are using premade switches, it is not as critical.

A sample switch schematic is shown. This example is more complicated than what the students need to create (for instance, they do not have to use two batteries and four switches).

Share the schematic example and discuss using the discussion prompts provided. Remind students that drawing a schematic diagram of their own electromagnetic switch is one expectation for their team.



▲ Sample switch schematic

Possible Discussion Prompts about the Schematic Example

Q: Why two batteries?
A: If one battery is dead, the other battery will hold the magnet. In practice, both batteries should drain about equally, but the life will be nearly double a single battery life. However, what happens if you have to change the battery in the middle of a test? With this setup, one battery can be replaced with a fresh one without interrupting the test. Could you replace the other battery (again, without interruption) and have a fresh set of batteries while the setup was still operating? You do not have to use more than one battery, which is a design choice (tradeoff).

Q: If the lockout switch is closed, what happens to the drop switches?
A: They don't do anything.

Q: If a drop switch is open and the lockout switch is opened, what happens?
A: A drop occurs immediately.

Q: What side of the battery is positive (with a + sign)?
A: On a schematic, the long bar is the plus side of the battery. The other side is the - or ground side.

Q: Does it matter which battery terminal is used?
A: Yes, because there are two batteries so the + sides must be connected together for the circuit to work properly.

Q: Could the drop switches be in the other 8' wire?
A: Yes. The circuit has to be broken, but it doesn't matter if it is the + side or the ground side. In fact, the electrons flow from - to + anyway, so putting in the plus side is fine, but so would be putting them on the other side.

Q: Could you put the lockout switch on the + side and the drop switches on the - side?
A: No. In this configuration, all switches would cause the spaceship to drop.

Important Notes

- Dimensions should always have measurement units either per dimension or a note somewhere (all dimensions are in inches, millimeters, or whatever units being used).
- Look for missing dimensions that you cannot deduce from other dimensions. For example, on the test box, it is common to have the outside dimensions and the dimensions of a window, but not have the dimensions of the location of the window.
- On the electrical schematic, the dimensions are not as important in most cases as the circuit values (such as, 6V battery). However, important dimensions might include the wire length to the battery and the wire length to the electromagnet.

Whole Group Discussion: Sharing Blueprints (10 minutes)

After 20 minutes of creating blueprints, teams should place their blueprints and justifications onto their table. Have students give feedback to the other engineering teams about their blueprints. Each group should rotate to every other group and write feedback for the other teams.

Emphasize that feedback should be written on blank paper and should be kind, specific, helpful, and focused on science ideas and justifications for design decisions.

Students should leave feedback sheets on the table. After students return to their blueprint and read their feedback, they should reflect on their feedback using the Blueprint Feedback Reflection on page 16 in the Soft Landing Student Handbook.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns. Allow time for students to share "shout outs" for work done by team members.

Have students write a reflection in their science notebooks or Day 5 of the Student Reflections and New Questions (page 2 in the Soft Landing Student Handbook). Possible questions to address should include:

- *What other information do you need in order to begin creating your models?*
- *After receiving feedback from your teammates, what changes are you going to make to your blueprints?*
- *What was challenging about today?*

Homework

Have students continue to make modifications to their blueprints. Students bring this information back to the next class session to help guide them during the next design stage.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Use the KLEWS Chart to gather data to determine student progress.
- Blueprints, specifically justifications for design decisions, can be used to monitor progress on all identified disciplinary core ideas, science and engineering practices, and crosscutting concepts. Blueprint justifications should be used as a primary source of student progress in this module.
- Soft Landing Student Handbook entries and reflections can always be used to monitor student progress during the module. Specifically, look at students' reflections on the Blueprint Feedback resource.

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

Think of several significant local or regional companies that likely use blueprints or models in their work. Share these examples with students. Consider asking some of those companies for examples of blueprints, models, or sketches to share with the class. Also consider asking individuals from those companies to mentor groups as they develop their own blueprints.

Suggested Teacher Resources

Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Soft Landing Student Handbook	[Resource Link]
KLEWS Chart	Ongoing from earlier lessons
Blueprint Examples	[Web Link]

Soft Landing

Days 5, 6, and 7: Work It!

Grade Level	Middle School
Lesson Length	Three 50-minute lessons

Lesson Overview

In this multiday lesson, students create their apparatus—circuit, spacecraft, and test hardware box. Teams use available materials to build the design they believe best addresses criteria, constraints, and tradeoffs. Students need to justify all design decisions using data science ideas developed on Days 1 through 3. Students also need to justify their purchases and use of time during the design phase.

Connecting to the Next Generation Science Standards

On Days 5 through 7, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. These lessons serve as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Revisit the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in this module's front matter. In addition, students dive more deeply into the engineering design performance expectations, which are interwoven throughout the module.

Basic Teacher Preparation

In these three important lessons, students begin to build the three components for the design challenge. If possible, build a design solution prior to Days 5 through 7 to gain first-hand experience constructing the testing apparatus and capsule.

Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All documents for this lesson can be found on pages 2–7, 17, and 18 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)
- Student Time Tracker (page 17)
- Expense Report Form (page 18)

The Suggested Teacher Resources at the end of Day 7 contains information to help teachers convey key concepts and instructions to students as they build the various components. Read through all of this information ahead of time. Additionally, review and print student handouts before class time.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List that follows
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources at the end of Day 7

Materials List

All materials listed for Day 4 should also be available on Days 5 through 7.

Lesson 5: Work It!

Introduction (5 minutes)

Refer students to the growing KLEWS Chart they have been updating for the past four lessons, and give them some time to review the information in addition to the design challenge.

Class discussion questions:

- What information from your KLEWS Chart will you use today as you design your apparatus?
- What information might you still need?

Design Work: Build Time (40 minutes)

During the next three sessions, students create their apparatus—the circuit, spacecraft, and test hardware box. Students use their blueprints to guide them while they build.

Show students the materials available to select from and work with. Refer students to the Student Time Tracker and the Expense Report Form (pages 17 and 18 in the Soft Landing Student Handbook), and explain that each team must keep track of time, tasks, and materials being used. Further, students must justify their time and purchases.

Any revisions to the design should be clearly documented on the blueprint and justified using science ideas and data developed during Days 1 through 3 or during prototype testing. Be sure that when students mark revisions, they do not erase original design decisions. If desired, instruct students to use a different color pencil or create a second set of blueprints to help keep track of versions.

Monitor the materials station closely. When students "purchase" (select) materials, they must bring their Expense Report Form with sufficient justifications for purchases. This form must be signed by the teacher each time a material is "purchased." Walk around and monitor students while they work, ask probing questions, and provide support as needed.

NGSS Key Moment

The design and build phase of this unit helps students deepen their understanding of both the Physical Science and the Engineering Design Performance Expectations.

Helpful Tips

- To ensure students are on task, project a digital clock onto the board to help keep students aware of the time constraints.
- Make sure students understand that everyone needs to work together for this project to work.
- Make sure students know the materials they should have, need to share, and need to purchase.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns. Allow time for students to share "shout outs" for work done by team members.

Have students write a reflection in their science notebooks or on Day 5 of the Student Reflections and New Questions Table (page 2 in the Soft Landing Student Handbook). Possible questions to address include:

- *What was challenging about today?*
- *What are you going to do tonight to ensure that your team is on track to be done by Day 7?*

Homework

Have students continue to modify their blueprints. Students bring this information back to the next class session to help guide them during the next stage in the Soft Landing Unit.

Lesson 6: Work It!

Introduction (5 minutes)

Refer students to the growing KLEWS Chart they have been updating and give them some time to review the information in addition to the design challenge.

Class discussion questions:

- What information from your KLEWS Chart will you use today as you design your apparatus?
- What information might you still need?

Design Work: Build Time (40 minutes)

For Day 6, repeat the activity sequence from Day 5. Continue to remind students to justify their use of time and purchasing decisions.

Remind students that any revisions to the design should be clearly documented on the blueprint and justified using science ideas and data developed during Days 1 through 3 or during prototype testing. Be sure that when students mark revisions, they do not erase original design decisions.

Once students have settled on a final design for the drop tower and capsule, students should create a final draft blueprint. The final blueprint should accurately represent the build and should include justifications for all design decisions. Justifications should be based in science ideas and data collected throughout the module, and they should include an explanation of the physical laws at play. Final blueprints should be created on large chart paper.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns. Allow time for students to share "shout outs" for work done by team members.

Have students write a reflection in their science notebooks or on Day 6 of the Student Reflections and New Questions Table (page 3 in the Soft Landing Student Handbook). Possible questions to address include:

- *What was challenging about today?*
- *What are you going to do tonight to ensure that your team is on track to be done by Day 7?*

Homework

Have students continue to modify their blueprints. Students bring this information to the next class session to help guide them during the next stage in the Soft Landing Unit.

Lessons 7: Work It!

Design Work: Repeat Lessons 5 and 6 (40 minutes)

For Day 7, repeat the activity sequence from Lesson 6.

Lesson Close (10 minutes)

Ask students, *What do engineers learn from failure?* Have students record their ideas and share their answers.

During the lesson's close, be sure to touch on the following ideas with students:

- Engineering teams rarely stick to their original designs completely. This is good, because a lot can be learned from ideas that do not work as expected during implementation or building.
- Sometimes, the original design needs to be updated because they work differently than expected, customer requirements have changed, or some other external force occurs (such as, you cannot get a specific part or material used in the design).

Knowing what they know now, ask students to think about what they would do differently if they had to start the design process over again. Some questions to ask:

- *Would you change your budget?*
- *Would you make your design simpler?*
- *Would you think more about how the different parts would join together?*

Tell students that there is an old saying that you should build something once to see how to build it, and then throw it away and build it again. This method is not practical, but it does point out the value of having an engineer or engineering team that is familiar with the kind of problem they need to solve.

Some students in class might have tried to build a design that was not possible to achieve. Point out that during projects, engineers often spend a lot of time figuring out why something doesn't work, because that information can be very valuable when they try again later. In fact, some engineers are *failure analysts* who specialize in figuring out why things fail.

Web Resources

For more information about how engineers learn from failure, visit these optional sites:

- Engineering Failures [Web Link]
- Brown's Ferry Nuclear Power Plant [Web Link]

Assessment

Several opportunities for formative assessment exist in this lesson:

- Use the KLEWS Chart to gather data to determine student progress.

- Use the Student Time Tracker logs to monitor student progress and justifications for time spent.
- Use the Expense Report to monitor student justifications for purchases.
- When students purchase materials at the store, students should continue to justify purchases. Use student responses to gage understanding of core ideas.
- Blueprint revisions, specifically justifications and revisions to justifications for design decisions, can be used to monitor progress on all identified disciplinary core ideas, science and engineering practices, and crosscutting concepts. Blueprint justifications should be used as a primary source of student progress in this 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

If any practicing engineers are willing to be guests or volunteers in the classroom during the build phase, their expertise and assistance can be invaluable. Furthermore, any assistance from the community in this phase would decrease the load on the teacher and allow more time for discovery and instruction.

Suggested Teacher Resources

KLEWS Chart	Ongoing from earlier lessons
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Engineering Failures website	[Web Link]
Browns Ferry Nuclear Power Plant article	[Web Link]

Background Information: Required Materials for This Module

Students can build the three components for this design challenge in many ways. As a result, the actual materials you select and use will vary accordingly. The following list contains some specific suggestions for building the apparatus as well as links to additional resources. Keep in mind that these are just a few possible options.

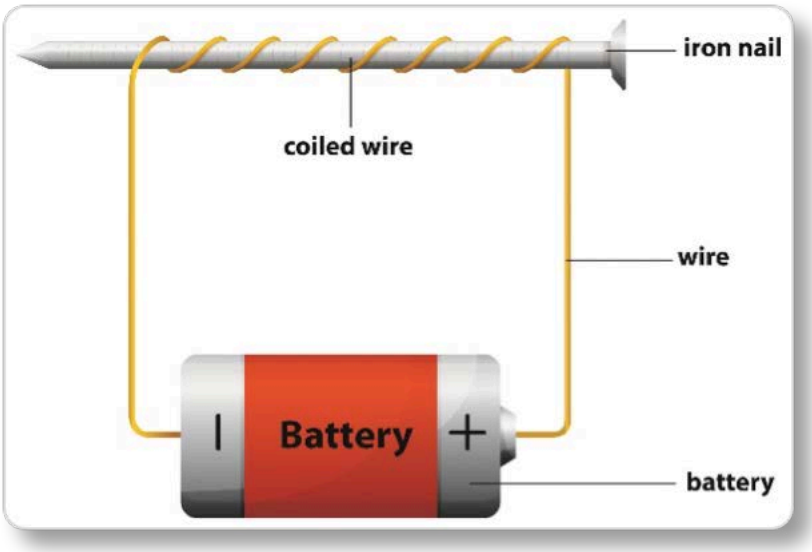
- **Inexpensive 2-gang electrical box**—Available at local hardware stores [Web Link]

  This box has two nails in it. The nails can be removed and used for the homemade electromagnets.

- **Inexpensive single switches**—Available at local hardware stores [Web Link] (2 recommended)

This box has two nails in it. The nails can be removed and used for the homemade electromagnets. Consider purchasing one white and one ivory switch (or other alternate color) so students can easily tell which switch is which (although this is not overly important). To ensure safety, have the switches in parallel so that both have to be off to drop the egg.

- **Wire**—Available at local hardware stores [Web Link] (stranded speaker wire recommended)
  Many wire options are available. One possibility is to use zip cord and split it. Old damaged extension cords can also be raided for wire (but this wire is bigger than necessary). You could also use 18- or 24-gauge wire. Regardless, stranded wire (such as the speaker wire identified above) is recommended because solid wire tends to break.
- **Wire nuts**—Available at local hardware stores [Web Link] (stranded speaker wire recommended)
  Wire nuts are used to connect wires. Many options are available. Choose an inexpensive option that fits the selected wire.
- **Battery**—Available at local stores [Web Link]
  Use a 6V lantern battery. The brand does not matter. Alkaline batteries last longer, but regular batteries are cheaper and will last long enough for this module. Alkaline batteries are available at local stores for about $5.00 and are usually located by the flashlights.
- **Electromagnet**—Available online [Web Link]
  If time allows, build the electromagnet. You can use the nails you removed from the electrical boxes and some magnet wire. Magnet wire is hard to strip, but any small (thin) wire will work. Ensure the wire is thin because it needs to be wrapped around the nail. You also need a razor and possibly a flame. To do a neat job, get some ¼-inch (or larger) steel nuts and bolts at the local hardware store and matching washers.



▲ Electromagnet example

Source: Purple Trail: Types of Magnets: http://www.purpletrail.com/partytrail/types-of-magnets/

Nails and salvaged wire can be used effectively, as well. Local electronic stores sometimes have sets of inexpensive magnet wire. Another option is to call someone who rewires motors or electronics; tell them you are a teacher, and ask for scraps.

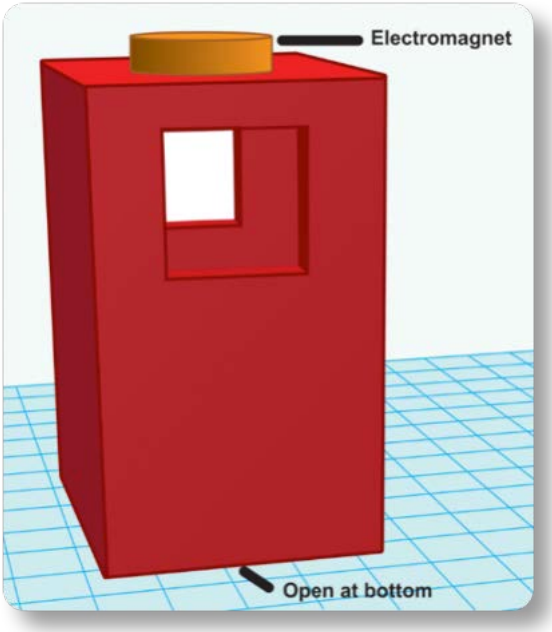
Several websites contain information about making your own electromagnets.

- Tin can lids

  Use one as an attach plate for the spaceship and another for the electromagnet, or connect the attach plate directly to the electromagnet.

- Drop box

  Use the largest box available. If possible, support the box on two chairs or other fixture to give the box some height. Use box cutters, scissors, and markers to decorate the box. Students might also want to use duct tape to attach the electronics and make the box stronger.



▲ Drop box example

- Capsule

  Many different materials can be used for the capsule. Ensure students have many opportunities to improvise. The simplest capsule would require a tin can lid and an egg in a plastic zip baggie. Hot glue or duct tape the lids to the inside of the Ziploc. Students can also pack the egg in the bag with extra shock-absorbent materials. A capsule could also be made out of an empty tissue box.

- Other items needed
  - Roll of electrical tape
  - Scissors for tape
  - Wire cutters
  - Wire strippers or razor or knife. Wire cutters can also be used for stripping. Place a finger inside the handle of the wire cutters to keep them from closing fully, create a

small gap in the cutter jaws, and pull the wire through it. Some wire cutters also have a wire stripper feature.

- If you use magnet wire, a razor or hobby knife and maybe some emery cloth is needed for stripping as the wire is hard to strip. A flame also works.

Soft Landing
Day 8: Feedback

Grade Level	Middle School
Lesson Length	50-minute lesson

Lesson Overview

In this lesson, students present their first draft apparatus to representatives from Soft Landing Systems (community volunteers) and receive important feedback from volunteers and classmates. As students present their apparatus, they must present an argument based on evidence for why their design is safe, cost-effective, and reliable. Students can use this feedback to make adjustments and improvements to their model prior to testing in the next lesson.

Connecting to the Next Generation Science Standards

On Day 8, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. These lessons serve as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Revisit the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in this module's front matter. In addition, students dive more deeply into the engineering design performance expectations interwoven throughout the module.

Basic Teacher Preparation

In today's lesson, students receive feedback from representatives from Soft Landing Systems and from their classmates. Recruit volunteer community members to serve as representatives from Soft Landing Systems. Train observers to ask probing questions while students are presenting.

Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All documents for this lesson can be found on pages 3–7 and 19–21 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (page 3)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Presentation Rubric (pages 19 and 20)
- Apparatus Feedback Reflection (page 21)

Required Preparation	Links/Additional Information
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources section at the end of this lesson
❑ Recruit community volunteers to serve as representatives from *Soft Landing Systems*	

Materials List

No additional materials are needed for this lesson.

Day 8: Feedback

Introduction (15 minutes)

Today, students present their apparatus to representatives from Soft Landing Systems (community volunteers) and their classmates. Students are expected to present an argument for why they believe their astronaut will survive and why the testing apparatus is safe, cost-effective, and reliable. All arguments should be grounded in evidence and should include some explanation of the science ideas involved.

After students present their arguments, their classmates and representatives from Soft Landing Systems provide feedback. Explain to the class that in engineering settings, engineers often get feedback from their teammates and other stakeholders to ensure they are creating high quality projects.

Allow students several minutes to prepare their arguments. Students should not need a great deal of time to prepare their arguments if they have adequately justified design decisions and revisions over the course of Days 5 through 7.

NGSS Key Moment

Presenting an argument for why students think their astronaut will survive and why they think their testing apparatus is safe, cost-effective, and reliable emphasizes the practice of Arguing from Evidence and the Structure and Function crosscutting concept in combination with the engineering DCI.

Design Work: Team Presentations (15 minutes)

In small groups or as a whole class (depending on the number of community volunteers and time constraints), have students present their arguments for why the astronaut will survive and why they believe their testing apparatus is safe, cost-effective, and reliable. Arguments should be grounded in evidence and should incorporate key science ideas. Consider having students and community partners use the presentation rubric on pages 19 and 20 in the Soft Landing Student Handbook to evaluate presenting groups.

After presenting, representatives from Soft Landing Systems (community volunteers) and classmates should ask probing questions and provide feedback.

Design Work: Revising the Apparatus (15 minutes)

Have the teams discuss the feedback they received. After teams receive feedback, they should complete the Apparatus Feedback Reflection on page 21 in the Soft Landing Student Handbook.

Instruct teams to start making any desired changes. Teams will have 10 minutes at the beginning of the next lesson to finish making any changes.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns.

Have students write a reflection in their science notebooks or on Day 8 in Student Reflections and New Questions. Possible questions to address include:

- *What was challenging about today?*
- *What are you going to do tonight to ensure your team is on track to be done by Day 9?*

Homework

Ask students to think about ways to modify their apparatus and how they plan to use their ideas to guide their team on Day 9.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Use the KLEWS Chart gather data to determine student progress.
- Listen to or record student presentations. Use the content of student presentations to gage student progress on core disciplinary ideas, science and engineering practices, and crosscutting concepts. Consider using the Presentation Rubric on pages 19 and 20 in the Soft Landing Student Handbook and in Appendix D.
- Use the Apparatus Feedback Reflection form on page 21 in the Soft Landing Student Handbook to monitor student reflections after feedback sessions.

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

This lesson relies heavily on community involvement. Invite community volunteers to serve as representatives from Soft Landing Systems. Community volunteers should be prepared to listen to student arguments, ask probing questions, and provide feedback.

Suggested Teacher Resources

KLEWS Chart	Ongoing from earlier lessons
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Presentation Rubric	Soft Landing Teacher Handbook, Appendix D

Soft Landing

Day 9: Let's Drop That Egg!

Grade Level	Middle School
Lesson Length	50-minute lesson

Lesson Overview

In this lesson, teams test the design and "builds" they have produced. The entire class serves as the audience as each team tests its apparatus.

Connecting to the Next Generation Science Standards

On Day 9, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire unit. These lessons serve as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Revisit the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in this module's front matter. In addition, students dive more deeply into the engineering design performance expectations interwoven throughout the module.

Basic Teacher Preparation

Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All documents for this lesson can be found on pages 3–7, 19, and 20 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (page 3)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Presentation Rubric (pages 19 and 20)

Required Preparation	Links/Additional Information
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

No new purchased or outside materials are necessary for this lesson.

Day 9: Let's Drop that Egg!

Introduction (10 minutes)

Refer students to the feedback they received. Provide 10 minutes for teams to make final revisions to their apparatus. If teams have already completed their revisions, allow them to use this time to practice their presentations.

Team Presentations and Tests (35 minutes)

Tell students they are going to present their work today. Each team should have 6 minutes to give their presentations. Their time should be structured as follows:

- 1 minute to introduce the team
- 3 minutes to introduce their apparatus (1 minute for each apparatus)
- 2 minutes to test the apparatus

Use the Soft Landing Design Problem Scoring Guide on pages 5 and 6 in the Soft Landing Student Handbook to evaluate students or have students evaluate each other.

Helpful Tip

If the time and space is available, have teams give their presentations and conduct their tests in front of a whole grade level or an invited audience. This enables more students to see the team projects and learn about the engineering design process and how it is used.

Consider using the Presentation Rubric on pages 19 and 20 in the Soft Landing Student Handbook and Appendix D.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns.

Students write in their science notebooks or on Day 9 of the Student Reflections and New Questions. Possible questions to address include:

- *What was challenging about today?*
- *What changes would you make if you had the chance to do everything again?*

Assessment

Student presentations and tests should serve as the assessment of student learning.

Ensure that the Soft Landing Scoring Guide is on display. Use the scoring guide to evaluate student design solutions. Students may evaluate their own design solutions or design solutions from other groups.

Also, consider using the Presentation Rubric on pages 19 and 20 in the Soft Landing Student Handbook and Appendix D. Have students self-rate their designs prior to the teacher evaluation. Using outside volunteers to score the projects makes the process more authentic. Whether the egg broke should have less weight than the justifications with evidence for design choices.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

A showcase celebration might be a rewarding extension. Invite engineers, designers, and entrepreneurs to visit your classroom to create an authentic audience experience.

Suggested Teacher Resources

KLEWS Chart	Ongoing from earlier lessons
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Presentation Rubric	Soft Landing Teacher Handbook, Appendix D

Soft Landing

Day 10: Report It Out!

Grade Level	Middle School
Lesson Length	50-minute lesson

Lesson Overview

On the final day of the unit, students summarize their relevant experiences and data in a written testing report for Soft Landing Systems. Consider adding an additional day to the module for students to present their Testing Reports to the class.

Connecting to the Next Generation Science Standards

On Day 10, students demonstrate understanding of the performance expectations and three dimensions developed throughout the module. These lessons serve as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Revisit the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in this module's front matter. In addition, students dive more deeply into the engineering design performance expectations.

Basic Teacher Preparation

Students use all of the data they collected as well as their testing experiences to create their summative presentations. Refer to the Soft Landing Student Handbook ahead of time so you can address any questions students might have. All documents for this lesson can be found on pages 3–7 and 22 in the Soft Landing Student Handbook. The documents used in this lesson are:

- Student Reflections and New Questions (page 3)
- Soft Landing Design Problem (pages 4–6)
- KLEWS Chart (page 7)
- Final Test Report (page 22)

Required Preparation	Links/Additional Information
❑ Review suggested teacher preparation resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

No new purchased or outside materials are necessary for this lesson.

Day 10: Report It Out!

Introduction (5 minutes)

Today, students create their test reports for Soft Landing Systems. The report should be written to Soft Landing Systems to justify their design decisions and to argue for the adoption of their capsule and tower design.

Students should use computers to complete this task. Student reports should include the following:

- Design Challenge with criteria, constraints, design trades, and budget
- Initial design and redesign(s)
- Science ideas informing the initial design and redesign(s)
- Recommendations for future designs to correct failure points and/or optimize the design
- A final argument to support the claim that the capsule will keep the astronaut safe and the testing apparatus is safe, reliable, and cost-effective.

A rubric for the Final Test Report can be found on page 22 in the Soft Landing Student Handbook and Appendix E. Students may want to use sentence stems found in Appendix B as prompts.

Spend time introducing the team report and answering questions.

Individual Work: Test Reports (30 minutes)

Students work individually on the team test reports. Prompt students to format their reports as formally as possible. Students should include data charts and references to blueprints.

Lesson Close (10 minutes)

Remind the class about the old saying that you should build things twice—once to learn how to build it and then the second time to build the version you want to use. Unfortunately, most projects do not have the time or budget to build things twice.

Explain to students that regardless of whether they are successful, engineers always document their results for many reasons, including:

- Stakeholders may require written documentation to consider the project complete.
- Future engineers can learn what was done and why, and use that information to improve the design the next time something similar is created.
- Engineers and technicians may need to understand the system in order to improve it, duplicate it, or repair it.

Inform students that some engineers may not enjoy having to copiously capture results, but it is very important to do so. Ask them to think about all of the documentation they have produced during this module (blueprints, test reports, and so forth). How hard would it be for a new group

of students to re-create their designs without having to ask questions? Could they do it without looking at the apparatus?

Even when a project fails, documenting it can be an important part of preventing others from having the same failure. For example, consider the amount of documentation surrounding the loss of the Challenger Space Shuttle. The Rogers Commission report, which contained details about what happened and what could be done to ensure it would not happen again. When the Shuttle Columbia was lost years later, there was another investigation and report.

Student Reflection (5 minutes)

Refer students to the growing KLEWS Chart, and ask them to add to any of the columns.

Students write in their science notebooks or on Day 10 of the Student Reflections and New Questions (page 3 in the Soft Landing Student Handbook). Possible questions to address include:

- *What was challenging about today?*
- *What changes would you make if you had the chance to do everything again?*

Have students place all handouts in their team folders.

Web Resources

- The Rogers Commission Report [Web Link]
- Shuttle Columbia Report [Web Link]

Assessment

Use the Final Test Report on page 22 in the Soft Landing Student Handbook or the Argument Rubric (Appendix E) as a summative assessment for the unit.

Reference Appendix B for suggestions for meeting the needs of all learners.

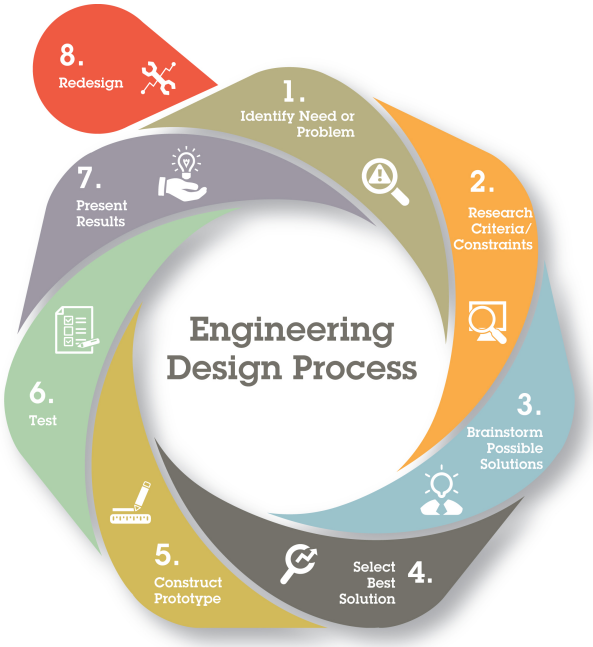
Community Connections

A showcase celebration might be a rewarding extension. Invite engineers, designers, and entrepreneurs to visit your classroom to create an authentic audience experience.

Suggested Teacher Resources

KLEWS Chart	Ongoing from earlier lessons
Meeting the Needs of All Learners	Soft Landing Teacher Handbook, Appendix B
Argument Scoring Guide	Soft Landing Teacher Handbook, Appendix E
The Rogers Commission Report	[Web Link]
Shuttle Columbia Report	[Web Link]

Appendix A
Engineering Design Process



Step 1 Identify the Need or Problem

Describe the engineering design challenge to be solved. Include the limits and constraints, customer description, and an explanation of why solving this challenge is important.

Step 2 Research Criteria and Constraints

Research how others have solved this or similar problems, and discover what materials have been used. Be sure to thoroughly research the limitations and design requirements for success.

Step 3 Brainstorm Possible Solutions

Use your knowledge and creativity to generate as many solutions as possible. During this brainstorming stage, do not reject any ideas.

Step 4 Select the Best Solution

Each team member presents their solution ideas to the team. Team members annotate how each solution does or does not meet each design requirement. The team then agrees on a solution, or combination of solutions, that best meets the design requirements.

Step 5 Construct a Prototype

Develop an operating version of the solution.

Step 6 Test

Test your solution. Annotate the results from each test to share with your team.

Step 7 Present Results

Present the results from each test to the team.

Step 8 Redesign

The design process involves multiple iterations and redesigns. Determine a redesign to address failure points and/or design improvements. Redesign is based on the data from your tests, your team discussions as to the next steps to improve the design, and the engineering design process Steps 1 through 7.

Once your team is confident of a prototype solution, you present the results to the client.

- The client may accept your solution as is, or
- The client may ask for additional constraints and criteria to be included in the solution. At this point, you and your team revisit the engineering design process and resume the iterative redesign cycle.

Appendix B
Meeting the Needs of All Learners

Every learner is unique. To meet the needs of all learners in your class, consider the following strategies:

- Provide students with sentence stems for models, arguments, and explanations (see below).
- Use a graphic organizer to help students organize their thinking prior to creating their final presentation (see below).
- Prior to each group discussion, engage students in individual or small group discussions to help them prepare to share their ideas in a larger group.
- Provide students with a vocabulary list using the Glossary.
- Offer additional extension problems or challenges in math or science.
- Provide students with additional time to formulate their ideas prior to sharing with the class.
- Offer opportunities for students to engage in additional investigations to extend learning. This may include additional readings, science investigations, or research.

Design Problem:
Science Ideas related to the Design Problem:
First Draft Design Solution: *Reflection/Modifications Needed:*
Second Draft Design Solution: *Reflection/Modifications Needed:*
Final Design Solution and Justification:

Sentence Stems

Contributed by Karl Muench, Collins Middle School, Salem, MA

Claim

You frame the question and answer it. This may take a sentence or a paragraph. Examples of claim sentences include the following.

- Analysis (breaking down the elements)
  - Our analysis looked at the parts and their function in …
  - We know from our data that … is comprised (made of) …, … and …
- Comparison (similarities and differences)
  - … (A) and … (B) are alike in that both …
  - However, while … (A) does this …, the other, … (B), does this …
- Evaluation (testing against a set of rules)
  - The … (subject of study) best matched the rule that …
  - In the situations involving …, the … (subject of study) showed …
- Problem/solution
  - … is a problem, and the best solution is …
  - Very often, … will have a problem with … The way to fix it is …
- Cause/Effect
  - … causes … to happen.
  - … is created when …
  - … if … then …

Give a preview of how you will prove your claim. Follow the above statements with the word ***because***.

Evidence

Include research and results of demonstrations or your own experimentation that support your claim. In science, you need to cite ALL available evidence, even some that may work against your claim. (You can deal with that issue by using reasoning.)

- Analysis
  - We conducted this experiment … The results are shown in the following table.
  - We graphed … over … and saw this pattern …
  - In most cases, we saw … Sometimes, however, … would happen.
  - We found the following analysis of this in our research … (direct quotes with sources)
- Comparison
  - We compiled the following T-chart showing where these things are alike and unalike.
  - In this Venn diagram, we can see where these things are similar and different.
  - In both cases, … is true. But only for ... is … true.
  - We have both things on this graph. You can see here … where they meet.
- Evaluation
  - We were looking for the following criteria … The following met those criteria … The following did not meet those criteria …
  - The rule … applies to the following … and does not work for …

- Scientists say … (quotation with source). We found this applied to ...

- Problem/Solution
  - These sources … point to this issue …
  - We tested our prototypes by … These were the results …
  - Experts such as … (sources) say … is a common problem.
  - … (source) emphasizes that … is a problem, with this possible solution ...

- Cause/Effect
  - Every time … happened, … would happen.
  - Scientists believe that … is caused by … (quote with source)
  - The following graph shows how … influences …
  - This chart shows when … happens (or is present) and what happens next.
  - Statistics indicate that ...

Reasoning

You need to explain in your own words how your evidence supports your claim. In the case of evidence that contradicts your claim, you must explain why other evidence has more merit or reliability.

- Analysis
  - The evidence supports our claim because …
  - The graph shows that as … rises, … rises/falls at a (steady or increasing) rate. This allows us to predict …
  - Taking the evidence as a whole shows …

- Comparison
  - These things behave similarly when … but differently when …
  - Considering these similarities and differences indicates …
  - Looking at the chart of evidence, we see how … is similar to …, but different in ...

- Evaluation
  - If … is true, we should see … This is exactly what we see in the case(s) of …
  - Every time (or almost every time) we tried this …, this happened …
  - ... did not meet our criteria as well as …, eliminating it as an option.

- Problem/Solution
  - As you can see, our test (or research) indicates this solution will solve the problem because …
  - Our research and testing found … can best solve this problem by …
  - We were looking for this … and found it in ...

- Cause/Effect
  - The evidence shows that … causes … because …
  - Looking at the data, we see that … followed … every time.
  - Our research shows that scientists support that … causes … because ...

- Dealing with contrary evidence
  - By looking at all of this, we can see that these data … are outliers.
  - While some scientists say …, most scientists agree that …
  - Some of our results are less reliable because ...

Appendix C
Fishbowl Discussion Rubric

Observer name: _____ Partner name: _____ Date: _____

Discussion subject: _____

Directions: Make a tally mark each time your partner demonstrates one of the following.

1. **Speaks** constructively in the discussion.
2. **Adds** to and advances an **interpretation** or **analysis** of the problem.
3. Provides **evidence** for claims.
4. **Interrupts** or cuts off another speaker without acknowledgment.

Directions: After the discussion, answer these questions.

What is the most interesting statement made by your partner? Why?

Directions: After the discussion, count the marks above to evaluate your partner's performance.

	4: Exceeds Expectations	3: Meets Expectations	2: Nearly There	1: Not Yet
Speaks	more than 5 times	4 times	4 times	3 times or less
Asks Questions	more than 3 times	3 times	3 time	1 time or less
Provides Evidence	more than 3 times	3 times	2 times	1 time or less

Total: _____ /10 points

Total interruptions _____

Appendix D
Presentation Rubric

The Presentation Rubric is intended to be used as a guide for the development of the assessment for the final presentations. Teachers should tailor the rubric to fit the specific needs of the module and the design problem.

Science and Innovation
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PRESENTATION RUBRIC

	No Evidence	Beginning	Developing	Advanced
Quality of Design Product NOTE: This section should be tailored to assess specific module and performance expectations.	Design product fails to address most aspects of the performance task. Design product shows no evidence of thoughtful problem solving. Design product shows evidence of low-quality craftsmanship.	Design product addresses some aspects of the performance task. Design product shows little evidence of thoughtful problem solving. Design product shows evidence of mediocre-quality craftsmanship.	Design product addresses most aspects of the performance task. Design product shows some evidence of thoughtful problem solving. Design product shows evidence of mostly high-quality craftsmanship.	Design product addresses all aspects of the performance task. Design product shows clear evidence of thoughtful problem solving, deliberation, and decision making. Design product shows clear evidence of high-quality craftsmanship.
Explanation of Science Ideas Science ideas include science and engineering practices, disciplinary core ideas, and crosscutting concepts. NOTE: This section should be tailored to assess specific module and performance expectations.	Relevant science ideas are not addressed. Evidence is not cited.	Most relevant science ideas are stated and partially described in relation to the design problem. Some evidence is cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are stated and described in relation to the design problem. Several lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are clearly stated and described in detail in relation to the design problem. Multiple lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.
Organization	The presentation does not include all of the required components. The presentation does not have a main idea or presents ideas in an	The presentation includes most of the required components. The presentation moves from one idea to the next, but the main idea may not be clear or some ideas	The presentation includes all of the required components. The main idea is clearly stated. The presentation moves from one idea to the next in a logical order,	The presentation includes all of the required components and either provides additional information for each component or adds additional

	order that does not make sense.	may be in the wrong order.	emphasizing main points in a focused, coherent manner.	components relevant to the presentation. The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing the main points in a focused, coherent manner. (CC 6-8. SL.4)
Presenting Skills	The presenter does not look at the audience and reads notes or slides. The presenter wears clothing inappropriate for the occasion. The presenter mumbles or speaks too quickly or slowly. The presenter speaks too softly to be understood.	The presenter makes infrequent eye contact and reads notes or slides most of the time. The presenter dresses professionally. The presenter speaks clearly most of the time, although sometimes too quickly or slowly. The presenter speaks loudly enough for most of the audience to hear, but may speak in a monotone.	The presenter keeps eye contact with audience most of the time and only glances at notes or slides. The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)	The presenter engages the audience by drawing their sustained attention. The presenter maintains eye contact with the audience most of the time and only glances at notes or slides. (CC 6-8.SL.4) The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)

Appendix E
Argument Scoring Guide

Aspect of the Argument	Point Value 0	1	Comments or Suggestions
Identify role, audience, and task (1)			
Accurately complete task		X2	
Claim			
The claim is sufficient.			
The claim is accurate.			
Evidence			
Includes data/research			
Includes an analysis of the data/research			
Includes an interpretation of the analysis			
Reasoning: Justification of the Evidence			
Explains why each piece of evidence is important/relevant			
Links the evidence to a scientific concept or principle			
Identifies a line of logic or values that define success			
Reasoning: The Challenge			
Alternative explanation(s) explained clearly			
Demonstrates why the alternative explanation is inaccurate			
Mechanics			
Order and arrangement of sentences enhances argument			
Appropriate word usage, spelling, grammar, and punctuation			
Total Score		/15	

Adapted from: Sampson, Victor, and Sharon Schleigh. *Scientific Argumentation in Biology*. Arlington, VA: NSTA, 2013

Glossary

The key terms below are frequently used in the module. Students should develop a strong conceptual understanding of each term throughout the module. Definitions from dictionary.com unless otherwise noted.

blueprint	A design plan or other technical drawing.*
circuit	A path between two or more points along which an electrical current is carried.*
electromagnet	A device consisting of an iron or steel core that is magnetized by an electric current in a coil that surrounds it.
engineer	A person trained and skilled in the design, construction, and use of engines or machines, or in any of various branches of engineering.
engineering	The action, work, or profession of an engineer.
force	A push or pull on an object resulting from the object's interaction with another object.**
kinetic energy	The energy of motion. An object that has motion—whether it is vertical or horizontal—has kinetic energy.**
optimize	To make as effective, perfect, or useful as possible.
power source	A device that provides power to electric machines. Examples of power sources include a generator or a power outlet.*
prototype	The original or model on which something is based or formed.
schematic	A diagram, plan, or drawing.
switch	A device for turning on or off, or directing an electric current, or for making or breaking a circuit.

**Definition developed by module authors.*
***Definition from physicsclassroom.com.*