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.

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**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.

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**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.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
<th>Connections to Classroom Activity</th>
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</thead>
<tbody>
<tr>
<td><strong>Science and Engineering Practices</strong></td>
<td><strong>Asking Questions and Defining Problems</strong></td>
<td>Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.</td>
</tr>
<tr>
<td></td>
<td><strong>Developing and Using Models</strong></td>
<td>Develop a model to generate data to test ideas about design systems, including those representing inputs and outputs.</td>
</tr>
<tr>
<td></td>
<td><strong>Constructing Explanations and Designing Solutions</strong></td>
<td>Apply scientific ideas or principles to design an object, tool, process, or system.</td>
</tr>
<tr>
<td></td>
<td><strong>Engaging in Argument from Evidence</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Disciplinary Core Ideas</strong></td>
<td><strong>ETS1.B: Developing Possible Solutions</strong></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td><strong>PS2.A: Forces and Motion</strong></td>
<td>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).</td>
</tr>
<tr>
<td></td>
<td><strong>PS2.B: Types of Interactions</strong></td>
<td>Electrical and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of...</td>
</tr>
</tbody>
</table>
the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.

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

- Gather or purchase the required materials for the lesson
- Review suggested teacher preparation resources

Links/Additional Information

- Refer to the Materials List that follows
- Refer to the Suggested Teacher Resources at the end of this lesson
## Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soft Landing Student Handbook</strong></td>
<td>Download, print, and copy for students to use throughout the module</td>
<td>1 per student</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Chart paper or graph paper</td>
<td>Chart paper can be used as an alternative to the student handbook to draw blueprints</td>
<td>Plenty for every group</td>
<td>Available at most schools</td>
</tr>
<tr>
<td>Cardboard boxes</td>
<td>The larger, the better</td>
<td>Many per class or team</td>
<td>Bring from home or grocery store</td>
</tr>
<tr>
<td>Eggs</td>
<td></td>
<td>1 per group</td>
<td>Grocery store</td>
</tr>
<tr>
<td>Tin snips (optional)</td>
<td></td>
<td>1 per group</td>
<td>Tin snips [Web Link]</td>
</tr>
<tr>
<td>Scissors</td>
<td></td>
<td>1 per group</td>
<td>Available at most schools</td>
</tr>
<tr>
<td>Box cutters</td>
<td>Make sure only the teacher or adult assistant has access to these</td>
<td>1 per teacher</td>
<td>Hardware store</td>
</tr>
<tr>
<td>Switches</td>
<td>Purchase or make switches using nails, wire, strips cut from cans, paper clips, and so forth</td>
<td>1 per group</td>
<td>Can be recycled from previous lessons</td>
</tr>
<tr>
<td>Battery/source</td>
<td>A 6V lantern battery works well</td>
<td>1 per group</td>
<td>Battery [Web Link]</td>
</tr>
<tr>
<td>Alligator clips</td>
<td>To attach to the terminals</td>
<td>1 per group</td>
<td>Clips [Web Link]</td>
</tr>
<tr>
<td>Electromagnets</td>
<td>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)</td>
<td>1 per group</td>
<td>Can be recycled from previous lessons</td>
</tr>
<tr>
<td>Wire</td>
<td>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</td>
<td>1 roll per group</td>
<td>Can be recycled from previous lessons</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Quantity/Source</td>
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<tr>
<td>Glue</td>
<td>6 bottles per class Available in most schools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newspaper</td>
<td>Many Brings from home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic zip bags</td>
<td>If using for entire spacecraft, suggest a larger bag. If just using it for the inner egg holder, a smaller bag can be used.</td>
<td>1 box per class Grocery store</td>
<td></td>
</tr>
<tr>
<td>Hot glue gun</td>
<td>May not need this if you are using duct tape and regular glue</td>
<td>1 per group Office supply or craft store</td>
<td></td>
</tr>
<tr>
<td>Glue sticks for hot glue gun</td>
<td>If using a hot glue gun</td>
<td>1 bag per group Office supply or craft store</td>
<td></td>
</tr>
<tr>
<td>Plain white paper</td>
<td>Needed for blueprint work</td>
<td>1 sheet per student Available in most schools</td>
<td></td>
</tr>
<tr>
<td>Wire cutters/strippers</td>
<td>Purchase a pair of diagonal cutters suitable for the wire being used</td>
<td>1 per group or class Wire cutters [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Wire nuts</td>
<td>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.</td>
<td>2-6 per group Wire nuts [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Electrical tape (optional)</td>
<td>Handy for wrapping connections</td>
<td>1 roll per group Hardware store, or bring from home</td>
<td></td>
</tr>
<tr>
<td>Duct tape (optional)</td>
<td>Useful for sticking things together. May substitute masking tape.</td>
<td>1 roll per group Hardware store, or bring from home</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous tools and supplies</td>
<td>Depending on switches, batteries, and electromagnets used, you may need screwdrivers, battery holders, and other similar items to facilitate building.</td>
<td>As needed for sharing Hardware store, or bring from home</td>
<td></td>
</tr>
</tbody>
</table>
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/s²) 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.

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.

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 through 3 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.

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.

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.
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.

**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.
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?
**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**

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<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Soft Landing Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Landing Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>KLEWS Chart</td>
<td>Ongoing from earlier lessons</td>
</tr>
<tr>
<td>Blueprint Examples</td>
<td>[Web Link]</td>
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</table>