Science and Innovation
A Boeing/Teaching Channel Partnership

BOLT CATCHER
Teacher Handbook
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.
Bolt Catcher

Background and Overview

In Bolt Catcher, students explore energy, motion, and engineering design as they work to create a bolt catcher—a device used to absorb energy from bolts during the separation of a space shuttle from booster rockets. In this design challenge, students design a model of a bolt catcher by attaching a box to a moving object and modifying the inside of the box so it can efficiently absorb impact while minimizing the distance the device travels during its rebound. Throughout the design challenge, students engage in the engineering design process and develop an understanding of key science ideas related to speed, energy, and transfer of energy during collisions.

Module Overview

Bolt Catcher kicks off with an optional mini-project in which students investigate the role of engineers (Days 1 and 2).

On Days 3 and 4, students are introduced to the design challenge and consider the technology of a bolt catcher. Students learn how a rocket separates from a crew capsule during a shuttle launch.

Students model what happens when the rocket and crew capsule separate.

After learning that a pyrotechnic explosion separates the bolts keeping the booster rockets and the space shuttle attached, students model how a bolt catcher absorbs the energy from the impact of the bolt on the crew capsule.

Students are challenged to design their own bolt catcher to absorb energy on impact. In the classroom, a model of the bolt catcher is built using a skateboard and a tissue box. A lead sinker (or rubber ball) is fired at the tissue box. The distance the skateboard travels depends on the amount of energy absorbed by the bolt catcher.

On Day 5, students develop blueprints for their bolt catcher, and on Day 6, students model the hypothesized energy transfer using their blueprints. Students revise their models according to the hypothesized energy transfers.

On Days 6 through 9, students iteratively test their design solutions. Finally, on Day 10, students present their work and the science ideas behind their decisions.
Engineering Design in the Module

The design challenge of creating a bolt catcher is intended to help students understand the transfer of energy when objects collide. The core project will also help students learn the importance of force and motion in aerospace science. Along with the science concepts and design challenge, this module also affords students an opportunity to learn more about engineering careers, including work and design processes, various fields of engineering, and the necessary interests, aptitudes, and programs of study for engineers.

Sequencing

Bolt Catcher is intended as a 4th-grade engineering and physical science module. This module was designed to help students make progress on four performance expectations: 3-5-ETS1-2, 3-5-ETS1-3, 4-PS3-1, 4-PS3-3. The performance expectations address the engineering design process, energy, speed, and energy transfer.

Bolt Catcher is most appropriately placed at the beginning of the study of energy as students are beginning to understand the connection between speed and energy. Students should have already mastered the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts included in kindergarten Physical Science and Engineering Design.

- Students should have mastered K-PS2-2, which relates to the idea that when objects collide, they push on one another and can change motion. Ideally, students should already have had some exposure to 4-PS3-1, and should begin to understand the relationship between speed and energy, but it is not necessary for students to have fully developed this idea.
- Beyond the Physical Science performance expectations, students should have already demonstrated deep conceptual understanding for all of the K-2 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: Constructing Explanations and Designing Solutions and Developing and Using Models.
- Students should also have made grade-appropriate progress on the following crosscutting concepts: Influence of Engineering, Technology, and Science on Society and the Natural World, and Energy and Matter.

Performance Expectations

- 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- 4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.
- 4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.
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 module were selected to align with the Next Generation Science Standards. In classrooms using local or state standards, this module may fall within a different grade band and may address different standards. Teachers should adapt this module to meet local and state needs.

Furthermore, teachers should adapt the module 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:**

- **3-5-ETS1-2.** Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

- **3-5-ETS1-3.** Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

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

- **4-PS3-1.** Use evidence to construct an explanation relating the speed of an object to the energy of that object.

- **4-PS3-3.** Ask questions and predict outcomes about the changes in energy that occur when objects collide.

### Dimension | NGSS Elements
--- | ---
**Science and Engineering Practices** | **Constructing Explanations and Designing Solutions**
- Use evidence (e.g., measurements, observations, patterns) to construct an explanation.
- Apply scientific ideas to solve design problems.
**Developing and Using Models**
- Develop and use a model to describe phenomena.
**Disciplinary Core Ideas** | **ETS1.B: Developing Possible Solutions**
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.
- Tests are often design to identify failure points or difficulties, which suggest the elements of the design that need to be improved.
### ETS1.C: Optimizing the Design Solution
- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.

### PS3.A: Definitions of Energy
- The faster a given object is moving; the more energy it possesses.
- Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.

### PS3.B: Conservation of Energy and Energy Transfer
- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.

### PS3.C: Relationship Between Energy and Forces
- When objects collide, the contact forces transfer energy so as to change the objects’ motions.

### Crosscutting Concepts

#### Influence of Science, Engineering, and Technology on Society and the Natural World
- People’s needs and wants change over time, as do their demands for new and improved technologies.
- Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.

#### Energy and Matter
- Energy can be transferred in various ways and between objects.
In addition to connecting to the *Next Generation Science Standards*, this module can support student growth in multiple *Common Core State Standards*. This module can be easily adapted to support growth in the following standards:

**English Language Arts**

- **CCSS.ELA-Literacy.RI.4.2**: Determine the main idea of a text and explain how it is supported by key details; summarize the text.
- **CCSS.ELA-Literacy.RI.4.4**: Determine the meaning of general academic and domain-specific words or phrases in a text relevant to a *grade 4 topic or subject area*.
- **CCSS.ELA-Literacy.RI.4.6**: Compare and contrast a firsthand and secondhand account of the same event or topic; describe the differences in focus and the information provided.
- **CCSS.ELA-Literacy.RI.4.9**: Integrate information from two texts on the same topic in order to write or speak about the subject knowledgeably.
- **CCSS.ELA-Literacy.SL.4.4**: Report on a topic or text, tell a story, or recount an experience in an organized manner, using appropriate facts and relevant, descriptive details to support main ideas or themes; speak clearly at an understandable pace.

**Mathematics**

- **CCSS.MATH.Content.4.MD.A.1**: Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit. Record measurement equivalents in a two-column table. For example, know that 1 ft is 12 times as long as 1 in. Express the length of a 4 ft snake as 48 in. Generate a conversion table for feet and inches listing the number pairs (1, 12), (2, 24), (3, 36),...
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 design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?

- **What Students Are Doing**
  - Students investigate engineering careers and meet with a visiting engineer.
  - Students model a separation event to explain why a shuttle isn’t damaged during the event.
  - Students design blueprints for their bolt catchers and model the energy transfers that occur in their bolt catchers.
  - Students build and revise bolt catchers.

- **What Students Figure Out**
  - Engineering is a profession that encompasses many different types of work. Engineers solve problems.
  - Bolt catchers absorb energy from a moving bolt that gained energy from an explosion, so the crew capsule is unharmed during a separation event.
  - Bolt catchers slow down the lead sinker by absorbing energy from the lead sinker.
  - Engineering is an iterative process that requires engineers to continually reference science ideas related to the design problem.
Bolt Catcher

Days 1 and 2: What Is Engineering? (Optional)

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Grade 4</th>
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</thead>
<tbody>
<tr>
<td>Lesson Length</td>
<td>Two 50-minute sessions</td>
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</tbody>
</table>

Lesson Overview

In these optional opening days, students research various engineering careers and present their findings to their classmates. They learn about the field of engineering and how engineers begin the process of designing and creating new products. Students also learn that engineering plays an integral role in our daily lives. In an optional extension, students gain firsthand knowledge from actual engineers about their field of work.

Days 1 and 2 are designed to allow for the integration of Common Core State Standards into the module. After learning about engineers on Days 1 and 2, students engage in science and engineering practices to solve the design problem presented on Days 3 through 10.

Connecting to the Common Core State Standards

The central focus of Days 1 and 2 is to help students make progress on the key Common Core State Standards in English Language Arts listed below. The lesson should be modified according to each teacher’s needs to meet one or two key Common Core State Standards for English Language Arts.

Connections to the Common Core State Standards

Days 1 and 2 can be easily adapted to support student growth in one or more of the following Common Core State Standards for English Language Arts:

- **CCSS.ELA-Literacy.RI.4.2**: Determine the main idea of a text and explain how it is supported by key details; summarize the text.
- **CCSS.ELA-Literacy.RI.4.4**: Determine the meaning of general academic and domain-specific words or phrases in a text relevant to a grade 4 topic or subject area.
- **CCSS.ELA-Literacy.RI.4.6**: Compare and contrast a firsthand and secondhand account of the same event or topic; describe the differences in focus and the information provided.
- **CCSS.ELA-Literacy.RI.4.9**: Integrate information from two texts on the same topic in order to write or speak about the subject knowledgeably.
- **CCSS.ELA-Literacy.SL.4.4**: Report on a topic or text, tell a story, or recount an experience in an organized manner, using appropriate facts and relevant, descriptive details to support main ideas or themes; speak clearly at an understandable pace.
Basic Teacher Preparation

Divide students into design teams of no more than four students per team. These design teams can be students’ teams for the duration of the project.

Present each team with a packet containing a Presentation Rubric (Appendix C), a piece of poster board, research materials (such as books, Internet sources, and so forth), and journals, which are used throughout the project.

Present a list of various types of engineers to the whole group. Each team picks a type of engineering to research.

This lesson requires students and teams to do research (preferably online), so access to a computer lab, cart, or laptop computers should be arranged ahead of time.

Ideally, on Day 2, students have the opportunity to engage in a conversation with an engineer invited to visit the classroom. In most communities, engineers are willing to come and discuss their work and the work of other engineers. The intent is for students to understand what engineers do and how they spend their days. Students should also understand the training necessary to work in such fields and the various types of engineering career paths found in most regions. If audio-visual tools (computer, overhead projector, and so forth) are needed for the engineer’s presentation, be sure to set them up ahead of time.

Required Preparation

<table>
<thead>
<tr>
<th>Required Preparation</th>
<th>Links/Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Gather or purchase all required materials for the lesson</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>☐ Ensure that technology is available to project information from the recommended websites, or print and copy useful copies for students to place in their notebooks</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson</td>
</tr>
<tr>
<td>☐ Make arrangements to have an engineer prepare and give a presentation to the class</td>
<td></td>
</tr>
</tbody>
</table>

Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science journal</td>
<td>Can be bound notebook paper or a spiral notebook</td>
<td>1 per student</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Poster board</td>
<td></td>
<td>1 per team</td>
<td>Available in most schools or at craft stores</td>
</tr>
</tbody>
</table>
Day 1: What Is Engineering?

**Introduction (5 minutes)**

Introduce students to the overall topic of engineering. Ask pairs of students to use a Know/Need to Know (N2K) chart about engineering.

<table>
<thead>
<tr>
<th>Know...</th>
<th>Need to know...</th>
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<tbody>
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</table>

Give students several minutes to complete their Know/Need to Know chart, and then have students share their ideas with the whole class.

**Mini-Lesson: What Is Engineering? (10 minutes)**

Show the class one or both of the identified videos—NASA for Kids: Intro to Engineering and Celebrating Engineering at Boeing. Briefly discuss the videos, and, based on the information gleaned from them, ask students to add to the N2K chart.

Inform students that they are using the next two class periods to complete a mini-research project about the field of engineering and the various types of engineers. Review several types of engineers including:

- Aerospace engineer
- Chemical engineer
- Civil engineer
- Electrical engineer
- Mechanical engineer
- Computer Science engineer

**Research Directions**

Allow teams to choose the engineering career they want to learn more about. Alternatively, teams can draw from a cup, or engineering careers can be assigned to teams.

Each team researches its engineering career and selects the most valuable notes and information. At a minimum, students need to provide a clear description of the type of work their engineers do and explain the education or training needed. Encourage students to include several examples and to highlight the information they find most interesting.

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**Video Links**

- NASA for Kids: Intro to Engineering [Web Link]
- Celebrating Engineering at Boeing [Web Link]

**Web Resources**

- Engineering Go for It [Web Link]
- Engineering Is... [Web Link]
- PBS Engineering Videos [Web Link]
- Engineer Girl [Web Link]
- Try Engineering [Web Link]
- Turtle Diary [Web Link]
- Encyclopedia Britannica [Web Link]
- BrainPOP [Web Link]
Each team creates a brief 5-minute oral presentation summarizing their findings. Each member of the team should have a role in the presentation. Each team should create a related visual for their presentation on poster board.

Presentations are scored using the Presentation Rubric (Appendix C). Review the rubric when giving directions.

Mini-Lesson: Team Research (30 minutes)

Provide the teams with a starter list of possible research sites. (See the Suggested Teacher Resources at the end of Day 2.) However, you can also add to this list with materials from your school library or other websites you identify. Additionally, teams should be encouraged to do their own online research.

Teams work together to review sources, take notes, and organize information for their presentations.

Lesson Close (5 minutes)

Instruct teams to review the remaining tasks to prepare for their presentations in the next lesson. Assign homework tasks for members of the team as needed.
Day 2: What Is Engineering?

**Introduction (5 minutes)**

Allow each team to assemble their materials and make any last-minute preparations for their presentations.

**Whole Group Discussion: Team Presentations (20 minutes)**

Have teams take turns giving their 5-minute presentations. Allow some time at the end for questions from the teacher and class. Use the Presentation Rubric (Appendix C) during and after each presentation.

**Whole Group Discussion: A Conversation with an Engineer (20 minutes)**

Introduce the guest speakers, and explain that they will be sharing information about the engineering field with the class.

The invited guests should give brief presentations focusing on their work life, education and training, and descriptions of typical work projects. If possible, the invited guests should try to connect their presentations to the engineering disciplinary core ideas.

**CCSS Key Moment**

If you are able to find invited guests, have students compare what they learned from a primary source (an invited guest) and a secondary source (their research), which will help them make progress on CCSS.ELA-Literacy.RI.4.6.

**Lesson Close (5 Minutes)**

Ask each student to write a brief reflection in their science notebooks. They should list their most important observations and any questions they have about engineering.

**Assessment**

Several opportunities for formative assessment exist in this lesson:

- The mini presentations are a synthesizing activity and assessment artifact showing student understanding.
- Consider gathering evidence of student progress through small group and whole group discussions.
- Student contributions to the Know/Need to Know chart can be monitored.
Students’ reflections in their science notebooks should be regularly reviewed to inform instructional decisions.

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**

Encourage students to embed any information they can find about local or regional engineers into their mini-presentations. The opportunity to bring a working engineer into the classroom ties the lesson back to authentic work in the community.

**Suggested Teacher Resources**

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Bolt Catcher Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation Rubric</td>
<td>Bolt Catcher Teacher Handbook, Appendix C</td>
</tr>
<tr>
<td>NASA for Kids: Intro to Engineering (video)</td>
<td>[Web Link]</td>
</tr>
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<td>Celebrating Engineering at Boeing (video)</td>
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Lesson Overview

During this introductory lesson, students are introduced to the design problem. They learn that space shuttles need to have bolt catchers to absorb the energy transferred to the space shuttle when the space shuttle separates from the booster. Students work to clearly define the design problem by exploring the use of bolt catchers in space shuttles. Students develop and revise models to explain the energy and motion involved in the separation event. As students develop and revise models, they begin to connect the energy of an object to the speed of an object. Students also begin to develop the idea that energy can be transferred between objects during a collision.

Connecting to the Next Generation Science Standards

On Days 3 and 4, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices**: Constructing Explanations and Designing Solutions, Developing and Using Models
- **Crosscutting Concepts**: Influence of Science, Engineering, and Technology on Society and the Natural World, Energy and Matter

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:

- **4-PS3-1**. Use evidence to *construct an explanation relating the speed of an object to the energy of that object.*
- **4-PS3-3**. Ask questions and predict outcomes about the changes in energy that occur when objects collide.

**Specific Connections to Classroom Activity**

In this lesson, students make sense of and model the separation of a space shuttle and rocket boosters. The separation event involves a pyrotechnic device that separates the bolts holding the shuttle and the boosters together. A bolt catcher absorbs the energy transferred from the explosion to the bolt before the bolt damages the space shuttle. As students figure out what happens during a separation event and model the event, they begin to connect the speed of the bolt and the energy of the bolt. For instance, when the bolt catcher absorbs...
the energy from the bolt, the bolt slows down. In addition, students consider the collision between the bolt and the bolt catcher as compared to the potential collision between the bolt and the shuttle. Students ask questions and predict outcomes about the changes in energy during these collisions.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Elements</th>
<th>Connections to Classroom Activity</th>
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<tbody>
<tr>
<td>Science and Engineering Practices</td>
<td>Constructing Explanations and Designing Solutions</td>
<td>Before students know what a bolt catcher does, they wonder why the bolt pushing against the space shuttle doesn’t damage the space shuttle. Students work to construct an explanation for this phenomenon. Students create and revise models to describe different components of the separation event.</td>
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<tr>
<td></td>
<td>Developing and Using Models</td>
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<td></td>
<td>• Use evidence (e.g., measurements, observations, patterns) to construct an explanation</td>
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<td>• Develop and use a model to describe phenomena</td>
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<td>Disciplinary Core Ideas</td>
<td>PS3.A: Definitions of Energy</td>
<td>As students consider the separation event, they begin to connect the speed of an object to the energy it possesses. Students begin to form the idea that a bolt catcher absorbs energy and slows the bolt down. This is an example of energy moving from place to place by moving objects. When students are first introduced to the bolt catcher, they work with the idea that the energy from the moving bolt is transferred to the bolt catcher, slowing down the bolt.</td>
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<td>PS3.B: Conservation of Energy and Energy Transfer</td>
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<td>• When objects collide, the contact forces transfer energy so as to change the objects’ motions.</td>
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<tr>
<td>Crosscutting Concepts</td>
<td>Influence of Science, Engineering, and Technology on Society and the Natural World</td>
<td>Students are exposed to new and improved technologies, such as bolt catchers, that keep astronauts and space shuttles safe. Students also figure out that engineers must work to design technologies such as the bolt catcher as advances are made in space travel. In this lesson, students work with the idea of energy transfer between the pyrotechnic device, the bolt, and the bolt catcher.</td>
</tr>
<tr>
<td></td>
<td>• Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.</td>
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<td>Energy and Matter</td>
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<td></td>
<td>• Energy can be transferred in various ways and between objects.</td>
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</tbody>
</table>
Basic Teacher Preparation

Divide students into teams of no more than 4. This should be their team for the duration of the project.

Review the video links and Suggested Teacher Resources ahead of time. Review the Talk Science Primer and the NASA SRB Article to prepare to lead the whole class consensus discussion.

Acquire the materials for the bolt catcher prototype and create the testing apparatus ahead of time. More information can be found in the Suggested Teacher Resources at the end of this lesson.

<table>
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<tr>
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<td>Gather or purchase all required materials for the lesson</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>Review the recommended videos and ensure technology is available to project the recommended videos</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson</td>
</tr>
<tr>
<td>Review the Background Information for Bolt Catcher Apparatus</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson</td>
</tr>
<tr>
<td>Prepare a bolt catcher testing apparatus prior to class</td>
<td>Refer to the Materials List for this lesson and the Suggested Teacher Resources at the end of this lesson</td>
</tr>
</tbody>
</table>

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<td>1 per student</td>
<td>Available in most schools</td>
</tr>
</tbody>
</table>
| Bolt catcher testing apparatus | • Tissue box  
• Duct or masking tape  
• Hammer and nails | 1 set per team | Tissue boxes, duct or masking tape, and hammer and nails can be brought from home, or available at school. |
<p>| Skateboard | | 1 set per team | Skateboard can be brought from home, or buy online [Web Link] |
| Rubber tubing for slingshot | | 1 set per team | [Web Link] |
| 3-oz fish sinker or small rubber ball | | 1 set per team | [Web Link 1] [Web Link 2] |</p>
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustable clamps</td>
<td>1 set per team</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Concrete blocks</td>
<td>1 set per team</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>2 ft. x 4 ft. piece of plywood</td>
<td>1 set per team</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Wood wedge</td>
<td>1 set per team</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Bubble wrap</td>
<td>1 small sheet per team</td>
<td>Available at local stores or online [Web Link]</td>
</tr>
<tr>
<td>Butcher paper</td>
<td>1 small sheet per team</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Large marbles</td>
<td>1 per team</td>
<td>Available at local stores or online [Web Link]</td>
</tr>
<tr>
<td>Flower foam</td>
<td>Half block per team</td>
<td>Available at local stores or online [Web Link]</td>
</tr>
<tr>
<td></td>
<td>You may use either the wet or the dry flower foam. The foam should easily change shape when pressed.</td>
<td></td>
</tr>
</tbody>
</table>
Day 3: Why Space Shuttles Need Bolt Catchers

Introduction (10 Minutes)

Begin by explaining to students that they are assuming the roles of engineers who have been asked to design a bolt catcher to catch the bolts that help a space shuttle separate from the booster rocket.

Introduce students to the Driving Question for this module, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?* Post the Driving Question so all students can see it throughout the module.

Tell students that they will work through the engineering design process as they design bolt catchers. Review the *Engineering Design Process (Appendix A)*. Tell students that their first task as an engineer is to clearly define the engineering design problem.

At this point, students may not be familiar with bolt catchers or crew capsule/rocket separation events. Encourage students to record a list of questions that may help them become more familiar with the engineering design problem. Start by developing one question as a class and then have students work in small groups to develop the remaining questions.

Questions might include:

- *What are bolt catchers?*
- *Why does the crew capsule need to separate from a rocket?*
- *How do bolts help with the separation event?*

Mini-Lesson: How Space Shuttles Are Launched (10 minutes)

Explain that in many real-life situations or in the development of new products, minimizing the force of impact is important. For example, when riding a bicycle, individuals should wear a helmet to minimize the force of impact on their head if they were to fall. Cars include multiple safety devices to minimize the force of impact during a crash. Ask students to think about other situations in which it is necessary to reduce the force of impact. Have students share their ideas.

Explain that space shuttle engineers also need to design technologies to reduce the force of impact.
Show students the videos of rocket and crew capsule separation events. The video clips are long, so preview the videos to capture key moments (the separation event).

In the CST-100 video, point out that the crew capsule can transport a crew to the International Space Station (crew capsule travel at 0:52). Highlight the key moment when the crew capsule separates from the rocket in the SpaceX video (16:20) and the Pyrotechnics video (6:08).

In each video, have students identify the crew capsule and rocket. Tell students that the booster rockets (Solid Rocket Boosters—SRBs) give the space shuttle the extra thrust it needs to leave Earth. After doing their job, the rockets are dropped to reduce weight.

Ask students to think about how they think the crew capsule separates from the rocket. Specifically reference the “zoomed in” video of the attachment between the rocket and the crew capsule in the Pyrotechnics video. Give students several minutes to share their ideas in small groups.

Prompt students to generate an initial model in their science notebooks showing how the rockets detach from the space shuttle. Students may use pictures, words, or diagrams in their model.

Whole Class Discussion: How Rocket Boosters Detach from a Shuttle (10 minutes)

Gather students in a Scientists Circle. Remind students that their goal is to develop a model to explain how booster rockets detach from a space shuttle. The goal of the whole class discussion is to come to a class consensus model about how the rockets detach. During the discussion, encourage students to share, challenge, and revise their ideas. By the end of the discussion, students should figure out that something on the rocket or the crew capsule breaks the attachment between the rocket and the crew capsule so the rockets can fall away.

Video Links

- CST-100 (0:52 Crew Capsule travel) [YouTube Link]
- SpaceX Pad Abort (16:00 pad abort, 16:20 separation event) [YouTube Link]
- Pyrotechnics and Deltas4 (1:16 ground test, 6:08 delta4 separation event) [YouTube Link]


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. Refer to the Talk Science Primer for useful strategies.
Explain to students that there is, in fact, a device that breaks the attachment. Show students the picture of the bolt catcher below. Explain that after approximately 2 minutes of flight, a pyrotechnic device fires (or explodes) to break the bolts that hold the crew capsule to the rockets.

A pyrotechnic device is an explosive device, similar to a firework. The energy released from the explosion is transferred to the bolts, which sends them flying at a high speed in both directions. Half of the bolt hits the booster rocket, and the other half is “caught” by the crew capsule.

Relate the discussion of the explosion and the movement of the shuttle to the ideas of energy and motion.

Investigation: Energy from the Bolt (15 minutes)

Prompt students to think about the bolt that flies into the space shuttle. The bolt is a large, heavy device traveling at a great speed. It has a great deal of energy, but it doesn’t damage the space shuttle! This is odd, because energy can’t just disappear. Where did the energy from the bolt go? Generate student interest in finding the answer to this question.

Students engage in an investigation to try to figure out where the energy from the bolt goes. In the investigation, students use a marble to represent the bolt and a piece of flower foam to represent the space shuttle.

Give each team a large marble and a piece of flower foam. Instruct the teams to drop the marble on the flower foam to represent the bolt flying into the space shuttle. When students drop the marble into the flower foam, they should see that the marble makes a dent in the flower foam (the bolt damages the space shuttle). Lead a class discussion focused on how the marble stops moving and why the dent is formed in the flower foam. Students should recognize that somehow some of the energy from the falling marble is transferred to the flower foam to make a dent. As the energy is transferred, the marble stops moving.

Next, give students a piece of bubble wrap and a piece of butcher paper. Instruct students to experiment with what happens when they use the butcher paper or the bubble wrap to protect the flower foam from the marble. Students should drop the marble on to the flower foam protected by bubble wrap and by butcher paper. Students should see that the marble makes a smaller dent.

NGSS Key Moment

Developing an initial understanding of how a rocket separates from a crew capsule and the role of the bolt catcher in the separation event sets the stage to further develop science ideas embedded in 4-PS3-1 and 4-PS3-3. Students begin to think about the relationship between energy (the pyrotechnic explosion) and speed (the movement of the bolts). Students also begin to think about changes in energy (from the explosion to the bolt to the bolt catcher).
when the flower foam is protected by bubble wrap. Students should also see that the marble makes a medium sized dent when the flower foam is protected by butcher paper.

Lead a class discussion focused on why the marble makes different sized dents in the flower foam when the foam is protected by bubble wrap or butcher paper. Students should conclude that the bubble wrap or butcher paper can absorb some of the energy from the marble so that less energy is transferred to the flower foam. Students should further conclude that different materials absorb different amounts of energy.

Instruct students to revise their models to incorporate an explanation for why the bolt flying into the space shuttle doesn’t damage the space shuttle. Prompt students to attempt to explain where the energy from the bolt goes.

**Lesson Close (5 Minutes)**

Ask each student to write a brief reflection in their science notebooks. They should list their most important observations and any questions about space shuttle separation. Students should focus their reflections on the Driving Question, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*
Day 4: Why Space Shuttles Need Bolt Catchers

Introduction (10 minutes)

Remind students that the Driving Question for the module is, How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?

On Day 3, students modelled what happens when the pyrotechnic device explodes. Students then incorporated the idea that the explosion releases energy which “pushes” half of a bolt into the booster rocket and half of a bolt into the space shuttle. Students modelled their ideas about the phenomenon that the bolt did not damage the space shuttle.

Instruct students to share their models with their design team. Students should critically consider one another’s models. Students should make revisions to their own models if they feel it is appropriate.

Whole Class Discussion: Why the Space Shuttle Wasn’t Damaged (15 minutes)

Gather the students in a Scientists Circle. Engage the class in a whole class discussion about why the space shuttle wasn’t damaged by the impact of the bolt. During the discussion, encourage students to share, challenge, and revise their ideas. Also encourage students to use evidence for their investigation with the marble and the flower foam.

By the end of the discussion, students should figure out that something on the crew capsule absorbs the energy from the bolt (like the bubble wrap absorbed the energy from the marble). Tell students that this “something” is called a bolt catcher. The bolt catcher works by dissipating the energy from the bolt, which slows the bolt down.

NGSS Key Moment

This discussion marks an important moment in the development of 4-PS3-1 and 4-PS3-3. Students continue to build the idea that energy and speed are related as they consider the idea that the bolt may slow down as the bolt catcher absorbs the energy. Students also begin to build the idea that energy is transferred when two objects (the bolt and the bolt catcher) collide.
Mini-Lesson: Introduction to the Design Challenge (15 minutes)

Remind students that the Driving Question for the module is, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Let students know that this module’s core engineering design challenge is for students to design their own energy absorption model. In other words, students create their own bolt catcher model.

In their model, a lead sinker (or rubber ball) is used to model the bolt, and a coffee can or tissue box is used to model the bolt catcher.

Students must manipulate the inside of the tissue box or coffee can so it absorbs energy from the lead sinker. Show students a prototype of the testing apparatus and the bolt catcher that you created ahead of time.

Then, play the identified videos to demonstrate the basic concepts of a bolt catcher and the testing process that will take place after students have created their own devices.

In the design challenge, the sinker is fired into a box attached to a skateboard. The goal is to design a bolt catcher such that the skateboard travels the shortest distance due to reduced energy absorption in the bolt catcher box. The design challenge is intended to model what happens on the space shuttle.

Design Work: Initial Ideas (5 minutes)

Now that students are more familiar with the design challenge, allow students to meet with their design team for 5 minutes to share their initial ideas for the design solution. Prompt students to record notes in their science journals.

Lesson Close (5 Minutes)

Ask each student to write a brief reflection in their science notebooks. They should list their most important observations and any questions about bolt catchers and the design challenge. Students should focus their reflections on the Driving Question, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Assessment

Several opportunities for formative assessment exist in this lesson:

- When students develop questions about the design challenge, check student questions to ensure students have accurately understood the design challenge. This is an opportunity
to check students’ understanding of their task as well as the concepts that students find challenging.

- Drafts of models of the separation event can be used to monitor progress on 4-PS3-1 and 4-PS3-3.
- Consider gathering evidence of student progress through small group and whole group discussions. Make notes about questions that could guide student teams to focus on ways to improve their designs.
- Student reflections in their science notebooks should be regularly reviewed to inform instructional decisions.

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

Invite engineers to the classroom to talk about working on problems that involve reducing the force of impact.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Engineering Design Process</th>
<th>Bolt Catcher Teacher Handbook, Appendix A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting the Needs of All Learners</td>
<td>Bolt Catcher Teacher Handbook, Appendix B</td>
</tr>
<tr>
<td>CST-100 (0:52 Crew Capsule travel)</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>SpaceX Pad Abort (16:00 pad abort, 16:20 separation event)</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Pyrotechnics and Delta4 (1:16 ground test, 6:08 delta4 separation event)</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Talk Science Primer</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>NASA SRB Article</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Regular Speed Demo of Firing Mechanism</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Slow Speed Demo of Firing Mechanism</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Slow Speed Demo with Energy Absorption Materials</td>
<td>[YouTube Link]</td>
</tr>
</tbody>
</table>
Background Information for Bolt Catcher Apparatus

The top image shows the overall setup for the standard bolt catcher apparatus. The device consists of a tissue box taped with duct tape or masking tape to a piece of wood that is 3 or 4 inches wide and .5 inches thick. The lower end of the wood must be nailed to a 2 x 4-foot piece of wood. That piece of wood is then clamped to the skateboard. A wooden wedge fills the gap and establishes support between the piece of wood and the skateboard.

The bottom picture shows an alternate bolt catcher that is a plastic coffee container with a cutout for the wood platform. This model does not require tape. Note that for both models, having the correct height relative to the launch platform is important.
Lesson Overview

Students begin to design their impact reduction boxes (bolt catchers). The only required item is a standard tissue box (9 inches long x 4.75 inches wide x 2.75 inches high). Otherwise, students design their bolt catchers as they see fit, keeping in mind that they are trying to reduce the distance that the skateboard will travel after impact.

After creating a blueprint for their device, students generate models to show the changes in energy taking place in their bolt catchers. Students use their models to justify their design decisions.

Connecting to the Next Generation Science Standards

On Days 5 and 6, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices**: Asking Questions and Defining Problems, Developing and Using Models
- **Crosscutting Concepts**: Energy and Matter

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:

3-5-ETS1-2. *Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.*

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

4-PS3-3. *Ask questions and predict outcomes about the changes in energy that occur when objects collide.*

Specific Connections to Classroom Activity

In this lesson, students generate and compare multiple designs for the bolt catcher. After sharing their ideas, students select a final design that they think will best meet the criteria and constraints of the problem. Students then model speed and energy transfer in their proposed solution. As students model, they work with the idea that the speed and the energy of an object are related, and changes in energy occur when objects collide.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Elements</th>
<th>Connections to Classroom Activity</th>
</tr>
</thead>
</table>
| Science and Engineering Practices | **Constructing Explanations and Designing Solutions**  
- Apply scientific ideas to solve design problems.  
**Developing and Using Models**  
- Develop and use a model to describe phenomena. | Students apply the science ideas of speed and energy to design bolt catchers. Students develop an explanation to justify their design decisions.  
Students develop a model to describe their hypotheses about speed and energy transfer in their design solutions. |
| Disciplinary Core Ideas | **ETS1.B: Developing Possible Solutions**  
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.  
**PS3.A: Definitions of Energy**  
- The faster a given object is moving; the more energy it possesses.  
- Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.  
**PS3.B: Conservation of Energy and Energy Transfer**  
- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.  
**PS3.C: Relationship Between Energy and Forces**  
- When objects collide, the contact forces transfer energy so as to change the objects’ motions. | Prior to building their design solutions, students draft possible designs. Students share their designs with their design teams and with other design teams to receive feedback.  
Students develop hypotheses to explain how the speed of the bolt and the bolt catcher relates to the energy. Students also develop hypotheses to explain how energy is transferred through the system. |
| Crosscutting Concepts | **Energy and Matter**  
- Energy can be transferred in various ways and between objects. | As students develop their bolt catchers and model speed and transfer of energy in their bolt catchers, they work with the concepts of energy and matter. |
Basic Teacher Preparation

Be sure to gather or purchase all the materials necessary prior to Days 5 and 6. In addition, consider having the materials shown in the Material List for Days 7 through 9 (included below) available for students to view as constraints while drafting their design choices.

<table>
<thead>
<tr>
<th>Required Preparation</th>
<th>Links/Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gather and/or purchase all required materials for the lesson</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>Ensure that computer technology is available for students to print</td>
<td></td>
</tr>
<tr>
<td>Review the Blueprint Examples and recommended videos</td>
<td>Refer to the Suggested Teacher Resources at the end of Day 6</td>
</tr>
<tr>
<td>Download and print the Blueprint Examples, and place in envelopes for each team</td>
<td>Bolt Catcher Teacher Handbook, Appendix D</td>
</tr>
</tbody>
</table>

Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blueprint Examples</td>
<td></td>
<td>1 copy per team</td>
<td>Bolt Catcher Teacher Handbook, Appendix D</td>
</tr>
<tr>
<td>Butcher paper</td>
<td></td>
<td>1 sheet for each team</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Markers</td>
<td></td>
<td>Several per team</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Rulers</td>
<td></td>
<td>Make available for use as needed</td>
<td>Available in most schools</td>
</tr>
</tbody>
</table>

Materials List for Days 7 through 9

<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>Bubble wrap</td>
<td></td>
<td>2 or 3 rolls per class</td>
<td>Available at local stores or online [Web Link]</td>
</tr>
<tr>
<td>Butcher paper</td>
<td></td>
<td>2 or 3 sheets per class</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Item</td>
<td>Required per class/team</td>
<td>Source</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------</td>
<td>---------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Wooden blocks</td>
<td>3 or 4 per class</td>
<td>Bring from home or buy online [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Toilet paper</td>
<td>2 rolls per class</td>
<td>Bring from home</td>
<td></td>
</tr>
<tr>
<td>Large tissue boxes</td>
<td>9 inches long x 4.75 inches wide x 2.75 inches high per team</td>
<td>Ask students to bring from home and save</td>
<td></td>
</tr>
<tr>
<td>Foam rubber</td>
<td>10–12 feet per class</td>
<td>Foam rubber [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Cotton balls</td>
<td>3 per class</td>
<td>Bring from home or buy at local store</td>
<td></td>
</tr>
<tr>
<td>Shaving cream</td>
<td>3 containers per class</td>
<td>Bring from home or buy at local store</td>
<td></td>
</tr>
<tr>
<td>Plastic cups</td>
<td>3–5 per class</td>
<td>Bring from home or buy at local store</td>
<td></td>
</tr>
<tr>
<td>Aluminum pans</td>
<td>2 per class</td>
<td>Bring from home or buy at local store</td>
<td></td>
</tr>
<tr>
<td>Bags of sand</td>
<td>3 bags per test site</td>
<td>Sand [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Filled balloons</td>
<td>Several per class</td>
<td>Buy at local store</td>
<td></td>
</tr>
<tr>
<td>Plastic pot scrubbers</td>
<td>1 per team</td>
<td>Bring from home or buy at local store</td>
<td></td>
</tr>
<tr>
<td>Packing peanuts</td>
<td>10 sheets</td>
<td>Packing peanuts [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Rocks</td>
<td>2 per class</td>
<td>Bring from home or buy online [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Metal weights</td>
<td>Several per class or team</td>
<td>Metal weights [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Balances to obtain mass</td>
<td>1 set per class</td>
<td>Balances [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Masking tape</td>
<td>1 or 2 rolls per class</td>
<td>Available in most schools, or bring from home</td>
<td></td>
</tr>
<tr>
<td>Scissors</td>
<td>Several per class</td>
<td>Available in most schools</td>
<td></td>
</tr>
<tr>
<td>Hot glue gun</td>
<td>1 or 2 per class</td>
<td>Hot glue gun [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Stapler</td>
<td>Several per class</td>
<td>Available in most schools</td>
<td></td>
</tr>
</tbody>
</table>
Day 5: How to Design a Bolt Catcher to Absorb Energy

**Introduction (5 minutes)**

Remind students that the Driving Question for the module is, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Kick off the design phase of the project by recapping the design challenge. Teams create a bolt catcher box that can best absorb the energy of impact. Refer to the demonstration device and the videos from the previous lesson.

**Design Work: Model Design and Planning (20 minutes)**

Students work with their teams for this team design activity. A recommended protocol is outlined below, but steps can be modified as needed.

1. Each team reviews the overall design problem.
2. Individuals on the team think about and write down two ideas for maximizing impact reduction using common materials and design attributes based on the prior lesson’s demonstration and videos.
3. Students take turns sharing their two ideas with their team members.
4. The teams discuss all the options, and they collaboratively determine which ideas and features to include in their team designs.
5. Teams examine examples of several different types of models or blueprints.
6. Teams begin working on a drawn model or blueprint of their bolt catcher on a large piece of butcher paper.

**Design Work: Model Refinement (20 minutes)**

During the next 20 minutes, team members continue work on their bolt catcher blueprints. As students work, prompt them to think about the speed and energy of objects at various points throughout the collision. Have students draw models for the bolt catcher at various times during the collision.

**NGSS Key Moment**

Working as a team to design blueprints helps students realize the value of sharing ideas as part of the design process.

**Extension**

As an optional extension, consider having students share their models with other teams and provide feedback.
Lesson Close (5 minutes)

Ask each team to complete a written reflection of the day’s work in their individual science notebooks. Topics might include:

- Progress made
- Biggest challenge
- Remaining questions

Students should focus their reflections on the Driving Question, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*
Day 6: How to Design a Bolt Catcher to Absorb Energy

Introduction (10 minutes)

Remind students that the Driving Question for the module is, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Have design teams share their ideas with a different design team. Instruct students to give kind, specific, and helpful feedback as they share. After sharing and receiving feedback, students should modify their designs.

Investigation: Modeling Speed and Energy (30 minutes)

Now that students have designed their bolt catchers, they need to justify their design decisions using the ideas of speed and energy.

Tell students that today, they hypothesize how the speed and energy of different parts of a bolt catcher and a bolt changes as the bolt collides with the bolt catcher. Students model their hypotheses on the blueprints.

Students work with their teams for this team design activity. A recommended protocol is outlined below, but steps can be modified as needed.

1. Each student individually thinks about and creates a model to show their hypothesis for how the speed and energy of the different parts of the bolt catcher change. Students must describe the speed and energy of the:
   - Bolt when it is launched
   - Bolt just before it hits the bolt catcher
   - Bolt catcher just before the bolt hits
   - Bolt and bolt catcher during the collision
   - Bolt and bolt catcher after the collision
2. Students take turns sharing their ideas with the other members of their team.
3. Each team discusses all the options, and collaboratively determines which ideas and features to include in their model.
4. Each team draws a model of their hypotheses for the speed and energy of their bolt catcher on a large piece of butcher paper.

NGSS Key Moment

Developing hypotheses about how the speed and energy of the bolt and the bolt catcher changes helps students make progress on 4-PS3-3.
Teams may find that they would like to make revisions to their blueprint after modeling the speed and energy of their bolt catchers. Encourage students to continually revise their blueprints.

**Extension**

Consider showing one or more of the following videos to help students clarify their understanding of how the speed and energy of the different parts of the bolt catcher change:

- Bill Nye the Science Guy on Energy [YouTube Link]
- Force, Work, and Energy for Kids [YouTube Link]
- MakeMeGenius.com: Work, Force, and Energy Relationship [YouTube Link]
- Billy Nye: Force and Motion [YouTube Link]
- NASA Inventions You Didn’t Know They Created [YouTube Link]

**Lesson Close (10 minutes)**

Ask each team to complete a written reflection of the day’s work in their science notebooks. Topics might include:

- Progress made
- Biggest challenge
- Remaining questions

Students should focus their reflections on the Driving Question, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

**Assessment**

Several opportunities for formative assessment exist in this lesson:

- Completion of the bolt catcher models serves as evidence of team decision-making and learning.
- Consider gathering evidence of student progress through small group and whole group discussions.

**NGSS Key Moment**

Encouraging iterative revisions to the design solution helps students make progress on 3-5-ETS1.2. Students should document what they changed about their models and why.
• Students’ reflections in their science notebooks should be regularly reviewed to inform instructional decisions. Reviewing reflections can provide insight into the kinds of challenges and questions students have at this point in 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

Ask students to discuss with a parent, guardian, or other adult family member, how team planning and problem solving occurs in their workplace. Invite students to share some real-world examples during the next lesson.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Bolt Catcher Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blueprint Examples (placed in envelopes)</td>
<td>Bolt Catcher Teacher Handbook, Appendix D</td>
</tr>
<tr>
<td>Bill Nye the Science Guy on Energy</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Force, Work, and Energy for Kids</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>MakeMeGenius.com: Work, Force, and Energy Relationship</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Bill Nye: Force and Motion</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>NASA Inventions You Didn’t Know They Created</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>D3O—Smart Shock Absorbing Material</td>
<td>[YouTube Link]</td>
</tr>
</tbody>
</table>
Lesson Overview

Over the next three sessions, students select and use their preferred materials to reduce the effect of force on their bolt catchers and minimize the distance they move on impact. Students discuss and weigh the benefits of the materials based on their physical properties. They then build, test, and optimize their bolt catchers.

Connecting to the Next Generation Science Standards

On Days 7 through 9, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. This lesson serves as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Please reference the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in the front matter of this module.

Basic Teacher Preparation

For Days 7 through 9, all of the necessary materials should be available and displayed for easy selection by the teams. Students may need guidance in facilitating team discussions and coming to consensus. Monitor student teams to ensure efficient time management and that they are able to meet each day’s deliverables.

<table>
<thead>
<tr>
<th>Required Preparation</th>
<th>Links/Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Gather or purchase all required materials for the lesson, and display them for easy selection by students</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>- Review all suggested teacher resources, including the document with information about Claim Evidence Reasoning (CER) charts</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson</td>
</tr>
</tbody>
</table>
## Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble wrap</td>
<td></td>
<td>2 or 3 rolls per class</td>
<td>Available at local stores or online [Web Link]</td>
</tr>
<tr>
<td>Butcher paper</td>
<td></td>
<td>2 or 3 sheets per class</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Wooden blocks</td>
<td></td>
<td>3 or 4 per class</td>
<td>Bring from home or buy online [Web Link]</td>
</tr>
<tr>
<td>Toilet paper</td>
<td></td>
<td>2 rolls per class</td>
<td>Bring from home</td>
</tr>
<tr>
<td>Large tissue boxes</td>
<td>9 inches long x 4.75 inches wide x 2.75 inches high</td>
<td>1 per team</td>
<td>Ask students to bring from home and save</td>
</tr>
<tr>
<td>Foam rubber</td>
<td></td>
<td>10–12 sheets per class</td>
<td>Foam rubber [Web Link]</td>
</tr>
<tr>
<td>Cotton balls</td>
<td></td>
<td>3 per class</td>
<td>Bring from home or buy at local store</td>
</tr>
<tr>
<td>Shaving cream</td>
<td></td>
<td>3 containers per class</td>
<td>Bring from home or buy at local store</td>
</tr>
<tr>
<td>Plastic cups</td>
<td></td>
<td>3–5 per class</td>
<td>Bring from home or buy at local store</td>
</tr>
<tr>
<td>Aluminum pans</td>
<td></td>
<td>2 per class</td>
<td>Bring from home or buy at local store</td>
</tr>
<tr>
<td>Bags of sand</td>
<td></td>
<td>3 bags per test site</td>
<td>Sand [Web Link]</td>
</tr>
<tr>
<td>Filled balloons</td>
<td></td>
<td>Several per class</td>
<td>Buy at local store</td>
</tr>
<tr>
<td>Plastic pot scrubbers</td>
<td></td>
<td>1 per team</td>
<td>Bring from home or buy at local store</td>
</tr>
<tr>
<td>Packing peanuts</td>
<td></td>
<td>10–12 feet per class</td>
<td>Packing peanuts [Web Link]</td>
</tr>
<tr>
<td>Rocks</td>
<td></td>
<td>2 per class</td>
<td>Bring from home or buy online [Web Link]</td>
</tr>
<tr>
<td>Metal weights</td>
<td></td>
<td>Several per class or team</td>
<td>Metal weights [Web Link]</td>
</tr>
<tr>
<td>Balances to obtain mass</td>
<td></td>
<td>1 set per class</td>
<td>Balances [Web Link]</td>
</tr>
<tr>
<td>Masking tape</td>
<td></td>
<td>1 or 2 rolls per class</td>
<td>Available in most schools, or bring from home</td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>Availability</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>-----------------------------------</td>
<td></td>
</tr>
<tr>
<td>Scissors</td>
<td>Several per class</td>
<td>Available in most schools</td>
<td></td>
</tr>
<tr>
<td>Hot glue gun</td>
<td>1 or 2 per class</td>
<td>Hot glue gun [Web Link]</td>
<td></td>
</tr>
<tr>
<td>Stapler</td>
<td>Several per class</td>
<td>Available in most schools</td>
<td></td>
</tr>
</tbody>
</table>
Day 7: Materials Selection, Building, and Testing

**Introduction (10 minutes)**

Students check in as a team. Consider assigning roles to each team member, or have students select their own roles. Some possible roles include design lead, materials collector/organizer, time manager, marketing agent, and testing agent. Students should create job descriptions for each of their roles. Have students share and discuss, one at a time, with their team members the goals and responsibilities of their individual roles. Then, have students discuss how they plan to work in their roles with others to complete and test their bolt catcher models. Finally, have students review their blueprints and justifications to make any final revisions prior to building.

**Design Work: Materials (15 minutes)**

Allow the teams to examine, handle, and discuss the materials that have been set out in advance. Each team must decide if they want to stick with their original blueprint or make any adjustments. The blueprints should be modified to reflect any changes. Refer students to the *Engineering Design Process—Step 4 Select the Best Solution* (Appendix A).

**Design Work: Prototype Construction (20 minutes)**

Teams select and use their materials to construct their first bolt catcher prototype. Let students know that during the next class session, they test their prototypes, collect data, and determine how to optimize their prototypes for a second round of testing trials. Remind students that the criteria for success involves minimizing the distance the skateboard travels, while accepting the constraints of the materials available to use.

**Lesson Close (5 minutes)**

Have students clean up their work stations. Then, instruct students to complete a reflection about the lesson’s activities in their science notebooks. Students can choose their own topic or be given a specific prompt, such as, *One thing I’d like to try but we didn’t during this first round is... because...* or *One question I have about this process is... because...*

Students should focus their reflections on the Driving Question, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Another option for wrapping up today’s lesson is to have students write in their science journals about how they worked together during today’s planning time. Consider asking:

- *What were the most significant disagreements your team faced today?*
- *How did you come to consensus?*
- *What did you find most challenging about meeting today’s deliverables?*
Day 8: Materials Selection, Building, and Testing

Introduction (5 minutes)

Have teams collect their bolt catcher models from Day 7. In preparation for today’s activities, share the following information with students.

The intent of today’s testing is to determine which material (or materials) would be best to use on a bolt catcher for a shuttle launch. Each team’s goal is to reduce the distance their model travels on impact.

After each team tapes its bolt catcher box to the impact board, one team member sits on the board (as demonstrated in earlier photos and videos) and tests their model by placing the fish sinker into the slingshot, pulling the slingshot back to the specified point, and releasing.

After the skateboard stops moving, students measure the distance traveled and enter the information into a chart.

Each team should complete three trials and calculate the average of the trials.

After testing is completed, the entire class discusses the following questions:

- Based on the data, which materials performed the best or resulted in the shortest distance traveled? Why?
- Which materials performed the worst? Why?
- What material properties are the most important to consider?
- What are the connections between today’s testing and space travel?
- How could the information from today’s tests be used to improve your bolt catcher models?

Design Work: Bolt Catcher Testing—Round 1 (25 minutes)

Teams complete their first round of bolt catcher testing. Data recorders must capture the data for each trial. Additionally, a combined whole class data chart should be completed so trends can be noted across teams. Work with each team to facilitate testing and data recording.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Distance Traveled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Avg. Distance = (D1 + D2 + D3)/3

Helpful Tip

One pilot teacher found using a rubber ball as the bolt rather than a lead sinker was a safer option.

Helpful Tip

Consider developing a data recording sheet for students, or have the teams develop their own.
Design Work: Analyze Data and Revise Designs (20 minutes)

Have the teams review the data captured for their prototype as well as the class data from other teams. Instruct students to pay attention to trends in the data and make predictions about what caused those trends. Based on the information and predictions, have each team determine the best way to optimize their bolt catcher.

As time permits, allow teams to use the available materials to optimize, or improve the performance of, their models.

Instruct students to record their optimization plans.

NGSS Key Moment

By collecting data and revising design solutions, students make progress on 3-5-ETS1.2.
Day 9: Materials Selection, Building, and Testing

Introduction (15 minutes)

Have teams retrieve their bolt catchers and use the available materials to revise and finalize their models.

Design Work: Bolt Catcher Testing—Round 2 (25 minutes)

Have teams conduct a second round of testing using their optimized bolt catchers. Students should follow the same testing procedures they followed on Day 8, being certain to capture both individual teams and whole-class data. Monitor the testing station to ensure safety.

Design Work: Team Analysis (10 minutes)

Each team completes a Claim Evidence Reasoning (CER) chart (example shown below) addressing the essential question, How did the design and materials used make the difference between the more and less effective bolt catchers?

If students are unfamiliar with CER charts, explain that they need to answer the question by making their own claims and then explain their reasoning for that claim while providing evidence. Remind students that the evidence for their claims should be based (at least in part) on the data collected during the testing trials. The reasoning should be based on their ideas (and hypotheses) about speed and the transfer of energy.

| How did the design and materials used make the difference between the more and less effective bolt catchers? |
|-----|----------------|
| Claim | Evidence |
| Reasoning | |

Helpful Tip

Review the Suggested Teacher Resources at the end of Day 9 for a more complete description of CER charts.

Helpful Tip

If students have never been exposed to writing a CER, consider completing this activity as a whole class discussion.
Allow students to complete their individual charts, and then ask them to share responses with their team without providing feedback or offering suggestions for correction. This is an initial opportunity for students to construct their own ideas and explanations, which they can revisit and revise later.

**Assessment**

Several opportunities for formative assessment exist in this lesson:

- Team CER charts on Day 9 are a record of team understanding and application of learning and activities thus far.
- Data collection charts on Days 7 and 8 can serve as evidence of understanding.
- Consider gathering evidence of student progress through small group and whole group discussions.
- Students reflections in their science notebooks should be regularly reviewed to inform instructional decisions.

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**

Gather information about job titles in local companies that are recognizable to students. Many companies post organizational charts or directories online. Discuss some of the roles with the class to underscore the need to distribute critical tasks and workloads to meet shared goals.

**Suggested Teacher Resources**

<table>
<thead>
<tr>
<th>Engineering Design Process</th>
<th>Bolt Catcher Teacher Handbook, Appendix A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting the Needs of All Learners</td>
<td>Bolt Catcher Teacher Handbook, Appendix B</td>
</tr>
<tr>
<td>Claims, Evidence, Reasoning (video)</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>NSTA Claim, Evidence, Reasoning</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>
Lesson Overview

In this culminating lesson, student teams present a synopsis of the learning that has occurred throughout the module. Team presentations should include a description of the project in students’ own words, an explanation of the science concepts being applied (speed and energy), how the team improved on their design, and how their product could be applied in other real-life applications. The presentations should also include what students have learned about the field of engineering. Presentations involve verbal and visual elements that are scored using a rubric.

Connecting to the Next Generation Science Standards

On Day 10, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. This lesson serves as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Please reference the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in the front matter of this module.

Basic Teacher Preparation

During this culminating lesson, students present their findings and reflect on the Bolt Catcher project.

<table>
<thead>
<tr>
<th>Required Preparation</th>
<th>Links/Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Download, print, and copy the Presentation Rubric</td>
<td>Bolt Catcher Teacher Handbook, Appendix C</td>
</tr>
</tbody>
</table>

Materials List

<table>
<thead>
<tr>
<th>Item</th>
<th>Description/Additional Information</th>
<th>Quantity</th>
<th>Where to Locate/Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation Rubric</td>
<td></td>
<td>1 copy per team</td>
<td>Bolt Catcher Teacher Handbook, Appendix C</td>
</tr>
</tbody>
</table>
Day 10: Final Presentation

Introduction (5 minutes)

Remind students that the Driving Question for the module is, *How can we design a bolt catcher to catch the bolts that help a crew capsule separate from a rocket?*

Tell students they must conduct a Critical Design Review for NASA based on their work throughout this module.

Encourage students to determine their team’s work assignments to ensure that each presentation addresses the Critical Design Review for NASA Criteria.

Critical Design Review for NASA Criteria

Each presentation should address the following criteria:

- *Description of the project in students’ own words*
- *Explanation of the science concepts being applied (speed and energy)*
- *Description of the energy transfers in the bolt catcher*
- *Explanation of how they improved on their design and how the product they designed could be applied in other real-life applications*
- *Description of what students learned about the field of engineering*
- *Final model of their design, including descriptions of speed and energy transfer*

Review the Presentation Rubric in Appendix C with students before they begin their work.

Design Work: Presentation Planning (20 minutes)

Allow the student teams time to prepare their presentations. Depending on time constraints, students can either give their presentations to other engineering teams or to the whole class.

Helpful Tip

Consider making a handout for each student team with the Critical Design Review for NASA Criteria.

Helpful Tip

If needed, consider adding an additional day for students to prepare and give their presentations.
Whole Group Discussion: Final Presentations (20 minutes)

Students make their presentations and respond to questions. Use the Presentation Rubric found in Appendix C to assess student presentations.

Lesson Close (5 minutes)

Have students reflect in their science journals about the following questions:

- Did you enjoy this module? Why or why not?
- What did you learn from it?
- What surprised you about the engineering design process?
- How does this experience relate to something in your daily lives or the products/machines you most like to use?
- After this, what would you like to learn/study next?

Assessment

The final presentation can be used as a summative assessment for the module. Consider using the Presentation Rubric in Appendix C to assess the final presentations. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Consider having students present and defend their designs as part of a “high stakes” showcase engineering design presentation to invited engineers, designers, and entrepreneurs.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Bolt Catcher Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation Rubric</td>
<td>Bolt Catcher Teacher Handbook, Appendix C</td>
</tr>
</tbody>
</table>
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
Determine a redesign to address failure points and/or design improvements. The design process involves multiple iterations and redesigns. 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
- 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.
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.

<table>
<thead>
<tr>
<th>Design Problem:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science Ideas related to the Design Problem:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First Draft Design Solution:</th>
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</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

*Reflection/Modifications Needed:*

<table>
<thead>
<tr>
<th>Second Draft Design Solution:</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

*Reflection/Modifications Needed:*

<table>
<thead>
<tr>
<th>Final Design Solution and Justification:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
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 …
• Problem/Solution
  o Scientists say … (quotation with source). We found this applied to …
  o These sources … point to this issue …
  o We tested our prototypes by … These were the results …
  o Experts such as … (sources) say … is a common problem.
  o … (source) emphasizes that … is a problem, with this possible solution …

• Cause/Effect
  o Every time … happened, … would happen.
  o Scientists believe that … is caused by … (quote with source)
  o The following graph shows how … influences …
  o This chart shows when … happens (or is present) and what happens next.
  o 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
  o The evidence supports our claim because …
  o The graph shows that as … rises, … rises/falls at a (steady or increasing) rate. This allows us to predict …
  o Taking the evidence as a whole shows …

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

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

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

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

• Dealing with contrary evidence
  o By looking at all of this, we can see that these data … are outliers.
  o While some scientists say …, most scientists agree that …
  o Some of our results are less reliable because …
### Science and Innovation
**A Boeing and Teaching Channel Partnership**

**PRESENTATION RUBRIC**

<table>
<thead>
<tr>
<th>Quality of Design Product</th>
<th>No Evidence</th>
<th>Beginning</th>
<th>Developing</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOTE: This section should be tailored to assess specific module and performance expectations.</td>
<td>Design product fails to address most aspects of the performance task.</td>
<td>Design product addresses some aspects of the performance task.</td>
<td>Design product addresses most aspects of the performance task.</td>
<td>Design product addresses all aspects of the performance task.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Explanation of Science Ideas</th>
<th>No Evidence</th>
<th>Beginning</th>
<th>Developing</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOTE: This section should be tailored to assess specific module and performance expectations.</td>
<td>Relevant science ideas are not addressed.</td>
<td>Most relevant science ideas are stated and partially described in relation to the design problem.</td>
<td>All relevant science ideas are stated and described in relation to the design problem.</td>
<td>All relevant science ideas are clearly stated and described in detail in relation to the design problem.</td>
</tr>
<tr>
<td></td>
<td>Evidence is not cited.</td>
<td>Some evidence is cited. Evidence was gathered through science investigations or critical analysis of existing sources.</td>
<td>Several lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.</td>
<td>Multiple lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organization</th>
<th>No Evidence</th>
<th>Beginning</th>
<th>Developing</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>The presentation does not include all of the required components.</td>
<td>The presentation includes most of the required components.</td>
<td>The presentation includes all of the required components.</td>
<td>The presentation includes all of the required components and either provides additional information for each component or adds additional components relevant to the presentation.</td>
<td></td>
</tr>
<tr>
<td>The presentation does not have a main idea or presents ideas in an order that does not make sense.</td>
<td>The presentation moves from one idea to the next, but the main idea may not be clear or some ideas</td>
<td>The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing main</td>
<td></td>
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</tr>
<tr>
<td>Presenting Skills</td>
<td>Presenting Skills</td>
<td>Presenting Skills</td>
<td>Presenting Skills</td>
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<td>-------------------</td>
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<tr>
<td>The presenter does not look at the audience and reads notes or slides.</td>
<td>The presenter makes infrequent eye contact and reads notes or slides most of the time.</td>
<td>The presenter keeps eye contact with audience most of the time and only glances at notes or slides.</td>
<td>The presenter engages the audience by drawing their sustained attention.</td>
<td></td>
</tr>
<tr>
<td>The presenter wears clothing inappropriate for the occasion.</td>
<td>The presenter speaks clearly most of the time, although sometimes too quickly or slowly.</td>
<td>The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4)</td>
<td>The presenter maintains eye contact with the audience most of the time and only glances at notes or slides. (CC 6-8.SL.4)</td>
<td></td>
</tr>
<tr>
<td>The presenter mumbles or speaks too quickly or slowly.</td>
<td>The presenter speaks loudly enough for most of the audience to hear, but may speak in a monotone.</td>
<td>The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)</td>
<td>The presenter dresses professionally.</td>
<td></td>
</tr>
<tr>
<td>The presenter speaks too softly to be understood.</td>
<td></td>
<td></td>
<td>The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)</td>
<td></td>
</tr>
</tbody>
</table>
Blueprint Examples can be found on [Wikimedia](https://www.wikimedia.org) or create one for free at one of these two sites:

- RoomSketcher ([http://planner.roomsketcher.com/#/?pid=493174](http://planner.roomsketcher.com/#/?pid=493174))
- Blueprint Software ([www.smartdraw.com/software/blueprint-software.htm](http://www.smartdraw.com/software/blueprint-software.htm))
The U.S.S. ENTERPRISE NCC-1701-D is the fifth starship to bear the name. Larger and technologically superior to its predecessors, diplomacy and discovery are its primary missions. Its advanced warp technology and design allow deep space exploration and a mission that can last 15 to 20 years.

Source: http://images.libregraphicsworld.org/3d/2013/05/freestyle-jot/models_blueprint2-580px.jpg
Source: http://starshipmodeler.biz/shop/images/products/Zarkus/atpt2.gif
Darth Vader: Helmet/Breath Mask

## 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.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>aerospace engineer</td>
<td>An engineer who deals with the design, development, construction, testing, and operation of vehicles operating in Earth’s atmosphere or in outer space.**</td>
</tr>
<tr>
<td>chemical engineer</td>
<td>An engineer who deals with the development of processes and the design and operation of plants in which materials undergo changes in their physical or chemical state.**</td>
</tr>
<tr>
<td>civil engineer</td>
<td>An engineer who deals with the design and execution of structural works that serve the general public.**</td>
</tr>
<tr>
<td>computer science</td>
<td>An engineer who deals with the design, development, and maintenance of computer software.*</td>
</tr>
<tr>
<td>computer science</td>
<td>engineer An engineer who deals with the design, development, and maintenance of computer software.*</td>
</tr>
<tr>
<td>constraint</td>
<td>A limitation of restriction.</td>
</tr>
<tr>
<td>electrical engineer</td>
<td>An engineer who deals with the practical applications of electricity in all its forms, including those of the field of electronics.*</td>
</tr>
<tr>
<td>engineer</td>
<td>A person who designs, builds, or maintains engines, machines, or public works.</td>
</tr>
<tr>
<td>force</td>
<td>Something that causes a change in the motion of an object.*</td>
</tr>
<tr>
<td>kinetic energy</td>
<td>Energy that a body possesses by virtue of being in motion.</td>
</tr>
<tr>
<td>mechanical engineer</td>
<td>An engineer who focuses on the design, manufacture, installation, and operation of engines and machines and with manufacturing processes.**</td>
</tr>
<tr>
<td>potential energy</td>
<td>The energy possessed by a body as a result of its position rather than its motion.</td>
</tr>
</tbody>
</table>

* Definition developed by authors.
** Definition by Britannica ([www.britannica.com](http://www.britannica.com)).