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.
Composites are materials made up of two or more components that, when combined, become a new material that has properties different than each of the materials alone. A composite material is made up of a reinforcement ingredient (such as fiberglass or carbon fiber) and a matrix ingredient (such as epoxy resin).

This engineering design module introduces the design and use of composite materials; with a special focus on carbon fiber composites and their use in modern airplane design and manufacture, such as with the Boeing 787 Dreamliner. Students design a model composite to be used as a strong and lightweight material in airplanes. Connections are built between materials science, composite engineering, and aeronautical engineering as students explore the benefits that composites—especially carbon fiber composites—offer to airplane designers. Through their work developing composites, students build an understanding of the engineering design process and materials science.

Module Overview

The module includes several mini-design challenges that lead up to a multiday engineering design challenge. In the culminating challenge, students spend three days defining a problem, generating solutions, building prototypes, testing, redesigning, and optimizing their best weave patterns for a new composite material with high tensile strength. Once students have chosen their best prototype, each design team adds a “matrix” ingredient by painting a polymer glue onto their optimized design prototypes to create a new type of composite material.

Teams then test the optimized prototype consisting of both the reinforcement and matrix ingredients and compare the composite’s performance to the performance of the optimized prototype consisting of just the reinforcement ingredient.

By designing their own weave patterns, constructing their own woven mats, and adding a polymer to create a composite, students model the process of designing carbon fiber composites for use in the commercial airplane industry. The module concludes with student design teams presenting their optimized design prototypes and reflecting on their experiences with the engineering design process.

Throughout this module, students build an understanding of the engineering design process as well as build an understanding of core physical science ideas. Specifically, students make observations and measurements to identify materials based on the properties. Students also investigate what happens when they mix two or more substances.
Engineering Design in the Module

In this module, students design a model composite material. Students design a strong, lightweight composite that can be used in airplanes. Students engage in a series of engineering design challenges to figure out the properties of composites and test possible design solutions. Students record and document their engineering process and iterative design in a notebook.

Sequencing

Composites is intended as a 5th-grade engineering and physical science module. This module was designed to help students make progress on five performance expectations: 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3, 5-PS1-3, and 5-PS1-4. The performance expectations address the engineering design process and the structure and properties of matter.

Composites is most appropriately used during the 5th-grade year. Within grade 5, this module can be used at any point throughout the development of 5-PS1-3 and 5-PS1-4, which both address the structure and properties of matter. Students should have already mastered the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts included in 2nd-grade Physical Science and Engineering Design.

- Students should have mastered 2-PS1-1, 2-PS1-2, and 2-PS1-3. All three of these performance expectations address the Structure and Properties of Matter (PS1.A).
- 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: Asking Questions and Defining Problems, Planning and Carrying out Investigations, and Constructing Explanations and Designing Solutions.
- 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, Cause and Effect, and Structure and Function.

Performance Expectations

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

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.

5-PS1-3. Make observations and measurements to identify materials based on their properties.

5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
The lessons and activities outlined in this module are just 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-ETS1-1.** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **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:

- **5-PS1-3.** Make observations and measurements to identify materials based on their properties.
- **5-PS1-4.** Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science and Engineering</td>
<td><strong>Asking Questions and Defining Problems</strong></td>
</tr>
<tr>
<td>Practices</td>
<td>• Define a simple design problem that can be solved through the development of</td>
</tr>
<tr>
<td></td>
<td>an object, tool, process, or system and includes several criteria for success</td>
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<tr>
<td></td>
<td>and constraints on materials, time, or cost.</td>
</tr>
<tr>
<td></td>
<td><strong>Planning and Carrying Out Investigations</strong></td>
</tr>
<tr>
<td></td>
<td>• Make observations and measurements to produce data to serve as the basis for</td>
</tr>
<tr>
<td></td>
<td>evidence for an explanation of a phenomenon.</td>
</tr>
<tr>
<td></td>
<td><strong>Constructing Explanations and Designing Solutions</strong></td>
</tr>
<tr>
<td></td>
<td>• Generate and compare multiple solutions to a problem based on how well they</td>
</tr>
<tr>
<td></td>
<td>meet the criteria and constraints of the design problem.</td>
</tr>
</tbody>
</table>
**Disciplinary Core Ideas**

<table>
<thead>
<tr>
<th>ETS1.A Defining and Delimiting Engineering Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ETS1.B: Developing Possible Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions.</td>
</tr>
<tr>
<td>Tests are often designed to identify failure points or difficulties, which suggest the elements of a design that need to be improved.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ETS1.C: Optimizing the Design Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements of a variety of properties can be used to identify materials.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PS1.B: Chemical Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>When two or more different substances are mixed, a new substance with different properties may be formed.</td>
</tr>
</tbody>
</table>

**Crosscutting Concepts**

<table>
<thead>
<tr>
<th>Influence of Engineering, Technology, and Science on Society and the Natural World</th>
</tr>
</thead>
<tbody>
<tr>
<td>People’s needs and wants change over time, as do their demands for new and improved technologies.</td>
</tr>
<tr>
<td>Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cause and Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause and effect relationships are routinely identified, tested, and used to explain change.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure and Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different materials have different substructures, which can sometimes be observed.</td>
</tr>
<tr>
<td>Substructures have shapes and parts that serve functions.</td>
</tr>
</tbody>
</table>

**Connections to the Common Core State Standards**

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.SL.5.1**: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 5 topics and texts, building on others' ideas and expressing their own clearly.

- **CCSS.ELA-Literacy.SL.5.4**: Report on a topic or text or present an opinion, sequencing ideas logically and using appropriate facts and relevant, descriptive details to support main ideas or themes; speak clearly at an understandable pace.
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 strong and lightweight material for use in airplanes?

<table>
<thead>
<tr>
<th>Question/Problem</th>
<th>What Students Are Doing</th>
<th>What Students Figure Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the different types of materials and how can we measure the performance of materials?</td>
<td>Students categorize everyday materials and develop tests to measure the performance of different materials.</td>
<td>There are many different types of materials used in everyday objects. Each material has different properties.</td>
</tr>
<tr>
<td>What kinds of materials are best suited for airplanes?</td>
<td>Students construct paper airplanes from different materials and evaluate their alignment with decision criteria.</td>
<td>The best materials for an airplane are strong and lightweight. Composites are strong and lightweight.</td>
</tr>
<tr>
<td>What are composites? How do we make a composite?</td>
<td>Students design a candy composite to meet certain criteria and constraints.</td>
<td>Composites are made by combining a reinforcement ingredient with a matrix ingredient. The resulting composite has different properties than the ingredients.</td>
</tr>
<tr>
<td>How can we test the performance of composites?</td>
<td>Students test cardboard pieces to determine the ways cardboard can be strong and weak. Students examine materials used in airplane design.</td>
<td>There are three types of material strength—compressive, tensile, and shear. Carbon fiber composites are used in modern airplane design because they are strong and lightweight.</td>
</tr>
<tr>
<td>How do we make a carbon fiber composite?</td>
<td>Students explore the manufacturing methods of carbon fiber composites by examining parts textiles.</td>
<td>There are several ways to manufacture carbon fiber composites depending on the criteria and constraints of the problem.</td>
</tr>
<tr>
<td>How can we design a strong and lightweight composite for use in airplanes?</td>
<td>Students engage in the engineering design process to build a strong and lightweight composite.</td>
<td>Different designs yield different tensile strengths and address the design constraints in different ways.</td>
</tr>
</tbody>
</table>
Lesson Overview

All human-made products are made of materials, but what are materials? How are new materials invented? Once a new material is created, how is it changed and used in products?

Day 1 launches the module by introducing the design challenge that drives students’ exploration of composites and airplane design. Through a Materials Science Scavenger Hunt, students develop their understanding of the categories of materials that make up everyday objects. The class works together to develop a Materials Class Chart of everyday materials (such as wood, ceramic, metal, plastic, and so forth) that they categorize into different types of materials. Advanced materials, such as composites, are discussed.

Day 1 leads directly into Day 2 in which students freely explore different materials in the Materials Science Lab, describing their properties and developing their own tests of performance.

This lesson sets students up to investigate the use of materials in airplane design. In later lessons, students explore the use of composites, particularly carbon fiber composites.

Connecting to the Next Generation Science Standards

On Days 1 and 2, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices**: Asking Questions and Defining Problems, Planning and Carrying Out Investigations
- **Crosscutting Concepts**: Cause and Effect

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-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

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

**5-PS1-3.** Make observations and measurements to identify materials based on their properties.

### Specific Connections to Classroom Activity

On Days 1 and 2, students are challenged to design a lightweight and strong composite for use in airplanes. Students begin to define the design problem by building a Driving Question Board (DQB). Students use the DQB to further define and delimit the design problem in later lessons.

The focus of Days 1 and 2 is on 5-PS1-3 and 3-5-ETS1-3. On Days 1 and 2, students engage in a series of three investigations in which they progressively build understanding of both performance expectations. In all three investigations, students make observations to answer the question, *What are the different kinds of materials?* In addition, students build their understanding of planning and carrying out tests.

### Dimension | NGSS Element | Connections to Classroom Activity
--- | --- | ---
**Science and Engineering Practices** | **Asking Questions and Defining Problems**<br>• Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost. | Students are introduced to the design problem. As students construct the Driving Question Board (DQB), they further define the design problem. In the Materials Science Lab, students make observations and measurements to describe materials and to identify materials based on their properties.

| **Planning and Carrying Out Investigations**<br>• Make observations and measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon. | |

**Disciplinary Core Ideas** | **ETS1.A Defining and Delimiting Engineering Problems**<br>• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. | Students are introduced to the design problem and begin to define it. Students build an initial understanding of materials, an understanding which is then used when students design solutions to the design problem. The concepts of properties and performance of materials later connect to the concepts of design criteria and constraints. On both days, students observe and measure properties of different materials to determine the material type.

| **PS1.A: Structure and Properties of Matter**<br>• Measurements of a variety of properties can be used to identify materials. | |

**Crosscutting Concepts** | **Cause and Effect**<br>• Cause and effect relationships are routinely identified, tested, and used to explain change. | In the Materials Science Lab, students design a materials test. Students learn that materials respond to tests in different ways because they have different properties.

| **Crosscutting Concepts** | **Cause and Effect**<br>• Cause and effect relationships are routinely identified, tested, and used to explain change. | |

| **Crosscutting Concepts** | **Cause and Effect**<br>• Cause and effect relationships are routinely identified, tested, and used to explain change. | |
Basic Teacher Preparation

Organize the class into design teams of 2 or 3 students. Students work in the same teams throughout the module. These working teams should be established before beginning Day 1.

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. All documents used on Days 1 and 2 can be found on pages 1 through 4 in the Composites Student Handbook. The documents used in this lesson are:

- 1.1: Materials Scavenger Hunt (pages 1 and 2)
- 2.1: Materials Science Lab (pages 3 and 4)

<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>Download, print, and prepare the Composites Student Handbook packets for students</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>Review all suggested teacher preparation resources</td>
<td>Refer to Suggested Teacher Resources at the end of Day 2</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>Composites Student Handbook</td>
<td>Download, print, and copy for students. Bind handouts into a Composites Student Handbook for each student.</td>
<td>1 per student</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Pencil</td>
<td>Wooden, graphite pencils</td>
<td>1 or more per team</td>
<td>Available in most schools or local craft store</td>
</tr>
</tbody>
</table>
| Assorted materials | Materials for Materials Science Lab activity. Each team needs a different material. Examples include, but are not limited to:  
  • Silly Putty  
  • Play dough or modeling clay  
  • Aluminum foil  
  • Balsa wood  
  • Plastic wrap  
  • Wax paper  
  • Rubber band  
  • Pantyhose  
  • Foam  
  • Polystyrene | 1 material per team | From student or local craft store |
<table>
<thead>
<tr>
<th>Equipment for Testing Materials</th>
<th>Equipment that could be used for testing materials in the Materials Science Lab activity. Examples include, but are not limited to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Ruler • Balance/scale • Scissors • Ice or access to freezer • Permanent markers • Spray bottle with water • Thermometer • Heat source (with appropriate safety gear)</td>
</tr>
<tr>
<td>Assortment</td>
<td>Available in most schools</td>
</tr>
</tbody>
</table>
Day 1: Squish It! Stretch It! Smash It!

Introduction (10 minutes)

Introduce the module by explaining that over the next several days, students will work as materials scientists to design strong and lightweight material for use in airplanes. The Driving Question is, How can we design strong and lightweight materials for use in airplanes? Post the Driving Question on the Driving Question Board (DQB). Have students develop a list of questions about the design problem. Start by developing one question as a class and then have students work in small groups or individually to develop the remaining questions. Questions may include:

- What are the different types of materials?
- How can we test materials?
- What makes a material strong?
- What makes a material lightweight?
- How do we design a material?

As students share their questions, post the questions to the DQB. Try to categorize the questions into a few main categories. At a minimum, guide the class toward developing the following three categories:

- What are the different kinds of materials?
- How do we design a material?
- How do we make a material strong and lightweight?

Tell students that these three questions will drive their work over the next several days. In addition, these three questions will help them answer the overarching Driving Question, How can we design strong and lightweight materials for use in airplanes? Post the questions on the DQB. Leave space under the questions to add sticky notes.

Important Note

The Driving Question Board is used throughout the module to guide student learning. Make sure the Driving Question Board is placed in a prominent location and can be accessed easily by students.

DRIVING QUESTION BOARD

How can we design strong and lightweight materials for use in airplanes?

What are the different types of materials? How do we design a material?

How do we make a material strong and lightweight?

Tell students that they will work through the engineering design process to create strong and lightweight materials for use in airplanes. Introduce students to the Engineering Design Process Diagram found in Appendix A and on page 18 in the Composites Student Handbook. In later lessons, students continue to work with the Engineering Design Process Diagram.
Investigation: Materials Used to Make a Pencil (10 minutes)

Tell students that on Day 1, they try to answer the question, *What are the different types of materials?* To begin this exploration, students examine an everyday object—a pencil—from a materials science perspective. Allow time in pairs for students to consider what materials they think are used to make a pencil. Develop a class list of pencil materials, which may include:

- Wood (often cedar)
- Graphite lead (graphite and clay)
- Paint
- Erasers (usually synthetic rubber or vinyl)
- Metal (for the band that secures the eraser in place)

Prompt students to make connections between the materials and their properties. Prompts might include:

- *How did you know the pencil is made of wood?*
- *What makes graphite lead a good ink source for the pencil?*
- *What properties of the metal make it a good metal for holding the eraser?*

Summarize that all objects are made of materials. This includes everyday objects like pencils as well as complicated, high-tech objects like laptops, cars, and airplanes. Some materials can be found in nature and others can be discovered and designed by humans.

Lead a short discussion about materials in other everyday objects. Encourage students to think about materials used to make desks, sports equipment, and vehicles. Emphasize the differences between natural materials and materials designed by humans.

Inform students that new materials are discovered and designed by engineers and scientists in order to build materials that are smaller, lighter, faster, stronger—and better!

**Material scientists** are interested in discovering new materials and then examining the structure and properties of the material to better understand how it might best be used.

Tell students that throughout this module, they act as material scientists. Their role is to design new materials with properties particularly well-suited for use in airplanes!
Investigation: Materials Scavenger Hunt (20 minutes)

Remind students that their goal in this lesson is to answer the question, *What are the different types of materials?* Tell students that they began to answer this question by identifying the materials in a pencil. Although this helped to answer the question, there is still more work to do! Students continue to investigate the question by examining many different everyday objects.

Challenge students to complete the student handout 1.1: Materials Scavenger Hunt on pages 1 and 2 in their Composites Student Handbook. The scavenger hunt can be done individually or in groups. Choose a setting (such as the classroom, lunchroom, or playground) and a time limit. The challenge is to investigate different objects in the chosen setting and try to determine the different materials that make up each object, just like the pencil example.

Students can write the name of each object (such as *bookshelf* or *notebook*), draw each object, or, if smart phones, tablets, or digital cameras are available, take a photo of each object. Then, they should list the materials they think make up that object. This task may be quite difficult with objects that are electronic devices, so encourage students to record questions about objects for which they are unsure.

After the scavenger hunt, bring the class back together to create a class list of materials, with each group writing the names of the materials they found on the board. As each group adds to the list, they can add a checkmark next to a material that has already been listed.

Challenge the students to develop some overall categories in which they can organize the materials listed on the board. With teacher support, have the class develop some categories of common materials, such as:

- **Ceramic** (tile, porcelain, pottery, and so forth)
- **Glass**
- **Metal** (including metal alloys)
- **Polymer** (plastic, paint, rubber bands, natural fibers, synthetic fibers, paper, and so forth)
- **Wood**

As an added bonus, challenge the class to identify whether the materials are natural or synthetic materials.

Extension

As an optional extension, consider having students compare a mechanical pencil to a standard pencil. Engage students in a discussion about natural and man-made components of the pencils.
Ask students if there are any outliers to their list of material categories. Suggest several other categories that may help capture some of the less common or more specialized materials that students may have encountered, such as:

- **Biomaterials** (bone, skin, hair, and so forth)
- **Manufactured composites** (a material made of two or more materials, like fiberglass, laminates, concrete, brick, carbon fiber composites, and so forth)
- **Semiconductors** (silicon-based electronic components)
- **Other materials** (strange manufactured materials, such as bucky balls and nanotubes)

**NGSS Key Moment**

As students categorize materials, they make progress on developing understanding of 5-PS1-3. In addition, grouping materials into categories helps students discover that some materials are very difficult to categorize. Many of these materials may be manufactured composites. The remaining lessons in the module focus on composites, so it is important to begin to spark student curiosity about composites.

**Important Note**

There are other categories of materials, such as **nanomaterials** and **optical materials**. For simplicity’s sake, this list includes the most commonly used material categories. There is some overlap with how materials can be categorized. The cellulose in wood and paper can be considered a polymer, and paper itself can be considered a composite. Shell and bone can be considered as natural composites. Brick is categorized as a ceramic, but when made the old-fashioned way with clay and straw, is sometimes used as an example of one of the first manufactured composites. If students disagree about which category a material should be slotted, this is a great opportunity for students to engage in a discussion about what they know, do not know, and need to know in order to make the determination.

**Lesson Close (10 Minutes)**

Reference the question on the DQB, *What are the different types of materials?* Ask students if they think that they made progress in answering the question. Tell students to record their progress on a sticky note. They should try to answer the question with as much evidence as they can. Students can use evidence from the investigations or the class discussion. When students are done, have them read their sticky notes out loud to the class and post them to the DQB.
Day 2: Squish It! Stretch It! Smash It!

Introduction (5 minutes)

Introduce the lesson by reminding students that the Driving Question for the module is, *How can we design strong and lightweight materials for use in airplanes?* In the last lesson, students began to identify different types of materials using the visual properties of the materials. Engage students in a whole class discussion to identify better ways to identify and describe the properties of materials. In this discussion, students might suggest that they could test the materials. Have students brainstorm different kinds of tests.

Investigation: Materials Science Lab (40 minutes)

In today’s lesson, students develop their own tests. They then carry out their tests to find out more about the properties and test the performance of different materials. Divide students into their design teams and refer students to student handout 2.1: Materials Science Lab on pages 3 and 4 in their Composites Student Handbook.

Give each team one material to investigate. Each team should be given a different material from all the other teams. You can choose your own materials for this activity. Some ideas include: Silly Putty, play dough, modeling clay, aluminum foil, balsa wood, plastic wrap, wax paper, rubber band, pantyhose, foam, polystyrene, ceramic tile, silicon baking cup, paper clip, bubble wrap, or pipe cleaner.

Allow time for students to observe the properties of the materials. The properties of the material are the characteristics that make up how it looks and how it behaves. For example:

- *What color is it?*
- *Is it heavy or light?*
- *Rigid or malleable?*
- *Opaque, translucent, or transparent?*
- *What words best describe the material?*

Besides examining the material’s properties, students should devise their own tests to determine a material’s performance, or how it behaves in different conditions. *What can they find out about the material?* Some ideas include stretching, squeezing, compressing, breaking, bending, ripping, dropping, bouncing, and more. *Is it waterproof? Can you color it with ink? Can you change its shape? Does it sink or float? Does it shatter when dropped? Does its behavior...*
change when it is cooled or heated? Does it dry out and change during that process? Is it waterproof?

Students should record the following in the spaces provided on 2.1: Materials Science Lab on pages 3 and 4 in their Composites Student Handbook:

- **Properties:** A list of adjectives to describe the material's appearance
- **Observations:** how the material behaves
- **Data Chart:** explain the tests devised and how the material performed
- **Ideas:** uses the material would work best for
- **Ideas:** uses the material would not work for

**NGSS Key Moment**

The materials science lab is an important opportunity for students to make progress on the 5-PS1-3 and Planning and Carrying Out Investigations. In this activity, students take the first steps in designing and carrying out a simple investigation in order to determine the properties of materials.

**Extension**

Challenge each group to choose a good use for their material and develop a jingle or marketing blurb to try to “sell” their material for this specific use. Extra points for being creative and thinking of a use that goes beyond the normal, everyday use of that material. For example, a ceramic tile may be well suited for a coaster that would hold a cup of hot cocoa. Ask each group to share their jingle or marketing blurb, or describe their material and the tests they performed. Encourage students to compare and contrast the properties and performance of the different materials.

**Lesson Close (5 minutes)**

Remind students that during this lesson they were introduced to the field of materials science and engineering. As this module progresses, students learn about the relationship between material science and aeronautical engineering by investigating the story of the discovery and application of a new kind of composite material. This new material—carbon fiber composite—allows engineers to design stronger and lighter airplanes. This makes the airplanes better because they are strong, safe, use less fuel, and have lower emissions that are harmful to the environment.

**Assessment**

Several opportunities for formative assessment exist in this lesson:

- **Composites Student Handbook** entries can be used to monitor student progress during the module. For this lesson, focus specifically on 1.1: Materials Scavenger Hunt and 2.1: Materials Science Lab.
• Whole class share-outs and discussions allows for formative assessment of student ideas.
• During small group work, visit each team to listen in on their conversations and provide just-in-time instruction.

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

Community Connections

This lesson shows personally relevant connections to the field of materials science and engineering. The objects we interact with daily—pencils, chairs, cars, bicycles, computers, art supplies—all are made of materials developed, designed, improved, and applied to different uses. Consider using materials familiar to students and specific to the local community.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Let’s Make a Pencil</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>

Sources


Lesson Overview

On Day 3, students are introduced to the engineering design concepts of **criteria** and **constraints** by focusing on the materials used to manufacture airplanes. A look back in time generates students’ curiosity about the materials used to build historic airplanes and how these have changed over time (from wood and fabric to high tech composites). Students are introduced to a Pugh chart as a matrix for evaluating design criteria and constraints. Students then participate in a mini-design challenge, the **Paper Airplane Mini-Design Challenge**, in which they construct paper airplanes from different materials and evaluate their alignment with the design criteria using a Pugh chart. An optional extension includes a viewing of the film, *Legends of Flight*.

This lesson builds on the concepts of material science introduced on Days 1 and 2. The **Paper Airplane Mini-Design Challenge** introduces basic concepts of the engineering design process—including criteria and constraints—while expanding students’ understanding of the importance of materials for achieving different design criteria. Pugh charts are introduced as a decision making tool for determining which solution best matches the design criteria.

Connecting to the Next Generation Science Standards

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

- **Science and Engineering Practices**: Asking Questions and Defining Problems, Constructing Explanations and Designing Solutions
- **Disciplinary Core Ideas**: ETS1.A Defining and Delimiting Engineering Problems, ETS1.B Developing Possible Solutions
- **Crosscutting Concepts**: Influence of Engineering, Technology, and Science on Society and the Natural World, Cause and Effect, Structure and Function

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

### Performance Expectations

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

- **3-5-ETS1-1**. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **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.
Specific Connections to Classroom Activity

In this lesson, students are introduced to a Pugh chart, which helps them identify and evaluate criteria and constraints for a design problem. Student use the Pugh chart to evaluate solutions to the design problem using model airplanes. Students also investigate previous solutions to the design problem by looking at historical designs of airplanes.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
<th>Connections to Classroom Activity</th>
</tr>
</thead>
</table>
| **Science and Engineering Practices** | **Asking Questions and Defining Problems**  
  - Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost. | Students clearly define the criteria and constraints of the design problem by creating a Pugh chart. Students compare multiple solutions to the design problem by comparing different materials used to create paper airplanes. |
|                            | **Constructing Explanations and Designing Solutions**  
  - Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem. | Students clearly define the design problem by creating a Pugh chart. Students compare multiple solutions to the design problem by comparing different materials used to create paper airplanes. |
| **Disciplinary Core Ideas** | **ETS1.A Defining and Delimiting Engineering Problems**  
  - Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. | Students clearly define the design problem by identifying the criteria and constraints of the design solution. Students use a tool—the Pugh chart—to evaluate how well a solution meets the criteria and constraints of a design problem. Students begin to design model solutions to the design problem by designing paper airplanes using different materials. Students test and compare different solutions. |
|                            | **ETS1.B: Developing Possible Solutions**  
  - Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. |                                                                                                    |
| **Crosscutting Concepts**  | **Influence of Engineering, Technology, and Science 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. | By examining the development of airplanes through the years, students see a timeline of change over time. Students recognize that engineers improve on existing technologies to increase their benefits and decrease known risks. Students consider their role in designing a composite material to continually improve materials used in airplanes. When testing model paper airplanes, students recognize that using different materials impacts how well an airplane performs. When students build and test their paper airplanes, they experiment with using different types of materials. |
|                            | **Cause and Effect**  
  - Cause and effect relationships are routinely identified, tested, and used to explain change. |                                                                                                    |
|                            | **Structure and Function**                                                                                                                |                                                                                                    |
Different materials have different substructures, which can sometimes be observed. Students begin to relate the structure, or materials, of the airplane to the function, or the ability to fly well.

Basic Teacher Preparation

This is a very interactive lesson for students. Collect the necessary materials, in their respective quantities, ahead of time. Review all Suggested Teacher Resources found at the end of the lesson. To prepare for the whole group discussions, review the Talk Science Primer.

Choose a paper airplane design and practice making the paper airplane so you will be able to support your students. All teams must make their paper airplanes using the same folding instructions.

When giving out the supplies to teams, most of the teams should be given one sheet of a particular material that has been precut into 8.5” x 11” pieces. Two teams should be given an 8.5” x 11” sheet of a particular material that has then been cut into smaller pieces. These teams should be given tape to use to fasten their small pieces back into a larger sheet before they begin folding their airplane. (This represents a material that can only be fabricated into small pieces and therefore results in an airplane with many seams and fasteners).

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. All Day 3 documents can be found on pages 5 through 8 in the Composites Student Handbook. The documents used in this lesson are:

- 3.1: Paper Airplane Mini-Design Challenge (pages 5–8)

<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 for this lesson</td>
</tr>
<tr>
<td>Make double-sided copies of the Airplane Design Cards (1 set per team)</td>
<td>Composites Teacher Handbook, Appendix D</td>
</tr>
<tr>
<td>Choose a paper airplane design</td>
<td>Use a favorite design, or search online to easily find many choices for simple airplane designs.</td>
</tr>
<tr>
<td>Collect the activity materials and divide them into kits for each team (each team needs a different material provided to them for paper airplane constructions)</td>
<td>Materials for paper airplane construction:</td>
</tr>
<tr>
<td></td>
<td>• Printer paper of different weights</td>
</tr>
<tr>
<td></td>
<td>• Cardstock</td>
</tr>
<tr>
<td></td>
<td>• File folder</td>
</tr>
<tr>
<td></td>
<td>• Tissue paper</td>
</tr>
<tr>
<td></td>
<td>• Wax paper</td>
</tr>
<tr>
<td></td>
<td>• Newspaper</td>
</tr>
<tr>
<td></td>
<td>• Aluminum foil</td>
</tr>
<tr>
<td></td>
<td>• Lightweight cardboard (like a cereal box)</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>Airplane Design Cards</td>
<td>Copy front to back and cut prior to distributing. Create one complete set per team.</td>
<td>1 per team</td>
<td>Composites, Appendix D</td>
</tr>
<tr>
<td>Paper airplane folding instructions</td>
<td>Select your favorite design from childhood or conduct a web search for simple airplane designs.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Different paper materials for paper airplane building for each team | Each team needs one 8.5 x 11” sheet of a material that is different from all the other teams. Examples include:  
  - Printer paper of different weights  
  - Cardstock  
  - File folder  
  - Tissue paper  
  - Wax paper  
  - Newspaper  
  - Aluminum foil  
  - Lightweight cardboard (like a cereal box) | 1 (8.5 x 11”) sheet per team | Available in most schools or from local store |
Day 3: Build an Airplane

Introduction (5 minutes)

Remind students that the driving question for the module is, *How can we design strong and lightweight materials for use in airplanes?* So far, students have investigated the different types of materials, but they have not yet considered how materials are used in airplanes. In this lesson, students further define the design problem by thinking about how materials are used in airplane design.

Challenge students to think like aeronautical engineers and determine the best materials to use for designing and building a new airplane. When engineers approach the design of any product—including an airplane—they have to first consider the criteria and constraints of the product. Explain what these terms mean:

- **Criteria** are the desired features of a design; the things you want to be sure your product has built into the design.
- **Constraints** are the limitations that you have to work around. Constraints include things like materials, durability, time, cost, function, size, weight, safety, cost of materials, manufacturing costs, how complicated the manufacturing process is, and the durability of the system over time (also known as the lifetime costs of using the materials).

**NGSS Key Moment**

The goal of Day 3 is to help students make progress in defining the problem. In this lesson, students realize that design solutions are limited by criteria and constraints. Students are introduced to a tool—the Pugh chart—to identify key criteria and constraints. Throughout this lesson, continually push on the ideas of defining a problem and clearly articulating criteria and constraints.

Design Work: Criteria and Constraints (5 minutes)

Have student teams brainstorm a list of a couple criteria and constraints that they think an aeronautical engineer would consider when choosing the best materials to use to build an airplane. After several minutes, bring the class together for a group share-out. As the students’ brainstormed ideas should show, many complicated factors go into the process of choosing materials to build an airplane. Each criterion directly links to a constraint, such as fuel efficiency, cost, or safety. Tell students that this lesson focuses on three of these criteria:

- Using *lightweight materials* means the plane weighs less. Less weight means the engines will burn less fuel, which costs less and reduces the amount of harmful emissions.
- Using *strong materials* improves the airplane’s safety. It also allows for the cabin to be pressurized at a level more comfortable for passengers.
- Using *materials that can be manufactured in large pieces*, rather than lots of small pieces, means the *number of seams and fasteners can be reduced*. All those seams and fasteners (rivets for example) can increase the weight of an airplane, meaning more fuel is needed. Additional seams and fasteners can also be initiation points for cracks, corrosion, and structural failures.
Mini-Lesson: Introduction to a Pugh Chart (5 minutes)

Explain that one way to think about the criteria and constraints for the design of our airplane is to use an organizer called a Pugh chart. A Pugh chart can help an engineer think through how their possible solutions best match the design criteria. Replicate the following chart on the board, adding a column for each student team.

Problem: What are the best materials for our new airplane?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Team #1 Solution</th>
<th>Team #2 Solution</th>
<th>Team #3 Solution</th>
<th>Team #4 Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal Number of Seams and Fasteners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flies Well</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To demonstrate how to use a Pugh chart, start by exploring the need to make a decision about a topic familiar to students. Choose a problem to solve, such as best book series, funniest movie, best team sport, and so forth. Together, define the problem, such as, What recess game would be the best fit for our class to play together? Create a list of criteria for solving the problem. As a class, complete a Pugh chart, assigning points to determine which choice best aligns with the criteria.

Adapt the sample Pugh chart shown below to make it fit a topic you think will interest your students. The example is for choosing a recess game that meets specified criteria. Scores are assigned (0 and 1) based on whether a criterion is met. The sample Pugh chart shows that playing freeze tag might be the best option, based on the desired criteria.

Problem: What recess game does the class want to play?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Tetherball</th>
<th>Freeze Tag</th>
<th>Soccer</th>
<th>Shooting Hoops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involves a lot of running</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>For six or more players</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Does not require a ball</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Points</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Return to the Pugh chart for the airplane materials. Emphasize that the students’ designs should use materials that are lightweight, strong, and have the minimal number of seams and fasteners.
Mini-Lesson: Flying Backwards through Time (10 minutes)

Tell students that looking back in time can be helpful. History can show them what materials were used to build the earliest airplanes and how design choices have changed over time as new materials and manufacturing processes became available.

Distribute one set of Airplane Design Cards (Appendix D) to each team. Instruct students to place the cards on the table with the pictures of the airplanes facing up. Then, challenge each team to create a timeline of airplane design by placing the airplane cards in order, from what they think is the earliest (oldest) airplane to the newest (most recent) airplane. Students can guess; the point is for them to have a discussion with their teammates.

Allow several minutes for the timeline activity. Then, bring the class together to discuss their ideas. After the discussion, have them check their timeline against the following, and rearrange their cards if necessary.

Timeline of Airplane Design

- Boeing Stearman Kaydet Bi-plane (1936–1948)
- Lockheed Constellation (1937–1967)
- Schleicher ASW-20 Glider (1977–1990)
- Boeing F/A-18 Hornet (1983–present)
- Airbus A380 (2007–present)
- Boeing 787 Dreamliner (2011–present)

Ask the class what they noticed about the differences among the airplanes and materials. Why might those differences have occurred? Example responses include: new materials becoming available or the designers having different design criteria for each plane (glider vs. fighter jet vs. commercial airline).

Next, have students flip over their cards, so the information about materials is facing up. Allow time for students to read the cards and then discuss the following questions briefly in their teams:

- How did the choice of materials change over time?
- What surprised you?
- What do you want to know?

Bring the class back together and provide some just-in-time instruction about any of the materials students have questions about. In particular, provide a definition of composite materials, letting students know that they will study these in greater depth over the next few days.

- A composite material is a material made up of two or more materials. When combined, they become a new material with properties different than each of the materials alone.
- A composite material is made up of a reinforcement ingredient (such as fiberglass or carbon fiber) and a matrix ingredient (such as epoxy resin). There are many types of composite materials, but some used in airplane construction include fiberglass, carbon fiber composites, GLARE (a fiberglass and aluminum composite), and thermoplastic composites.

NGSS Key Moment

Examining airplane designs throughout history helps students identify the ways by which new designs change over time according to societal wants and needs.
Explain that the engineers who designed each of these airplanes had different criteria for their
design, and different materials were available at different times. For instance:

- The designers of the Kaydet bi-plane could not use advanced composites, because
  materials scientists had not yet invented these materials.
- The designers of the Airbus 380 and the Boeing 787 Dreamliner had access to advanced
  composite materials that provide the benefit of being both stronger and lighter than other
  materials historically used to build airplanes.

**Design Work: Paper Airplane Mini-Design Challenge (10 minutes)**

Explain that today’s mini-design challenge is to choose materials for a new airplane design that,
as we saw in the Pugh chart, are lightweight, strong, and have the minimal number of seams and
fasteners. Since students won’t be designing and building an actual airplane, they model the
process by using different materials to design and build paper airplanes.

Distribute the paper airplane activity materials so each team has a different set of materials for
building their paper airplane (see the *Basic Teacher Preparation* section). Have students record
their results on 3.1: Paper Airplane Mini-Design Challenge on pages 5 through 8 in the
*Composites Student Handbook*.

The mini-design challenge rules are:

- Each team makes a paper airplane using the teacher-provided material and folding
  instructions.
- All teams *must* follow the same folding instructions.
- If a team’s material is in small pieces, they should use tape to reassemble the pieces into
  an 8.5” x 11” sheet before folding their airplane. This represents a material that can only be
  fabricated in small pieces and must be assembled using many seams and fasteners.
- All teams should fold their paper airplanes and complete multiple test trials. Record the
test results on 3.1: Paper Airplane Mini-Design Challenge on pages 5 through 8 of the
*Composites Student Handbook*.

**Whole Group Discussion: Paper Airplane Reflection (10 minutes)**

Bring the class together to share their results. Ask the students:

- *How did your airplane perform?*
- *What were the strengths and weaknesses of the design and the material?*
- *What surprised you?*
- *What do you want to know?*

As a class, come up with a definition for *flies well*. Then, ask each team to come up to the
board to fill out one column in the Pugh chart

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**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.
for their airplane material. A 1 should be used if the material was light, strong, used only one piece of material, or flew well. A 0 should be used if the material was heavier, weak, used many pieces of material and fasteners, or did not fly well. Calculate the points for each team’s solution.

**Problem: What are the best materials for our new airplane?**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Team #1 Solution</th>
<th>Team #2 Solution</th>
<th>Team #3 Solution</th>
<th>Team #4 Solution</th>
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<tbody>
<tr>
<td>Lightweight</td>
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<td></td>
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<tr>
<td>Strong</td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Points</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As a class, decide which materials best met the design criteria and are worth pursuing as possible design solutions. Be sure to compare the paper airplanes with “fasteners” (tape) to the ones that did not use fasteners. Have students record their observations and sketches and the class choices on 3.1: Paper Airplane Mini-Design Challenge and respond to the following prompts:

- *What surprised you?*
- *What do you still want to know?*

**Lesson Close (5 minutes)**

Connect today’s activities to the design and construction of modern airplanes. Since today’s aeronautical engineers have access to advanced composite materials, they can choose materials that meet their design criteria in a way that was not possible with historical aircraft. With the invention of composite materials, including carbon fiber composites, and new manufacturing processes, aeronautical engineers are creating planes that are lighter, stronger, and more fuel efficient and give off less emissions.

**Important Note**

Composites, particularly carbon fiber composites, are the focus of the remainder of the module. Have students consider why focusing on composites is important. At this point, have students brainstorm ideas. In subsequent lessons, they build a stronger understanding of composites so they can argue for the use of composites in airplanes.

**NGSS Key Moment**

Prompt students to consider why certain materials performed better than others. Have students identify the properties of the materials and think about how the properties helped the plane fly.
Show students a diagram of the Boeing 787 Dreamliner that illustrates where different materials are used in the plane. The diagram is clickable. Reference Background Information for Teachers (Appendix E) to learn more about the Boeing 787 Dreamliner.

Ask students to share their responses to one of the following prompts in their Composites Student Handbook:

- *Summarize what you learned today about the materials used to design and manufacture airplanes.*
- *What surprised you today when learning about the materials used to design airplanes?*
- *What did you already know but were challenged to think about in a new way?*

**Extension**

As an optional extension activity, show students the film *Legends of Flight*. The film is available on-demand from Amazon Instant Video. The 2010 film is not rated but is intended for general audiences. It has a run time of 45 minutes. It was originally filmed as an IMAX film and was shown at museums and theaters worldwide. It features many of the same planes used in this lesson plan.

Another video option is to choose one of the engaging aerospace engineering mini-documentaries or interactive media resources from The PBS Learning Media: Aerospace Engineering Collection.

**Assessment**

Several opportunities for formative assessment exist in this lesson:

- Composites Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus specifically on 3.1 Paper Airplane Mini-Design Challenge.
- Whole class share-outs and discussions allow for formative assessment of student ideas and building content knowledge.
- When students meet in their teams and work on the mini-design challenge, spend time with each team, listening in on their process and providing support as needed.

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

Field trips to aerospace museums can enhance student learning. For example, if you live in the state of Washington, the greater Seattle area is home to several Boeing Plants that manufacture modern airplanes, including assembly of the Boeing 787 Dreamliner. Curricular connections to the design and manufacture of this airplane can be relevant to the local community.

A field trip to the Museum of Flight (Seattle) or Future of Flight (Everett) allows students to further investigate the concepts introduced in this lesson as well as see historical and modern airplanes constructed with different materials.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Resource</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting the Needs of All Learners</td>
<td>Composites Teacher Handbook, Appendix B</td>
</tr>
<tr>
<td>Airplane Design Cards</td>
<td>Composites Teacher Handbook, Appendix D</td>
</tr>
<tr>
<td>Background Information for Teachers</td>
<td>Composites Teacher Handbook, Appendix E</td>
</tr>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Boeing 787 Dreamliner</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Legends of Flight</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>PBS Learning Media: Aerospace Engineering Collection</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Talk Science Primer</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>
Lesson Overview

During Day 3, students began to consider the use of composites in airplanes. They learned that many engineers use composites because they are lighter, stronger, and more fuel efficient and give off less emissions. But why? In this lesson, students begin to investigate composites’ characteristics. Students consider how composites could help an airplane perform better.

A retelling of the ancient Greek myth of *Daedalus and Icarus* helps students as they co-construct a basic recipe for a composite material:

\[
\text{reinforcement ingredient + matrix ingredient = composite material}
\]

This basic recipe is then applied to other examples of composite materials, including ancient Egyptian bricks, candy brittle, and carbon fiber composites.

A mini-design challenge engages students in designing a candy brittle recipe by evaluating the performance of different reinforcement ingredients. This design challenge provides students with the opportunity to engage in the engineering design process as well as deepens their understanding of the role of reinforcement and matrix ingredients in composite materials. The class collaboratively defines the challenge’s criteria and constraints, decides on a fair test, and uses a Pugh chart to evaluate the performance of each team’s candy composite.

This lesson builds on the concepts of material science introduced in previous lessons by focusing on a particular category of materials—composites. The lesson focuses specifically on what makes composite materials different from other kinds of materials, and illuminates the basic recipe for developing composite materials. This lesson leads directly into Day 5: Carbon Fiber Composites, which focuses on carbon fiber composites as an example of a composite material used widely for various uses, as well as the material’s use in the construction of airplanes.

Connecting to the Next Generation Science Standards

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

- **Science and Engineering Practices:** Asking Questions and Defining Problems, Constructing Explanations and Designing Solutions
- **Crosscutting Concepts:** Cause and Effect, Structure and Function

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

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

3-5-ETS1-1. *Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.*

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:

5-PS1-4. *Conduct an investigation to determine whether the mixing of two or more substances results in new substances.*

Specific Connections to Classroom Activity

In this lesson, students learn about the basic formula for making a composite (reinforcement ingredient + matrix ingredient = composite material). By considering many different examples of composites, students begin to realize that mixing two or more substances may result in a new substance with different properties. In a mini-design challenge, students create a candy brittle, an example of a composite. In the challenge, students define the design problem and generate and compare multiple possible solutions.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
<th>Connections to Classroom Activity</th>
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</thead>
<tbody>
<tr>
<td>Science and Engineering</td>
<td>Asking Questions and Defining Problems</td>
<td>In the candy brittle design challenge, students define the design problem and identify criteria and constraints using a Pugh chart. After creating candy brittle, students compare the various recipes against the identified criteria and constraints. Students consider which recipe best meets the needs of the design problem.</td>
</tr>
<tr>
<td>Engineering Practices</td>
<td>• Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.</td>
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<tr>
<td></td>
<td>Constructing Explanations and Designing Solutions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.</td>
<td></td>
</tr>
<tr>
<td>Disciplinary Core Ideas</td>
<td>ETS1.A: Defining and Delimiting Engineering Problems</td>
<td>In the candy brittle design challenge, students define the problem and identify criteria and constraints. After creating candy brittle, students compare the various recipes to determine how well each recipe meets the needs of the design problem.</td>
</tr>
<tr>
<td></td>
<td>• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.</td>
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<td></td>
<td>ETS1.C: Optimizing the Design Solution</td>
<td>After creating candy brittle, students compare the different solutions to determine which of them best solves the problem. Students observe the various ingredients used to make candy brittle. They then make observations of the candy brittle. Students recognize differences in the properties of all the materials and realize that when two substances are mixed, a new substance with different properties may be formed.</td>
</tr>
<tr>
<td></td>
<td>• Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.</td>
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<tr>
<td></td>
<td>PS1.B: Chemical Reactions</td>
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</table>
When two or more different substances are mixed, a new substance with different properties may be formed.

Students realize that by mixing two substances they can form a new substance with different properties.

When students learn the formula for making a composite (reinforcement ingredient + matrix ingredient = composite material), they learn that composite materials have substructure (matrix and reinforcement ingredients) that each serve functions.

Basic Teacher Preparation

This is another very interactive lesson for students that requires a station of materials be prepared for students ahead of time. Collect the necessary materials, in their respective quantities, prior to class. Access to a heat source, such as a stove top or microwave oven, along with a refrigerator is necessary to create the candy composite. Create an original candy brittle “matrix-only control” at least one day prior to class.

Prior to instruction, decide if students will engage in the optional 30-minute Candy Composite Challenge (Part 2), where students test their composite candy and complete a Pugh chart to evaluate the performance of each team’s candy composite.

If you are planning to allow students to eat their Candy Composites after the challenge, be sure to check local and state regulations regarding the consumption of food created in a lab setting.

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. All Day 4 documents can be found on pages 9 through 13 in the Composites Student Handbook. The documents used in this lesson are:

- 4.1: Early Composites (page 9)
- 4.2: Candy Composite Challenge (Part 1) (pages 10 and 11)
- 4.3: Candy Composite Challenge (Part 2) (pages 12 and 13)

<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>The Candy Composite Challenge activity is best if some “controls” are created ahead of time, including: Make an “original candy brittle control” by making one of the candy brittle recipes as written.</td>
<td>Refer to the Suggested Teacher Resources at the end of this lesson for peanut brittle recipes. The “original candy brittle control” allows students to compare their redesigned recipes to one made from the original recipe as well as compare to reinforcement-only and matrix-only controls.</td>
</tr>
</tbody>
</table>
- Make a “matrix-only control” using the same basic recipe, but only use the chocolate or candy syrup in a pan without adding any nuts or candies as reinforcement ingredients. This “matrix-only control” is used for comparison to show how the addition of reinforcement ingredients changes the structure and performance of the candy composite material.

- A “reinforcement-only control” does not need to be prepped ahead of time, because the candies or nuts themselves serve this purpose.

- Set-up a materials station with the pans and assortment of reinforcement ingredient options (coconut, candy, nuts, and so forth)

Refer to the Materials List below

---

**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>Heat source, such as a stove top or microwave oven</td>
<td>Access to a kitchen with a stovetop or a microwave oven</td>
<td>1 heat source</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>Access to overnight use of a refrigerator</td>
<td>1 refrigerator</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Aluminum pans</td>
<td>Disposable aluminum mini-loaf pans</td>
<td>1 per team</td>
<td>From student or local store</td>
</tr>
<tr>
<td>Cooking supplies</td>
<td>Cooking supplies for the recipe of your choice: measuring cups, bowls, spoons, hot pads, and so forth</td>
<td>As needed</td>
<td>From student or local store</td>
</tr>
<tr>
<td>Matrix ingredient</td>
<td>Matrix ingredient, depending on the recipe of your choice (melted chocolate or peanut brittle syrup)</td>
<td>Enough to make 1 pan per student team</td>
<td>From student or local store</td>
</tr>
<tr>
<td>Reinforcement ingredients</td>
<td>Assortment of reinforcement ingredients, such as Twizzlers®, gummy worms, Whoppers®, hard candies, Mike &amp; Ikes®, shredded coconut, nuts, Rice Krispies® Cereal, and so forth</td>
<td>At least 1 more reinforcement ingredient option than there are student teams</td>
<td>From student or local store</td>
</tr>
<tr>
<td>Disposable gloves</td>
<td>Disposable gloves for hygiene when handling food items</td>
<td>1 pair per student</td>
<td>Local store</td>
</tr>
</tbody>
</table>
Day 4: Composites Everywhere

Introduction (5 minutes)

Begin class by referring to the Driving Question Board. Tell students that they are going to focus on the remaining two questions, *How do we make a material strong and lightweight?* and *How do we design a material?* Students already made significant progress on the first question, *What are the different types of materials?* Tell students that in order to answer their questions about designing strong and light materials, the class is going to spend time investigating composites.

As a group, reflect on the concept introduced in the last lesson, that the creation of a new material by material scientists—carbon fiber composites—allowed aeronautical engineers to solve a problem. They were able to design and construct lighter and stronger airplanes using materials with few seams and fasteners, thus reducing drag and increasing fuel efficiency. Aeronautical engineers were able to use carbon fiber composite materials to meet their design criteria while working within their identified constraints.

Ask if anyone can define a composite material in their own words. Have students record their ideas on the 4.1 Early Composites on page 9 in the Composites Student Handbook. As needed, share the following definition:

- **Composite:** A material made up of two or more materials; when combined they become a new material that has properties different than each of the materials alone. A composite material is made up of a reinforcement ingredient and a matrix ingredient. The reinforcement ingredient provides structure, while the matrix ingredient binds or glues everything together.

Mini-Lesson: Early Composites (15 minutes)

Tell students that they are going to go way back in time, back to the time of Ancient Greece, to find one of the earliest descriptions of a composite material. For this, we turn to Greek Mythology for the story of Icarus and his father, Daedalus. Many versions of this story are available online if you prefer a written format; however, this video version of the story is a nice way to introduce the myth.

Ask students to talk with a partner about the role of composite materials in this story. Consider discussion prompts such as:

- *What materials did Daedalus use to make the wings?*
- *What role do they think the feathers and the wax played in the structure of the material they formed?*

Have students sketch a design for Daedalus’ wings, using only tree branches, feathers, and wax on 4.1: Early Composites on page 9 in the Composites Student Handbook.
Share another example of an early composite material from Ancient Egypt. Bricks were originally made of chopped up straw mixed with wet mud or clay that was scooped into rectangular molds. The material was then baked in the sun until it hardened. The new brick material—made of straw and mud or clay—had a different structure and different properties than either of the two ingredient materials.

**Video Link (Optional)**
Consider sharing this short video that shows the early way of manufacturing bricks:
- Brick Making in Egypt (How Stuff Works, 1 minute) [Web Link]

**Design Work: Recipe for a Composite (10 minutes)**

Refer students to 4.1: Early Composites (page 9) in their student handbooks to complete the sentence stems below. Ask students, *What is the basic recipe for a composite material?* As a class, co-construct this recipe. First, have students think about the composite definition shared earlier. Write a blank equation on the board:

\[
\text{________________} + \text{________________} = \text{Composite}
\]

Have students talk with a partner and share their ideas on how to complete the recipe. *What are the two ingredients?* After a few minutes, ask partners to share their ideas. Then, together determine that the recipe is as follows:

**Recipe for a Composite Material**

\[\text{Reinforcement ingredient} + \text{Matrix ingredient} = \text{Composite}\]

*What are reinforcement and matrix ingredients?* Together, overlay the ingredients from Icarus’ composite wings and ancient bricks onto this recipe. Have students record the information on page 9 in their *Composites* Student Handbook.

**Recipe for a Composite Material**

\[\text{Reinforcement ingredient} + \text{Matrix ingredient} = \text{Composite}\]

*Feathers (reinforcement)} + *Wax (matrix) = Wings (Composite)

*Straw (reinforcement)} + *Clay/Mud (matrix) = Bricks (Composite)

Explain that reinforcement ingredients—like feathers—are materials that create the structure of the material. In composites, the reinforcement ingredient is usually some kind of fiber-like material.

- **Examples of reinforcement materials** include straw or feathers, or in modern materials, the glass fibers in fiberglass composites, the wood fibers in plywood, or the carbon fibers in carbon fiber composites.

Matrix ingredients—like wax—are materials in liquid form that can be poured over or combined with the fiber reinforcement ingredient to bind it together. Through cooling, heating, high pressure, and/or chemical reactions, the matrix ingredient hardens.

- **Examples of matrix ingredients** include mud or wax, or in modern materials, epoxy resins and other types of polymers and glues.
Ask students to think of everyday examples of composite materials. Where are composite materials used in their own lives? Have students talk with a partner. Then, share as a whole group, creating a list of everyday composite materials on the board. Some ideas include:

- Concrete
- Fiberglass
- Plywood
- Some prepared foods, such as crispy rice treats (rice cereal and marshmallow) or peanut brittle. Note: Most likely this won’t come up, but if it does, it is an excellent segue to the optional Candy Composite Challenge activity.

Return to the class list of material categories that the students developed on Day 1. If you haven’t already added composites to the list, do so now.

The next challenge is to take what students know about composite materials in general and develop the recipe for a carbon fiber composite material, which is the focus of this module of study. Overlay the ingredients to create one more recipe:

**Recipe for a Composite Material**

Reinforcement ingredient + Matrix ingredient = Composite

- Feathers (reinforcement) + Wax (matrix) = Wings (Composite)
- Straw (reinforcement) + Clay or Mud (matrix) = Bricks (Composite)
- Carbon fiber (reinforcement) + Epoxy resin (matrix) = Carbon fiber composite

Like Daedalus’ wing design, or ancient Egyptian bricks, carbon fiber composites are made of a fiber reinforcement ingredient and a glue-like matrix ingredient. These ingredients are combined and then treated with heat and/or pressure. The new composite material has a different structure and performs in different ways than either of the two ingredients would on their own.

Carbon fiber composites have many qualities that make them different from other types of materials, which makes them a valuable new material for aeronautical engineers. This includes the fact that they can be:

- Made in very large pieces, which reduces the need for a lot of pieces, seams, and fasteners
- Formed in molds to create custom shapes
- Lightweight and strong
- Resist corrosion

Students learn more about how carbon fiber composites are made in the next lesson. But first, they work in their design teams to find the best solution to an engineering design problem.
Design Work: Candy Composite Challenge (Part 1) (20 minutes)

Ideally, conduct the Candy Composite Challenge in class (as a whole group or in small groups) if you have access to kitchen facilities including a stovetop or microwave oven as well as overnight use of a refrigerator.

Many stovetop and microwave candy brittle recipes are available online. Links to two microwave-versions are provided. The microwave peppermint brittle is the easiest since the matrix ingredient is simply melted chocolate. The peanut brittle recipe has a few extra steps because you have to make a sugar syrup for the matrix ingredient. Determine whether students should use a candy syrup as the matrix ingredient—as is traditionally used in peanut brittle—or melted chocolate.

- **Microwave Peanut Brittle Recipe.**
  Uses a sugar syrup, total prep time about 10 minutes.

- **Microwave Peppermint Brittle Recipe.**
  Uses melted chocolate, total prep time about 10 minutes.

Tell students that since they know the basic material for making a composite material, they are going to make a model of a composite material. They are going to make a candy composite!

**Helpful Tip**

This mini-design challenge provides students with the opportunity to design, make, and test their own composite material. This activity can be completed with several different options depending on time, access to kitchen facilities, and overall learning goals. Alternatively, the recipe can be sent home as a homework assignment so students who have access to a kitchen at home can make a batch of candy composite.

**Video Links (Optional)**

- Microwave Peanut Brittle Recipe [Web Link]
- Microwave Peppermint Brittle Recipe [Web Link]

**Important Safety Note**

Substitute the peanuts for another ingredient if your classroom is peanut-free. Be aware of any other food allergies. Use good hygiene practices, including hand washing and using gloves during handling of food items. Bowls, pans, and burners will be hot; provide hot pads/mitts and supervise students at all times. The candy syrup or melted chocolate will be very hot and could easily burn skin. An adult should be responsible for pouring them into the prepared pans.
Issue the design challenge to students, as follows:

In the *Candy Composite Challenge*, you are challenged to develop a recipe for a composite material made of candy. This is a composite we can eat! Even though our composite materials will be made of candy ingredients, they will serve as a model of a composite and will need to follow the basic recipe for a composite. This means the recipe will have both reinforcement and matrix ingredients, and will go through the processes of both heating and cooling to form the material.

Together, we will develop the criteria and constraints for the challenge. We will also collectively agree on the fair test that we will use to evaluate how the candy composites performed and which one best meets our criteria.

Explain that certain types of candy, called *brittles*, are an example of an everyday composite that is edible and delicious. Peanut brittle and peppermint bark are two examples. On the board, write the recipe for a candy composite.

**Recipe for a Candy Composite**

*Nuts/candy bits (reinforcement) + Caramel/chocolate (matrix) = Candy brittle (Composite)*

Explain that for our recipe for making a candy composite, nuts or candy pieces serve as the reinforcement ingredient. Caramel, sugar syrup, or chocolate serve as the matrix ingredient. When heated, these matrix ingredients can be poured over the reinforcement ingredients to combine together into a new material once it cools and becomes hard and brittle. A candy brittle is allowed to cool in a pan until hardened, and then it is broken into pieces so students can eat it. Show students a sample of candy brittle made using the original recipe.

Have students work in design teams to redesign the recipe and choose their own reinforcement ingredients to make a candy composite they think will best meet the criteria of the design challenge. Refer students to 4.2: *Candy Composite Challenge (Part 1)* on pages 10 and 11 in the *Composites Student Handbook*.

As a class, determine criteria and constraints. Ask students to help construct a list of criteria and constraints for this project. Some examples are shown below, but your class might have different ideas for this challenge.

**NGSS Key Moment**

In the *Candy Composite Challenge*, students practice clearly defining a design problem according to criteria and constrains and comparing multiple solutions. They also build an initial understanding of the idea that mixing two or more substances may result in the creation of a new substance with different properties.

To develop the understanding that mixing two or more substances may result in the creation of a new substance with different properties, students must first take careful note of the properties of the composite ingredients. Prompt students to consider the properties of the matrix and reinforcement ingredients. Later, build on this idea by prompting students to consider how the properties of the composite differ from the properties of the ingredients.
Design Criteria (example):
- Must include at least one reinforcement ingredient
- Must use the provided matrix ingredient (such as chocolate)
- Is edible
- Tastes good
- When tested using our testing protocol, fractures into pieces about the size of a tortilla chip for ease of consumption (not into little crumbles or tiny pieces)

Design Constraints (example):
- Can only use a total of 1 cup maximum of reinforcement ingredients
- Reinforcement ingredients can be used whole or broken/crushed
- Matrix ingredient poured into pans to a depth of 1.5”
- Final product must be edible
- Use only ingredients provided

Second, co-construct a Pugh chart students can use to evaluate their final products. Students record their Pugh chart on 4.2: Candy Composite Challenge on page 9 in the Composites Student Handbook. Write the Pugh chart on the board so it can be used for evaluating the teams’ final products.

Third, as a class, determine a fair test to evaluate how well the final products meet the project criteria. A fair test is an agreed-on protocol. All of the final products will be tested using the same protocol. For example, do you want to smack the pans on the counter to see how much they break? Or smack them with a hammer? How many times will you smack it? Or will you try to break the candy by hand? Who will do this? Will the candy composites be cold or at room temperature during testing? For a more controlled test, consider using a C-clip or a vice grip and measuring how many millimeters the screw portion is able to travel before the candy brittle breaks.

Have students record the testing protocol on 4.2: Candy Composite Challenge on page 11 in the Composites Student Handbook. Write the agreed-on testing protocol on the board for all to see.

Allow about 10 minutes for students to meet in their design teams. The students should develop a plan for their own candy composite, with the goal of developing a product that best meets the identified criteria and works within the constraints.

Have students record their sketches and notes on 4.2 Candy Composite Challenge on page 10 in the Composites Student Handbook. Provide an assortment of reinforcement ingredients (refer to the Materials List for this lesson). Encourage students to think about the properties of the different materials and how they think they will perform during testing. Students should consider
their *choice* and *amount* of reinforcement ingredients, and *how they assemble them* in the pan (close together, far apart, crisscrossing, using more than one type of candy, and so forth).

**Extensions**

Alternatively, provide different matrix ingredients (white chocolate, milk chocolate, caramel, peanut brittle syrup, melted hard candies, and so forth) but this makes the activity and comparisons more challenging than having everyone use chocolate as their matrix ingredient.

Each team arranges their reinforcement ingredients in a small aluminum bread pan. Have students sketch their arrangements on **4.2 Candy Composite Challenge** on page 11 in the *Composites Student Handbook*.

Have an adult pour the brittle syrup or melted chocolate into the pans, covering students’ reinforcement ingredients. For comparison’s sake, regulate how much syrup or chocolate is used so each team uses the same amount. For example, a specific number of inches or ounces of melted chocolate poured into the pans. If possible, cool the pans in a refrigerator overnight.

**Design Work: Candy Composite Challenge (Part 2) (Optional)**

(35 minutes)

The next day, remove the pans from the refrigerator. Conduct testing using the fair test that the class created. After conducting the fair test, facilitate a group discussion. Then, have students complete the questions on page 12 in the *Composites Student Handbook*:

- *How did your recipe redesign perform?*
- *Which teams’ candy composites best met the design criteria? What design strategies did they employ that were particularly successful*?
  - *Unsuccessful?*

Have students evaluate the candies created using their redesigned recipes, again using the Pugh chart. Facilitate a whole group discussion with the following questions:

- *What are the differences between the candies made from the original recipe, the syrup/chocolate-only (matrix-only) recipe, the candy-only (reinforcement-only) recipe, and their modified composite recipes?*
- *Which products best meet the criteria and constraints for the project?*
- *What is special about the combination of a reinforcement and matrix ingredient?*

Have students talk with their teams about what they would change if they could do another redesign. Students should record their ideas on **4.3: Candy Composite Challenge (Part 2)** on page 12 in the *Composites Student Handbook*.
Lesson Close (Optional) (15 minutes)

Summarize the lesson and connect to the use of carbon fiber composites in modern airplane design and manufacturing. Remind students they learned about the special properties of composite materials that enable them to perform in ways that have certain advantages—depending on the design criteria—than other materials. The Candy Composite Challenge showed them that a composite material—consisting of both reinforcement and matrix ingredients—when mixed and treated (through heating, cooling, or pressure) performs in a way unique to the individual ingredients.

Remind students of the evolution of airplane materials they explored during Day 3. Have students explain the advantages carbon fiber composites have over wood, fabric, steel, aluminum, and other materials that were once extensively used in airplane manufacturing.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Composites Student Handbook entries can be used to monitor student progress. For this lesson, focus specifically on 4.1 Early Composites, 4.2 Candy Composite Challenge (Part 1), and 4.3 Candy Composite Challenge (Part 2).
- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students meet in their teams and work on the mini-design challenge, spend time with each team, listening in on their process and providing support as needed.

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

Students may have made candy at home or seen it made in a local candy shop, thus allowing for connections between the candy composite activity and their own life experiences. Students may have also seen cake-design shows, like “Cake Boss,” on television where cake designers use blocks of Rice Krispie® treats to form the structure of oversized, complicated cake designs. Rice Krispie® treats can be considered as another example of an everyday, edible composite material. These treats are made from Rice Krispie® Cereal (reinforcement ingredient) and melted marshmallows (matrix ingredient). The mixture is heated, pressed into a form (a pan), and cooled. The treats have properties that make them desirable to cake designers: they are edible, malleable, moldable, able to be carved with a knife, lightweight, and strong.
Suggested Teacher Resources

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<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
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<tbody>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Daedalus and Icarus (Mimi the Storyteller, 6:31 minutes)</td>
<td>[YouTube Link]</td>
</tr>
<tr>
<td>Brick Making in Egypt (How Stuff Works, 1 minute)</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Microwave Peanut Brittle Recipe</td>
<td>[Web Link]</td>
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<tr>
<td>Microwave Peppermint Brittle Recipe</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>

Sources


Lesson Overview

This lesson introduces students to the variety of products that use a special kind of composite material. Students develop an understanding of three types of material strength (compressive, tensile, and shear) in a Cardboard Challenge. A composites criteria and constraints activity challenges students to examine why carbon fiber composites are used in modern airplane design.

The lesson connects to the concepts of material science introduced in the first three days and builds on the topic of composite materials introduced on Day 4. Students investigate what makes carbon fiber composite materials different than other materials, and specifically, what benefits carbon fiber composites bring to the design of airplanes. As such, this lesson leads directly into Day 6: Textile Technology, which examines the manufacturing processes used to make carbon fiber composites.

Connecting to the Next Generation Science Standards

On Day 5, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices:** Asking Questions and Defining Problems
- **Disciplinary Core Ideas:** ETS1.A Define and Delimiting Engineering Problems, ETS1.B Developing Possible Solutions, PS1.A Structure and Properties of Matter
- **Crosscutting Concepts:** Cause and Effect

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-ETS1-1.** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **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.

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

- **5-PS1-3.** Make observations and measurements to identify materials based on their properties.
Specific Connections to Classroom Activity

In this lesson, students observe corrugated cardboard and test the cardboard for three types of material strength. Students plan and carry out fair tests on the cardboard. Through the tests, students identify failure points and consider aspects of the cardboard that could be improved. Using their newly gained understanding of material strength, students further define the design problem and associated criteria and constraints.

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<th>Connections to Classroom Activity</th>
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<tbody>
<tr>
<td>Science and Engineering</td>
<td><strong>Asking Questions and Defining Problems</strong></td>
<td>By identifying three types of material strength, students further define the design problem. They add to their criteria that carbon fiber composites for airplanes should have strong tensile strength.</td>
</tr>
<tr>
<td>Engineering Practices</td>
<td>• Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.</td>
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<tr>
<td>Disciplinary Core Ideas</td>
<td><strong>ETS1.A Defining and Delimiting Engineering Problems</strong></td>
<td>Students recognize that a composite designed for an airplane must have high tensile strength. Students add material strength to their criteria.</td>
</tr>
<tr>
<td></td>
<td>• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.</td>
<td>Students research the types of strength exhibited by materials and consider the types of strength needed in airplane materials. Students perform an example test on cardboard to determine how well cardboard performs under a range of conditions. The tests identify failure points in the cardboard which helps students think about which elements of the cardboard design might need to be improved.</td>
</tr>
<tr>
<td></td>
<td><strong>ETS1.B: Developing Possible Solutions</strong></td>
<td>Students observe properties of cardboard to identify strengths and weaknesses.</td>
</tr>
<tr>
<td></td>
<td>• Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tests are often designed to identify failure points or difficulties, which suggest the elements of a design that need to be improved.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>PS1.A: Structure and Properties of Matter</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Measurements of a variety of properties can be used to identify materials.</td>
<td></td>
</tr>
<tr>
<td>Crosscutting Concepts</td>
<td><strong>Cause and Effect</strong></td>
<td>Students recognize that when a material is exposed to different conditions, it behaves differently.</td>
</tr>
<tr>
<td></td>
<td>• Cause and effect relationships are routinely identified, tested, and used to explain change.</td>
<td></td>
</tr>
</tbody>
</table>
Basic Teacher Preparation

This is another active lesson. Students design tests to determine strengths and weakness of corrugated cardboard samples. Collect the necessary materials, in their respective quantities, ahead of time.

If possible, find and bring to class an example of a consumer product that includes carbon fiber components or order a carbon fiber composite sampler pack from an online retailer (see Materials List below).

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. All Day 5 documents can be found on pages 14 through 16 in the Composites Student Handbook. The documents used in this lesson are:

- 5.1: Cardboard Challenge (pages 14–16)

### Required Preparation

<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>Gather or purchase all required materials for the lesson</td>
<td>Refer to the Materials List below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut cardboard into 3” x 6” (7.62 x 15.24 cm) pieces</td>
<td></td>
<td></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>Optional: Samples of products made with carbon fiber composites</td>
<td>Includes certain skateboards, kayak and canoe paddles, hockey sticks, bike frames, golf clubs, fishing rods, archery bows and arrows, baseball bats, sports helmets, and more.</td>
<td>Assortment</td>
<td>Students or school physical education department</td>
</tr>
<tr>
<td>Optional: Carbon fiber composite material samples</td>
<td>Sample pieces of carbon fiber epoxy laminate, carbon fiber sandwich, or assortment packs</td>
<td>Assortment</td>
<td>Local hardware store Carbon Fiber Samples [Web Link] (around $15.00)</td>
</tr>
<tr>
<td>Corrugated cardboard</td>
<td>Recycle old corrugated cardboard boxes by cutting into 3 x 6” (7.62 x 15.24 cm) pieces.</td>
<td>1 piece per student or pair</td>
<td>Students or local craft store</td>
</tr>
</tbody>
</table>
Introduction (5 minutes)

Reflect with students on the explorations conducted throughout Days 1 through 4. Remind students that carbon fiber composites have many qualities that make them different from other types of materials, which makes them a valuable new material for aeronautical engineers. When a new material is developed, it has the opportunity to change the way certain products are designed and manufactured.

Material scientists develop a new material and work in partnership with engineers to consider what problems the new material might help solve. For instance, it may improve the design, manufacture, or performance of a product. Material scientists and engineers work together to test, retest, and optimize the material for different uses—and to figure out the best and most efficient processes for manufacturing the new material. In the case of carbon fiber composites, specialists known as composite engineers test how these new materials and new ways of manufacturing them may help solve design and performance problems in many different spheres, including airplanes.

Summarize Day 4: Composites Everywhere and connect to the use of carbon fiber composites in modern airplane design and manufacturing. For example:

- *Yesterday we learned about the special properties of composite materials that enable them to perform in ways that have certain advantages—depending on the design criteria—than other materials.*
- *The Candy Composite Challenge showed us that a composite material—consisting of both reinforcement and matrix ingredients—when mixed and treated (through heating, cooling, or pressure) performs in a way unique from the individual ingredients. It becomes something entirely different.*

Remind students of the evolution of airplane materials they explored during Day 3: Build an Airplane. Ask them:

- *What advantages do carbon fiber composites have over wood, steel, aluminum (which is still the primary building material), and other materials that were once extensively used in airplane manufacturing?*

Listen to students’ ideas. Then, share some of the characteristics of carbon fiber composites that make them useful for specific kinds of purposes, such as

- Made in very large pieces, which reduces the need for a lot of pieces, seams, and fasteners
- Formed in molds to create custom shapes
- Lightweight and strong
- Resist corrosion

Students learn more about how carbon fiber composites are made on Day 6: Textile Technology. On Day 5, they work in pairs to find the best solution to an engineering design problem.
Whole Group Discussion: Carbon Fiber Composites (10 minutes)

Carbon fiber composites can be found in a growing assortment of products as designers and manufacturers find new ways to employ these materials. Challenge students to co-construct a list of products they think would benefit from the use of carbon fiber composites. Keep in mind that these materials are:

- Lighter and stronger than many other comparable materials
- Can be custom-molded into shapes
- Resist corrosion from humidity and salt water

**What type of products would benefit from these properties?**

Compare the students’ list with the list below, which highlights some products in which carbon fiber composites are used:

- **Sporting Goods**—Baseball bats, golf club shafts, fishing rods, archery bows and arrows, bicycle frames, hockey sticks, canoe and kayak paddles, surfboards, sports helmets, interior components of some basketball shoes, and so forth.
- **Vehicles**—Formula One race cars, some yachts, special edition cars from manufacturers including Porsche, Mitsubishi, Maybach, Chevrolet, Ford, and Bentley, and so forth.
- **Airplanes**—Some modern military aircraft, as well as the Boeing 787 and Airbus 380 commercial airplanes feature carbon fiber composites in their structures and components.
- **Other Uses**—Cell phone cases, bulletproof vests, shipping containers, office supplies, musical instruments, and more.

If possible, find and bring to class an example of a consumer product that includes carbon fiber components (see the list above) or order a carbon fiber composite sampler pack (see *Materials List* section). This allows students to see the weave pattern, feel the product’s weight, make a strength-to-weight comparison, and consider how the use of carbon fiber composites may have better met the designer’s criteria than other currently available materials.

**Helpful Tip**

Composite materials have many benefits. Only a few are featured in this module. For additional information, see American Composites Manufacturers Association (ACMA), *Why Composites?* [Web Link]

**NGSS Key Moment**

At this point in the lesson, emphasize the ideas embedded in 5-PS1-3. Students should focus on making observations of carbon composites to identify the materials by their properties. Encourage students to think carefully about the properties of carbon fiber composites.

**Helpful Tip**

If obtaining products containing carbon fiber composites is unfeasible, search online for “carbon fiber composites” images to find images of products made from carbon fiber composites as well as images of the signature woven pattern. Share these images using a projector.
Investigation: Cardboard Challenge (15 minutes)

All materials are designed to meet a specific design specification—to serve a need or solve a problem. Material scientists and composite engineers work together to develop carbon fiber composite products to meet the specific specifications of each application—whether it is a baseball bat, race car, or major components of a commercial airplane.

Material scientists and engineers sometimes work together to design a material that is strong in one way but may not need to be strong in other ways—or perhaps, needs to be flexible in one direction but rigid in another. After developing the material, engineers test it to see if the design specifications are met. Students try this with a Cardboard Challenge. Instead of using carbon fiber composites, students use cardboard to explore ways materials can be strong.

Hand out one piece of cardboard to each student or pairs. Have student pairs discuss and write a response to the following questions:

- What were the material scientists who developed corrugated cardboard trying to achieve?
- What do you think were their design specifications?

Refer students to 5.1: Cardboard Challenge on page 14 in their Composites Student Handbook. Tell students they are going to test the different types of strength of their cardboard piece by bending, tearing, crunching, and/or smashing it. Refer students to the chart at the top of 5.1: Cardboard Challenge. Encourage students to make notes and draw sketches in the Sketches box to capture the ways in which the cardboard is strong and weak.

Once students have completed their individual tests, discuss the following questions as a class. Consider having students pass around their cardboard sections during the class discussion.

- What were some of the ways you chose to test the material?
- How was the cardboard strong?
- How was the cardboard weak?

Have students summarize, How did the cardboard perform? What were its strengths and weaknesses? on page 15 in the Composites Student Handbook. Next have students complete the next two boxes by recording their responses to the following prompts:

- What do you think were the design criteria for the material scientists who developed corrugated cardboard? How did they want the material to perform?
- Did your own ideas about the design criteria change after you tested the cardboard? How?
Explain that there are many types of material strength that material scientists and engineers use to evaluate materials. Share the following definitions for three types of material strength. Have students record the definitions in their own words and sketches in the box provided on 5.1: Cardboard Challenge on page 16 in the Composites Student Handbook:

- **Compressive Strength**: The maximum amount of compression (squishing, crunching, and so forth) that a material can handle before it fails. An example of compressive strength is stomping on an aluminum soda can.

- **Tensile Strength**: The maximum amount of loading that a material can handle before it fails. Some materials stretch before breaking. An example of tensile strength is piling pennies on top of a paper towel until the towel tears.

- **Shear Strength**: The maximum amount of stress along a plane that a material can handle before it fails. An example of shear strength is tearing a piece of fabric into strips. Shear strength can be measured across the width, length, and diagonal of a material.

Explain that material strength is one of the many factors (structures, properties, and performance) that material scientists and engineers look at when developing, testing, and optimizing new materials or applying existing materials to new applications.

Lead the class in a short discussion about the types of strength. Ask students to think about how the different types of strength apply to various materials (such as baseball bat vs. fishing rods).

**Whole Group Discussion: Criteria and Constraints (15 minutes)**

In this lesson, students examine the idea that all materials are designed to meet a specific design specification—to serve a need or solve a problem. Remind students that on Day 3: Build an Airplane, they investigated the criteria and constraints that aeronautical engineers face when designing new commercial airplanes. Ask for a student volunteer to explain the meaning of criteria and constraints.

- **Criteria** are the desired features of a design; the things you want to be sure your product has built into the design.

- **Constraints** are the limitations that have to be worked around. Constraints include things like materials, durability, time, cost, function, size, weight, and safety.

Students continue to investigate the problem first introduced on Day 3, What are the best materials for our new airplane? Students have learned a lot of new information about materials and, in particular, carbon fiber composites, which they can apply to solving this problem.
Refer students to the Pugh chart they created on Day 3 to test the three main criteria for their new airplane. Each of these criteria directly links to a constraint, such as fuel efficiency, cost, or safety.

- Using lightweight materials means the plane weighs less. Less weight means the engines will burn less fuel.
- Using strong materials improves the safety of the airplane. It also allows for the cabin to be pressurized at a level more comfortable for passengers.
- Using materials that can be manufactured in large pieces, rather than a lot of small pieces, means the number of seams and fasteners can be reduced. Seams and fasteners (rivets) can increase weight and drag on the airplane, meaning more fuel is needed. Reducing the seams and fasteners also reduces maintenance costs and increases safety.

Re-create the Pugh chart below on the board or overhead projector. Together as a class, fill out the Pugh chart, comparing the first two criteria (lightweight and strong) across the four materials. Students have not yet learned how carbon fiber composites are made, so reserve the third criteria for Day 6.

**Problem:** What are the best materials for our new airplane?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Wood</th>
<th>Aluminum</th>
<th>Steel</th>
<th>Carbon Fiber Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal Number of Seams and Fasteners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Encourage students to look through their Composites Student Handbook and airplane cards from Day 3 to help them reflect on what they have learned about these materials. As students are likely not to be familiar with these materials personally, facilitate this activity, providing just-in-time instruction as needed for the first two criteria.

The class should come to consensus on how they want to fill out the Pugh chart, but the decisions should demonstrate evidence-based reasoning. An example is provided below.
Problem: What are the best materials for our new airplane?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Wood</th>
<th>Aluminum</th>
<th>Steel</th>
<th>Carbon Fiber Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Strong</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Minimal Number of Seams and Fasteners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Show students a diagram of the Boeing 787 Dreamliner that illustrates where different materials are used in the plane. This same diagram was first shown on Day 3. The diagram is clickable.

As a class, discuss students’ ideas for why the aeronautical engineers chose the particular materials illustrated on the website, and why they used different materials for various applications, including:

- Carbon fiber composites
- Laminate and sandwich
- Other composites
- Aluminum
- Titanium
- Other materials (as time permits)

Conclude the discussion with the question, *Why might carbon fiber composites be a good choice for the main barrel and wings of the plane?*

**Lesson Close (5 minutes)**

Discuss with the class as a whole, or have students respond to the following:

- *What is the relationship between the work of material scientists, composite engineers, and aeronautical engineers? Draw a picture or a diagram to help explain this.*
- *What surprised you today when learning about the materials used to design airplanes?*
- *What do you still need to learn in order to understand why carbon fiber composites meet our criteria for being lightweight, strong, and having a minimal number of seams and fasteners?*

**Assessment**

Several opportunities for formative assessment exist in this lesson:
• Composites Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus specifically on 5.1 Cardboard Challenge (pages 14–16).
• Consider monitoring student progress using student reflections from the closing activity.
• Whole class share-outs and discussions allow for formative assessment of student ideas and building content knowledge.
• Teachers can review students’ notes and sketches in their handbooks to gain an understanding of students’ takeaways from the lesson.

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

Students may have previously encountered sporting equipment or other consumer products that contain carbon fiber composites. Students may be able to think of other experiences they have had with building materials, such as wood or different types of metal.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Boeing 787 Dreamliner Advanced Composite Use Diagram</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Legends of Flight Informal Educator’s Toolkit (page 6)</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>ACMA’s Why Composites</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>
Lesson Overview

On Day 6, students explore the manufacturing methods of carbon fiber composites to further develop their understanding of what makes these materials unique. Given that carbon fiber composites are manufactured in a process akin to the textile industry, students investigate this analogy to textile technology by examining the parts of a deconstructed sweater.

An extension Craft Break engages students in a textile weaving or knitting activity. Students return to the Pugh chart they created on Day 3: Build an Airplane to determine how carbon fiber composites meet the design criteria for airplane construction materials.

This lesson is intentionally designed to be open-ended and flexible, providing the opportunity for the teacher to determine the content and activities that will best prepare students for the multi-day engineering design challenge presented on Day 7.

This lesson connects to the concepts of material science and composite materials that was introduced in previous lessons, in particular, carbon fiber composites from Day 4: Composites Everywhere. The lesson explores the manufacturing process of carbon fiber composites, what makes carbon fiber composite materials different than other kinds of materials, and specifically, what benefits carbon fiber composites bring to the design of airplanes.

This lesson leads directly into Day 7, in which students leverage their understanding of the properties and manufacturing process of carbon fiber composites along with their knowledge of textile technologies and apply it to a multiday engineering design challenge.

Connecting to the Next Generation Science Standards

On Day 6, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices**: Asking Questions and Defining Problems, Constructing Explanations and Designing Solutions
- **Crosscutting Concepts**: Influence of Engineering, Technology, and Science on Society and the Natural World

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-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

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:

5-PS1-3. Make observations and measurements to identify materials based on their properties.

Specific Connections to Classroom Activity

In this lesson, students explore the manufacturing methods of carbon fiber composites to further develop their understanding of what makes these materials unique. Students examine the carbon fiber manufacturing process by examining textiles, which use a similar weave technique. By examining the properties of textile weaves, students develop ideas to use as they design their own carbon fiber composite. Students also begin to compare multiple designs to determine how likely each design is to meet the criteria and constraints of the problem. This lesson helps students completely define the design problem and begin to brainstorm design solutions.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>NGSS Element</th>
<th>Connections to Classroom Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science and</td>
<td>Asking Questions and Defining Problems</td>
<td>Students develop a final definition of the design problem by identifying a final set of criteria and constraints. This helps students as they enter the design challenge on Days 7 through 10. Students compare multiple textile weaves and consider how each weave may help in their design solution.</td>
</tr>
<tr>
<td>Engineering</td>
<td>• Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.</td>
<td></td>
</tr>
<tr>
<td>Practices</td>
<td>Constructing Explanations and Designing Solutions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.</td>
<td></td>
</tr>
<tr>
<td>Disciplinary</td>
<td>ETS1.A Defining and Delimiting Engineering Problems</td>
<td>Students examine different weave patterns in textiles and consider how well each pattern may work in their carbon fiber composite. Students identify different textile properties according to their weave patterns.</td>
</tr>
<tr>
<td>Core Ideas</td>
<td>• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Measurements of a variety of properties can be used to identify materials.</td>
<td></td>
</tr>
</tbody>
</table>
Crosscutting Concepts

Influence of Engineering, Technology, and Science on Society and the Natural World
- Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.

Structure and Function
- Different materials have different substructures, which can sometimes be observed.
- Substructures have shapes and parts that serve functions.

Basic Teacher Preparation

Collect the necessary materials, in their respective quantities, ahead of time. Also, review the resources in the Selected Teacher Resources section.

To engage students in the extension Craft Break activity, survey your students, their families, your school PTA, and your own personal network to determine if anyone in your network has expertise in knitting, crocheting, finger knitting, weaving, or basket-weaving. There may be members of students’ families who pursue these activities as hobbies or occupations, or as part of their cultural heritage. You will need one or more people who are willing to share their craft with your class, either as a demonstration or as a group lesson.

If you can arrangements for the extension Craft Break activity, determine the materials you will need to provide for the demonstration and lesson (for example, yarn, crochet hooks, knitting needles, lap looms, fabric, or basket-weaving materials).

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. All Day 6 documents can be found on pages 17 and 18 in the Composites Student Handbook. The documents used in this lesson are:

- 6.1: Textile Technology (pages 17 and 18)

<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>☐ Cut thread into 6” (15.24 cm) pieces, one per team</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>☐ Cut one or more additional pieces of thread and separate the individual fibers, one piece of fiber per team</td>
<td>Refer to the Materials List below</td>
</tr>
</tbody>
</table>

Helpful Tip
If you are not able to secure someone for a live demonstration, consider searching online for a short video that demonstrates knitting, crocheting, basket weaving, or rug weaving.
Cut the yarn into 6” (15.24 cm) pieces, one per team

Refer to the Materials List below

---

### 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>Cotton thread, black</td>
<td>Cotton thread. Cut into 6” (15.24 cm) long pieces.</td>
<td>1 piece per team</td>
<td>Student or local craft store</td>
</tr>
<tr>
<td>Cotton yarn, black</td>
<td>Spool of black cotton yarn. Cut into 6” (15.24 cm) long pieces.</td>
<td>1 piece per team</td>
<td>Student or local craft store</td>
</tr>
<tr>
<td>Knitted clothing, black</td>
<td>Black knitted hat, scarf, or sweater.</td>
<td>1 or more</td>
<td>Student or local thrift store</td>
</tr>
<tr>
<td>Magnifying glasses or loupes</td>
<td>Magnifying glasses, loupes, digital microscopes, and so forth.</td>
<td>1 per team</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Scissors</td>
<td>For cutting thread and yarn.</td>
<td>1</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Optional: Carbon fiber composite material samples</td>
<td>Sample pieces of carbon fiber epoxy laminate, carbon fiber sandwich, or assortment packs.</td>
<td>Assortment</td>
<td>Carbon Fiber Samples [Web Link] ($15.00)</td>
</tr>
<tr>
<td>Optional: Craft supplies needed for the Craft Break activity</td>
<td>Depending on the chosen Craft Break activity (see Basic Teacher Preparation section above), may include yarn, crochet hooks, knitting needles, lap looms, fabric, or basket-weaving materials.</td>
<td>Assortment</td>
<td>Student or local craft store</td>
</tr>
</tbody>
</table>

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Day 6: Textile Technology

Introduction (5 minutes)

On Day 5, students examined samples of products made from carbon fiber composites and saw the weave structure that makes up these materials. Ask students where else in their everyday lives they have seen similar weave patterns (baskets, rugs, and so on).

Explain that some of the techniques used to manufacture carbon fiber composites for the aircraft industry actually came from the textile industry. Textiles are things like thread, yarn, ribbons, cloth/fabrics, and clothing. Textiles are manufactured with weaving and knitting techniques using tools such as looms.

Carbon fiber composites are manufactured in several ways—one way is quite similar to how a knitted hat, scarf, or sweater is created. In this lesson, students deconstruct a sweater to better understand how carbon fiber composite materials are manufactured in a way similar to textiles.

Mini-Lesson: Boeing’s One-piece Barrel (5 minutes)

Show students Boeing’s One-piece Barrel video. This short video shows some of the steps in manufacturing the barrel of the Boeing Dreamliner plane, where carbon fibers are woven into a fabric (or assembled into a unidirectional pattern), which is then followed by an application of a matrix resin to make the prepreg. The machine used throughout this process is called a prepregger.

Investigation: Fiber (15 minutes)

Pass out the fiber, thread, and yarn pieces to each team. If you have a knitted clothing item (hat, scarf, or sweater) for each team, hand that out as well. If not, pass a single sample from team to team. Also pass out magnifying glasses or loupes. If you have stereo microscopes or digital microscopes/cameras, make those available as well.

Encourage students to use their magnifying tools to examine each sample as you explain how textile products relate to the carbon fiber composite manufacturing process. Refer students to 6.1: Textile Technology on pages 17 and 18 in the Composites Student Handbook. Encourage students to sketch the materials (and magnified versions) in the circles in their notebooks.
Start with the piece of black fiber (that you pulled from a piece of thread). Explain that the process starts with the manufacture of carbon filaments. These filaments are very fine; they can be manufactured to be many times thinner than the diameter of a human hair.

Next, focus on the black thread. Explain that many pieces of carbon fiber filament are twisted together into carbon threads, much like these cotton fibers have been twisted together into a piece of thread.

Next, talk about the black yarn. Explain that many threads are woven together to create a material called a carbon fiber tape. This is much like the way cotton threads are woven together to create a piece of yarn. However, when a carbon fiber tape is made, the threads are mixed with an epoxy resin that hardens and binds the threads together. The tape is strong, flexible, and lightweight.

Hold up the spool of yarn. Explain that carbon fiber tape is wound onto spindles, similar to how this cotton yarn has been wound into a spool. The spindles can then be placed on a prepregger machine, which is similar to a very large loom (as shown in the video).

Next, pass around the sample(s) of knitted clothing—hat, scarf, or sweater. Explain that the prepregger works like a loom, pulling carbon fiber tape from multiple spindles and weaving them together using a series of combs to create a ribbon or a mat (as shown in the video). This mat, known as carbon fiber laminate, is like a sheet of woven fabric. These ribbons or mats are used in a few ways:

- To form the carbon fiber laminate into the desired shape, it can be mixed with epoxy resin, pressed into a mold, and cooked in an industrial oven (an autoclave) until it hardens.
- A carbon fiber sandwich panel can be made by sandwiching a honeycomb structure material between two sheets of carbon fiber laminate.
- To create very large, custom pieces—such as the one-piece barrel of the Boeing Dreamliner plane—the carbon fiber ribbons can be applied around a form to create the desired shape (as shown in the video).

Weaving is a way to transform a material’s structure and performance. Think about how weaving together a piece of yarn or a ribbon changes its shape, structure, and strength. Carbon fiber composites are woven to make them strong and yet lightweight. What kind of weave patterns are possible? Have students examine the weave patterns of the fabrics that make their clothing.

Using the magnifying glasses or loupes, have students examine different fabrics that make up their own clothing and those of their classmates. For example, cotton, denim, linen, rayon, polyester, and more. Have students complete the 6.1: Textile Technology prompts (on page 17 and shown below) in the Composites Student Handbook:

- Sketch magnified views of the weave patterns in two types of fabric. Label them.
- How are they similar/different?
Whole Group Discussion: Reducing the Rivets (10 minutes)

Explain that for the design of airplanes, using materials that can be manufactured in large pieces, rather than many small pieces, means the number of seams and fasteners can be reduced. Seams and fasteners (rivets) increase weight and drag on the airplane, which means more fuel is needed, which increases costs and increases the amount of emissions that are harmful to the environment. Reducing the seams and fasteners also reduces maintenance costs and increases safety.

Show students historic photographs of WWII-era airplanes constructed with many small aluminum panels connected with thousands of rivets. A quick Google search provides photos of airplanes from this era—including the Lockheed Constellation, which was featured on Day 3 Airplane Design Cards. You may also want to show students historic photographs of riveters at work connecting the aluminum panels together. The Library of Congress offers historic photographs of riveters. Two are shown below and can be downloaded for free from the Library of Congress.


Even though aluminum is still widely used as an airplane building material, it is slowly being replaced with composite materials (such as fiberglass, carbon fiber reinforced plastic, GLARE,
thermoplastics, and others) as they become available to aeronautical engineers. These newer composite materials allowed for panelized construction methods, where larger pieces could be used which lessen the number of seams and fasteners. However, engineers still want a better material to meet their design criteria.

Show students the One-piece Barrel Construction Diagram, which compares panelized construction to the new one-piece barrel construction afforded by carbon fiber composites.

Whole Group Discussion: Pugh Chart (10 minutes)

Return to the Pugh chart that the class developed on Day 5: Carbon Fiber Composites. The first two criteria were previously filled out. Now students can work together to fill out the chart for the third criteria, Minimal Number of Seams and Fasteners. An example chart is provided below, although your students may fill it out slightly differently.

Problem: What are the best materials for our new airplane?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Wood</th>
<th>Aluminum</th>
<th>Steel</th>
<th>Carbon Fiber Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Strong</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Minimal Number of Seams and Fasteners</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Points</strong></td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Discuss how the manufacturing process allows for carbon fiber composite materials to be designed in a way that minimizes the number of seams and fasteners. These types of composite materials can be molded to custom shapes, so instead of using many small pieces to form a shape, these composites can be molded out of one piece. Carbon fiber composites can also be made in very large pieces, as shown in the One-piece Barrel Construction Diagram.

Lesson Close (5 minutes)

Refer students to page 18 of 6.1: Textile Technology in the Composites Student Handbook. Ask students to respond to the following prompts:

- *What is special about carbon fiber composites that make them a good material choice for the design of an airplane?*
- *How does weaving change the structure and performance of a material?*
Assessment

Several opportunities for formative assessment exist in this lesson:

- **Composites Student Handbook** entries can always be used to monitor student progress during the module. For this lesson, focus specifically on 6.1 Textile Technology.
- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- Review students’ notes and sketches in their handbooks to gain an understanding of students’ takeaways from the lesson.

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

Students may have previously engaged in weaving or knitting crafts. Members of students’ families might pursue these activities as hobbies, occupations, or as part of their cultural heritage.

Students who participate in the optional Craft Break can learn textile craft techniques from a member of their local community.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>One-piece Barrel Video (Boeing, 53 minutes)</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>One-piece Barrel Construction Diagram</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>The story of Rosie the Riveter (Wikipedia)</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Library of Congress: Riveters at work on fuselage of Liberator Bomber</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Library of Congress: Nashville, Tennessee, Vultee Aircraft Company: Drilling holes for rivets in a fuselage in a sub-assembly line</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>
Sources


The Deconstructed Sweater activity is an adaptation of the “Textile Tests” activity from the Legends of Flight Informal Educator’s Toolkit: Sample Education Materials.


Photograph of female riveters from the Library of Congress. Riveters at work on fuselage of Liberator Bomber, Consolidated Aircraft Corp., Fort Worth, Texas.
Lesson Overview

In this multiday lesson, students engage in a Composites Engineering Design Challenge. Their task is to work in teams to identify the weave design that provides the most tensile strength for a new type of composite material called Paper Podge Composite (PPC).

Using paper towels as their reinforcement ingredient, student teams design, test, redesign, retest, and optimize prototypes of their weave designs for the highest tensile strength. Once they have chosen their best prototype, each team adds a matrix ingredient by painting Mod Podge® (a polymer glue) onto their optimized design prototypes to create a new type of composite material.

Teams then test their optimized PPC prototypes consisting of both the reinforcement and matrix ingredients and compare the composite’s performance to the performance of the optimized prototype consisting of just the reinforcement ingredient. The Composites Engineering Design Challenge leads to the PPC Design Showcase, in which students make brief presentations about their optimized PPC prototypes and experiences with the engineering design process.

Connecting to the Next Generation Science Standards

On Days 7 through 10, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. These days serve 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

Review the background information in the Suggested Teacher Resources section at the end of the lesson.

Refer to the Materials List below to collect the necessary materials, in their respective quantities, ahead of time. Create a material kits for each team. Consider allocating a secure space for teams to keep their prototypes throughout the four days of the design challenge.

Refer to the Composites Student Handbook ahead of time so you can address any questions students might have. The design challenge documents are on pages 19 through 29 in the Composites Student Handbook.

The documents required for Days 7 through 10 are:
- 7.1: Engineering Design Process Diagram (page 19)
- 7.2: Composites Design Challenge: Design Task (page 20)
- 7.3: Composites Design Challenge: Background Knowledge (page 21)
- 7.4: Composites Design Challenge: Brainstorm Possible Solutions (page 22)
- 8.1: Composites Design Challenge: Optimize the Design for the Weave (page 23–27)
- 9.2: Composites Design Challenge: Design Implementation (page 29)

### 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 day</td>
<td>Refer to the Materials List below</td>
</tr>
<tr>
<td>Assemble a materials kit for each team, and organize kits in tubs, trays, or bags</td>
<td>Each kit should include:</td>
</tr>
<tr>
<td>Review the recommended briefs for additional background information on working</td>
<td>• Practice Brief 7: Learning STEM through Design—Students Benefit</td>
</tr>
<tr>
<td>through design challenges with students</td>
<td>from Expanding What Counts as “Engineering.” [Web Link]</td>
</tr>
<tr>
<td></td>
<td>• Practice Brief 36: Failing Forward—Managing Student Frustration</td>
</tr>
<tr>
<td></td>
<td>During Engineering Design Projects [Web Link]</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>Scissors</td>
<td>At least 1 per team, but 1 per student is best.</td>
<td>1 per student</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Ruler</td>
<td>At least 1 per team, but 1 per student is best.</td>
<td>1 per student</td>
<td>Available in most schools</td>
</tr>
<tr>
<td>Pennies, banker rolls</td>
<td>One banker roll contains 50 pennies. Each team needs 100 pennies or 2 banker rolls.</td>
<td>2 banker rolls per team</td>
<td>Local bank</td>
</tr>
<tr>
<td>Paper towels</td>
<td>Kitchen-quality paper towels. All teams must have the same brand and size. You will need several rolls.</td>
<td>At least 10 sheets per team</td>
<td>Students or classroom sets</td>
</tr>
<tr>
<td>Cellophane tape, roll</td>
<td>At least 1 per team, but 1 per student is best.</td>
<td>1 roll per student</td>
<td>Students or classroom sets</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Quantity/Unit</td>
<td>Location</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Mod Podge®</td>
<td>Mod Podge® decoupage glue/sealer/finish. Mod Podge Wash Out for Kids® is formulated to wash out of clothes, but the regular formula is fine too. Both are non-toxic.</td>
<td>2 8 oz bottles per class</td>
<td>Available online or local craft store</td>
</tr>
<tr>
<td>Paint brushes</td>
<td>Inexpensive small paint brushes, foam, or bristle. For applying Mod Podge® to woven mats.</td>
<td>2 per team</td>
<td>Classroom sets, or local craft store</td>
</tr>
<tr>
<td>Cups or bowls</td>
<td>Small paper/plastic cups or bowls for distributing small amounts of Mod Podge® to each team.</td>
<td>1 per team</td>
<td>Classroom sets, or local store</td>
</tr>
<tr>
<td>Colored pens or pencils</td>
<td>For making notes and sketches in design notebooks.</td>
<td>Assortment per team</td>
<td>Available in most schools or local craft store</td>
</tr>
</tbody>
</table>
Day 7: Composites Engineering Design Challenge

Introduction (5 minutes)

Introduce the Composites Engineering Design Challenge by telling students that they are taking on the role of composite engineers over the next few days. As part of a design team, they are tasked with designing a new lightweight and strong composite. Even though students are working as composite engineers, remind them that in the world of airplane design, their ideas would also have to be discussed with material scientists and aeronautical engineers, like the designs they saw on the Boeing 787 Dreamliner. Ask students to think about how many people, including material scientists, composite engineers, and aeronautical engineers, have worked together to design carbon fiber composites for use in modern Airplanes, like the Boeing 787 Dreamliner.

Whole Group Discussion: Problem and Background (10 minutes)

Ask students to recall the basic recipe for a composite:

Reinforcement ingredient + Matrix ingredient = Composite

Explain that they are going to create a composite called Paper Podge Composite (PPC). Using this recipe, paper towels serve as the reinforcement ingredient and a polymer called Mod Podge serves as the matrix ingredient.

Paper towel (reinforcement) + Mod Podge (matrix) = Paper Podge Composite (PPC)

By using these easy-to-obtain materials and going through the engineering design process, students model what it is like to develop a new material for a specific purpose.

Remind students that during the previous Cardboard Challenge activity, students generated an understanding of three types of material strength—tensile, shear, and compressive. They also learned that a material can be strong in one way while being weak in another way, based on the desired criteria for a particular material. The Composites Engineering Design Challenge asks students to design a Paper Podge Composite that has the highest tensile strength. Together, recall what tensile strength means.

- Tensile strength: The maximum amount of loading that a material can handle before it fails. Flexible materials stretch before they break. Brittle materials will not.

Together with your students, choose a product application for the new composite material that most interests them. What do we want to be able to build with our new composite? What product would benefit from a material that is lightweight and has high tensile strength? For example, your students might choose a new composite material for use in remote-controlled...
airplanes, skateboards, dollhouses, or cafeteria trays. The goal is for students to choose an application that interests them.

Remind students that the previous Textile Technology activities demonstrated how some types of carbon fiber composites are manufactured by weaving together carbon fiber ribbons before adding the matrix ingredient (a polymer or resin), pressing into a mold, and cooking in an industrial oven. The challenge over the next few days is to design a weave pattern that creates the highest tensile strength for their Paper Podge Composite material.

Mini-Lesson: Engineering Design Process (15 minutes)

Have students meet in their design teams. Students need their Composites Student Handbooks and a pencil. Each team also needs a roll of cellophane tape.

Engineering Design Process

Review the 7.1 Engineering Design Process Diagram on page 19 in the Composites Student Handbook. See Appendix A in the Composites Teacher Handbook for additional information.

Help students develop an understanding of each step in the engineering design process, as well as the idea that the process is not unidirectional. Defining the problem, developing solutions, and optimizing the design are part of a multi-directional process. It can take many iterations of a design, with multiple phases of redesigning and retesting, to arrive at the “best” or “optimized” solution for the design problem.

Explain that failure is an important part of the design process. By identifying failure points, challenges, and difficulties, an engineer can develop ideas for how to improve his/her design. Failure provides important information about what did not work well and what could be changed. For engineers, failure is a critical step in creating new ideas and breakthroughs.

Allow 10 minutes for student teams to work together on the first three phases of the engineering design process—design task, background knowledge, and define design problems.

Refer students to the following pages in the Composites Student Handbook to capture their notes and sketches:

- 7.2: Composites Design Challenge: Design Task (page 20)
- 7.3: Composites Design Challenge: Background Knowledge (page 21)
- 7.4: Composites Design Challenge: Brainstorm Possible Solutions (page 22)

Encourage students to write notes and sketches in the Composites Student Handbook.
As a class, review the teams’ responses to the first three phases of the engineering design process.

- **Identify the Need or the Problem—Design Task:**
  - *What is the design task?*
  - *What is our chosen product application?*
  - *Does everyone agree?*

- **Research Criteria and Constraints**
  - *Background Knowledge:* What science concepts do you need to understand? Do you have any previous personal experience or knowledge that relates to the task (for example, with weaving)? What would be helpful to know?
  - *Criteria and Constraints:* What are the criteria for this design challenge (lightweight, high tensile strength, and so forth)? What are the constraints for this design challenge (woven, only can use paper towels and Mod Podge®, and so forth)?

- **Brainstorm Possible Solutions**

**Design Work: Rules, Fair Tests, and Failure (10 minutes)**

Review the rules for the Composites Engineering Design Challenge:

- **Prototype Creation:** Each mat should be made from only one paper towel. Cut the paper towel into strips (minimum of 6 strips). Then weave the strips together. Use cellophane tape to secure the outside edges of the woven mat, like a picture frame made out of tape. You can only put tape on the outside edges! Do not put tape anywhere else on the mat.

- **Weave #1 Experimental Control:** Use one regular paper towel to serve as your experimental control. Don’t do anything to this paper towel other than adding cellophane tape to the outside edges.

- **Weave #2 1/1 Plain Weave:** Cut one paper towel into 1” wide strips. Then weave the strips together to create a prototype with the following pattern:
  - i. 1 under 1 over...
  - ii. 1 over 1 under...
  - iii. 1 under 1 over... and so on

- **Weave #3 and #4 Design Prototypes:** Create two other prototypes using your own designs. Consider the number of strips, width of the strips, weave pattern, and tightness of the weave when generating ideas for what you think will be the best design solution.
Next, have the class as a whole generate the testing procedures everyone will follow to create a fair test of their design prototypes.

- Students use pennies to test the tensile strength of the experimental control and each design prototype.
- The test will likely differ depending on the product application the class chose for their new composite material.
- When testing, two students hold the mat by its outside edges while another student tests the tensile strength using one of the options listed below:

As a class, determine what failure looks like. Testing options:

1. Pennies slip through the holes between the woven strips.
2. Pennies fall through tears in the mat.
3. Both 1 and 2.

**Helpful Tip**

**Testing Procedure Ideas:**

- Stack pennies, one at a time, onto the mat. Count how many pennies the mat can support before it fails.
- Drop pennies, one at a time, onto the mat from a short distance. Count how many pennies the mat can support before it fails.
- Drop pennies, one at a time, onto the mat from a higher distance. Count how many pennies the mat can support before it fails.
- Drop multiple pennies taped together (how many) at a time from a short or high distance. Count how many pennies the mat can support before it fails.

**Design Work: Brainstorming (10 minutes)**

Allow time for students to work in their teams to brainstorm design solutions, such as different weave patterns and different ways of constructing their prototypes. Encourage students to make sketches and notes on a blank page of their design notebooks as well as complete 7.4: Composites Design Challenge: Brainstorm Possible Solutions on page 22 in the Composites Student Handout. Each team must decide on their top two designs for which they will create prototypes to test. Have students complete the following prompts:

- *Choose two designs that your team will build and test.*
- *Think about the design criteria and constraints. Why did you choose the designs?*

Tell students that they have time tomorrow to build, test, redesign, and retest their prototypes.
Important Note

If any groups have difficulty coming up with different design solutions, some possible ideas include:

- **2/2 Plain Weave:**
  - 2 over 2 under...
  - 2 under 2 over...
  - 2 over 2 under... and so on

- **2/2 Twill Weave:**
  - 2 over 2 under...
  - 1 over, then 2 under 2 over...
  - 2 under, 2 over...
  - 1 under, then 2 over 2 under...
  - 2 over 2 under... and so on

- Other weave patterns students make up
- Weaving two strips together
- Using all thin strips or all thick strips
- Varying thin strips with thick strips
Day 8: Composites Engineering Design Challenge

Design Work: Design and Test (30 minutes)

Distribute the material kits to each team as described in the Basic Teacher Preparation section.

For the rest of the class period, allow teams to a) build their prototypes and b) test their prototypes and the experimental control (plain paper towel) using the testing procedures that the class collaboratively created.

Refer students to 8.1: Composites Design Challenge: Optimize the Design for the Weave on pages 23 through 27 in the Composites Student Handbook. Encourage students to complete the testing chart, take notes, and draw sketches on these pages in their Composites Student Handbook during the testing phase. Students may want to number their prototypes so they can easily keep track of the physical models and their notes and sketches.

Monitor teams’ prototypes and testing. As students finish testing the experimental control and all their prototypes, they can move to the next phase in which they redesign one or more prototypes and retest the optimized designs. Repeat the redesign and testing as time allows.

Encourage students to take detailed notes and draw sketches in their Composites Student Handbook, beyond the Optimize the Design pages as needed, so this process is well documented. In addition to sketches, students may also choose to take photos of their prototype mats (if digital cameras are available). Students should also be encouraged to keep all of their prototypes—even if they are in pieces. Tell students they need this documentation for creating their team presentations for the PPC Design Showcase.

Important Note

Facilitate student team reflection on their designs, test results, and proposed improvements. Reflection prompts include:

► Was it difficult to create your prototype? If you had more people helping, or if you could invent a machine to help with one part of your design, how could you improve your building process?

► How many pennies did the prototype support before failing?

► What happened when failure occurred? Why do you think this happened?

► What were the strengths and weaknesses of this prototype?

► How could this prototype design be improved?

► How did the prototype perform as compared to the experimental control (plain paper towel)?
Design Work: Build (15 minutes)

At this point, each team should have an optimized design that they think demonstrates a weave pattern with the highest tensile strength, according to the class’ agreed-on testing procedures and definition of material failure. Direct students to record their optimized weave pattern in the space provided on 8.1: Composite Design Challenge: Optimize the Design of the Weave on page 23 in the Composites Student Handbook.

Each team needs two versions of their optimized prototype. If their optimized prototype survived the testing phase without tearing, they only need to make one. If their prototype tore, they need to make two new ones. Students should write their team name, or another identifier, on each prototype.

Matrix Ingredient

Distribute the Mod Podge®, paint brushes, and extra paper towels (for cleaning up messes) to each team. Remind students that to produce their Paper Podge Composite, they need to complete the recipe for a composite. The woven paper towels provide the reinforcement ingredient. The Mod Podge® polymer glue provides the matrix ingredient.

Students should brush their two woven mats with Mod Podge® on both sides and then hang them to dry overnight.

Lesson Close (5 minutes)

During the last 5 minutes of class, ask each team to clean up their materials. Provide a small container, shoe box, bin, or other storage container for each team to keep their materials.

Refer students to 8.1: Composites Design Challenge: Optimize the Design of the Weave on page 27 in the Composites Student Handbook. Have students complete the prompts in the spaces provided:

- Why is “failure” important in the engineering design process? What did you learn about your designs when they failed? How did each prototype’s failure help you improve your design?
- What surprised you today? Why?
Day 9: Composites Engineering Design Challenge

Design Work: Testing (25 minutes)

Today, student teams test one of their PPC prototypes (woven mat with Mod Podge® applied), using the same testing procedures and material failure definition used on the previous day. The second PPC prototype should be set aside; it will be used during the PPC Design Showcase.

Distribute each team’s materials and allow time for students to test one of their PPC prototypes. Refer students to 9.1 Composites Design Challenge: Optimize the Design for Your Paper Podge Composite on page 28 in the Composites Student Handbook. Encourage students to record their test results and make notes and sketches in the space provided.

Bring the class together for a brief share-out. Discussion questions might include:

- How many pennies did your PPC prototype support before failing?
- What happened when failure occurred? Why do you think this happened?
- What were the strengths and weaknesses of your PPC prototype?
- How did the PPC prototype compare to the woven mat prototype (before you added the Mod Podge matrix)?
- How did the PPC prototype compare to the experimental control (plain paper towel) that you tested the previous day?

Design Work: Implementation (15 minutes)

Review the questions posed on 9.2: Composites Design Challenge: Design Implementation on page 29 in the Composites Student Handbook. Directly relate the questions to students’ optimized PPC designs:

- Did your optimized PPC design meet all the criteria of the design task?
  - Review the criteria for the Engineering Design Challenge that was introduced during Day 1.
  - What was the product application for the new PPC material that the class chose? How well do you think your optimized PPC prototype would work in this application?

- Did your optimized PPC design create any new problems when it was implemented? How can you address these?
  - What are the advantages and disadvantages of the woven mat (without Mod Podge®) versus the PPC (with Mod Podge)?

- How do you think your Paper Podge Composite material would perform when applied to the product that the class chose?

After the class discussion, have student teams discuss the questions and record their answers in the spaces provided on page 29 in the Composites Student Handbook.
Lesson Close (10 minutes)

Introduce the PPC Design Showcase by telling students that tomorrow each team will make a brief presentation to the class about their optimized PPC prototype and their experience as a “composite engineer” going through the engineering design process. Also, the class will create a PPC Prototype Gallery and everyone will have a chance to view the other teams’ optimized designs.

Relate the Composites Engineering Design Challenge to the design and construction of a new airplane:

- An aeronautical engineer needs materials that can serve different purposes.
- Some materials need to be strong and rigid.
- Some materials need to be strong and flexible.
- Some materials need to be used to make small parts, others for very large components.
- Some materials need to be molded into particular shapes.
- Weight is always a critical factor that aeronautical engineers have to consider.
- Materials that are strong, but light—like carbon fiber composites—have many advantages.

When creating composites for use in airplanes, composite engineers need to consider the weave pattern of the carbon fiber, the particular choice of matrix (resin, polymer, and so forth), the manufacturing process, and the end product (fabric, sandwich, and others). Together, these factors can create carbon fiber materials that meet the engineers’ criteria with the minimum number of tradeoffs.

Helpful Tip

For more information on carbon fiber composites used for airplanes, refer to the Suggested Teacher Resources section at the end of Day 10.
Day 10: Composites Engineering Design Challenge

Design Work: Showcase (45 minutes)

Today is the PPC Design Showcase! Allow some planning time for each team to plan a brief (3 to 5 minute) presentation to the class about their optimized PPC prototype and their experience as composite engineers going through the engineering design process.

As a class, co-construct a list of the types of things students should talk about during their presentation. Have a PPC Prototype Gallery set up, where each team has space on a tabletop to display their optimized PPC design. Ask the teams to create small signs that tell visitors about their displays.

When all teams are ready, begin the PPC Design Showcase. Allow a maximum of 5 minutes for each team presentation, with several minutes for questions from the class. Invite students to view the other teams’ optimized designs by leading a “gallery walk” of the PPC Prototype Gallery. Encourage students to write notes, observations, or questions.

Lesson Close (5 minutes)

Bring the class together to reflect on the team presentations and gallery walk.

- What did they notice that was different among the designs?
- What was similar among the designs?
- What seemed to be the most successful design strategies?

As an exit ticket or a final reflective prompt, ask students to respond to the following question:

- Now that you have seen how the other teams approached the design of their PPC, how might you redesign your own prototype one more time? What would you do to improve it? How do you think its performance would change during testing?

Assessment

Several opportunities for formative and summative assessment exist in this lesson:

- During the PPC Design Showcase and Gallery, teams deliver short presentations on their experience with the engineering design process. Teams also share and compare their optimized PPC prototypes. The showcase provides the opportunity for summative assessment of the design challenge, including abilities related to the design process, creative problem solving, ability to construct physical models, carrying out fair tests, data collection and analysis, teamwork practices, communication skills related to engineering, engineering habits of mind, and application of science knowledge.
• The Presentation Rubric in Appendix C can be used to assess each team’s presentation. Audience members could assist with scoring.

• The prompts built into the Composites Student Handbook guide students through the engineering design process and provide opportunities for metacognition and reflection. Review students’ Composites Student Handbooks to gain insight into students’ processes and ways of thinking. Consider arranging short debrief meetings with each design team to talk through their process and reflect on the experience.

• When students are meeting in their design teams and working on elements of the engineering design challenge, spend time with each team, listening in on their process and providing support as needed.

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

The engineering design challenge can be connected to the work of professional engineers in any field of practice: biomedical, electrical, mechanical, civil, and more. Consider inviting local professionals who work in fields that use composite materials, or professors and graduate students from engineering colleges to share their insights during the showcase and gallery walk.

Suggested Teacher Resources

<table>
<thead>
<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation Rubric</td>
<td>Composites Teacher Handbook, Appendix C</td>
</tr>
<tr>
<td>Composites Student Handbook</td>
<td>[Resource Link]</td>
</tr>
<tr>
<td>Practice Brief 7: Learning STEM through Design—Students Benefit from Expanding What Counts as “Engineering.”</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Practice Brief 36: Failing Forward—Managing Student Frustration During Engineering Design Projects</td>
<td>[Web Link]</td>
</tr>
</tbody>
</table>

Sources


Appendix A
Engineering Design Process

Step 1 Identify the Need or Problem
Describe the engineering design challenge to be solved. Include the limits and constraints, customer description, and an explanation of why solving this challenge is important.

Step 2 Research Criteria and Constraints
Research how others have solved this or similar problems, and discover what materials have been used. Be sure to thoroughly research the limitations and design requirements for success.

Step 3 Brainstorm Possible Solutions
Use your knowledge and creativity to generate as many solutions as possible. During this brainstorming stage, do not reject any ideas.

Step 4 Select the Best Solution
Each team member presents their solution ideas to the team. Team members annotate how each solution does or does not meet each design requirement. The team then agrees on a solution, or combination of solutions, that best meets the design requirements.

Step 5 Construct a Prototype
Develop an operating version of the solution.

Step 6 Test
Test your solution. Annotate the results from each test to share with your team.

Step 7 Present Results
Present the results from each test to the team.

Step 8 Redesign
The design process involves multiple iterations and redesigns. Determine a redesign to address failure points and/or design improvements. Redesign is based on the data from your tests, your team discussions as to the next steps to improve the design, and the engineering design process Steps 1 through 7.

Once your team is confident of a prototype solution, you present the results to the client.
- The client may accept your solution as is, or
- The client may ask for additional constraints and criteria to be included in the solution. At this point, you and your team revisit the engineering design process and resume the iterative redesign cycle.
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>
</table>

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

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

Reflection/Modifications Needed:

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

Reflection/Modifications Needed:

<table>
<thead>
<tr>
<th>Final Design Solution and Justification:</th>
</tr>
</thead>
</table>
Sentence Stems

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

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

### Science and Innovation

**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>Science ideas include science and engineering practices, disciplinary core ideas, and crosscutting concepts.</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 detail 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>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>
<td></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</td>
<td></td>
</tr>
<tr>
<td>The presentation moves from one idea to the next, but the main idea may not be clear or some ideas</td>
<td>The presentation moves from one idea to the next in a logical order,</td>
<td>The main idea is clearly stated. The presentation moves from one idea to the next in a logical order,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presenting Skills</td>
<td>Relevant to the presentation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter does not look at the audience and reads notes or slides.</td>
<td>The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing the main points in a focused, coherent manner. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter wears clothing inappropriate for the occasion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter mumbles or speaks too quickly or slowly.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks too softly to be understood.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter makes infrequent eye contact and reads notes or slides most of the time.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<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>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks clearly most of the time, although sometimes too quickly or slowly. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks loudly enough for most of the audience to hear, but may speak in a monotone. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter keeps eye contact with audience most of the time and only glances at notes or slides.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter engages the audience by drawing their sustained attention.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<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>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)</td>
<td></td>
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</tbody>
</table>
### Appendix D

**Airplane Design Cards**

<table>
<thead>
<tr>
<th>Boeing Stearman Kaydet Bi-plane</th>
<th>Lockheed Constellation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1936—1948)</td>
<td>(1937—1967)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Schleicher ASW-20 Glider</th>
<th>Boeing F/A-18 Hornet</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Airbus A380</th>
<th>Boeing 787 Dreamliner</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2007—present)</td>
<td>(2011—present)</td>
</tr>
</tbody>
</table>
## Airplane Design Cards (cont.)

| Boeing Stearman Kaydet Bi-plane  
(1936–1948) | Lockheed Constellation  
(1937–1967) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, spruce wood, and fabric.</td>
<td>Steel and aluminum.</td>
</tr>
</tbody>
</table>

| Schleicher ASW-20 Glider 
(1983–present) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberglass composite.</td>
<td>Aluminum, titanium, steel, and composites (carbon fiber epoxy).</td>
</tr>
</tbody>
</table>

| Airbus A380 
(2007–present) | Boeing 787 Dreamliner  
(2011–present) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites (carbon fiber reinforced plastic, GLARE, and thermoplastics).</td>
<td>Composites (carbon fiber and fiberglass), aluminum, titanium, and steel.</td>
</tr>
</tbody>
</table>
Airplane Cards Citations

This activity is an adaptation of the cart activity for museum docents “Material Science: Build an Airplane” from the Legends of Flight Informal Educator’s Toolkit.


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**Boeing Stearman Kaydet Bi-plane**

Photograph of Boeing Stearman Kaydet Bi-plane. Carlos Delgado [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. http://commons.wikimedia.org/wiki/File%3ABoeing_Stearman_75_Kaydet_flying-close_up-2.jpg

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**Lockheed Constellation**


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**Schleicher ASW-20 Glider**

Photograph of Schleicher ASW20 at Camphill Veteran Glider Rally June 2013. TSRL [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. https://commons.wikimedia.org/wiki/File%3ASleicher_ASW_20.jpg

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**Boeing F/A-18 Hornet**


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**Airbus A380**

Photograph of Airbus A380. By Yummifruitbat (Own work) [GFDL (http://www.gnu.org/copyleft/fdl.html), CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/) or CC-BY-2.5 (http://creativecommons.org/licenses/by/2.5/)], via Wikimedia Commons. http://commons.wikimedia.org/wiki/File%3AAirbus_a380_fb06rs.jpg

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**Boeing 787 Dreamliner**

Photograph of Boeing 787 Dreamliner. By 787_First_Flight.jpg: Dave Sizer derivative work: Altair78 (787_First_Flight.jpg) [CC-BY-2.0 (http://creativecommons.org/licenses/by/2.0/)], via Wikimedia Commons. http://commons.wikimedia.org/wiki/File%3ABoeing_787_first_flight.jpg
Materials Information

All objects, including human-made objects are made up of different types of materials. Materials are categorized in groups such as ceramics, glass, metal, wood, polymers, composites, biomaterials, or superconductors. Materials can be described based on their structure, properties, and performance. Engineers choose materials for a particular purpose based on a number of factors, including how well they perform for a desired function.

Carbon Fiber Composites

Carbon fiber composites offer aeronautical engineers the following advantages:

- The material’s strength-to-weight ratio makes airplanes lighter, which reduces fuel use and helps to lower harmful emissions. It also allows for the cabin to be pressurized to a lower altitude and for the windows to be larger, which increases passengers’ comfort.
- The material’s ability to be molded into almost any shape allows airplanes to be assembled out of large, smooth-bodied pieces, including one-piece barrel construction, rather than many aluminum panels, which results in many seams and fasteners. This results in less drag, better fuel efficiency, and lower maintenance costs.
- The material’s corrosion resistance properties allow the cabin to be better humidified, which makes it more comfortable for passengers.

Fifty percent (by weight) of Boeing’s 787 Dreamliner is made out of composites, which includes carbon fiber composites (carbon sandwich and carbon laminate) and other types of composites (including fiberglass and glass/carbon hybrid composites).

The Boeing 787 Dreamliner is constructed of 50% composites (including carbon fiber laminate and carbon fiber sandwich), 20% aluminum, 15% titanium, 10% steel, and 5% other materials.

Carbon laminate is used for major structures including the fuselage. Boeing pioneered the use of carbon laminate to construct a one-piece barrel for the fuselage. The one-piece construct means less parts, joints, and fasteners than traditional airplane design, which ultimately results in less weight, less drag, and less maintenance costs.

The passenger experience is positively affected by the use of the one-barrel composite fuselage.
The strength of the carbon laminate composite also means that the Dreamliner’s cabin can be pressurized to a lower cabin altitude than an aluminum airplane would allow. The composite fuselage also allows for much larger windows.

The use of carbon fiber composites means that the manufacturing process produces less “scrap material and waste” than an airplane made of traditional materials.

**Composites Examples**

**Examples of Composites in Aeronautical and Aerospace Materials**

- The Boeing 787 Dreamliner uses carbon fiber reinforced polymer (CFRP).
- The new Airbus A380 uses CFRP and GLARE, an aluminum and fiberglass composite.
- Ceramic matrix composites (CMC) are used in heat shields to protect space vehicles as they reenter Earth’s atmosphere.

**Video Links**

- Boeing 787 Dreamliner One-Piece Barrel Video [Web Link]
- Boeing 787 One-Piece Barrel Construction [Web Link]

**Examples of Composites in Construction Materials**

- Plywood contains layers of fiber reinforced polymers (FRP).
- Fiberglass is also known as glass-fiber reinforced plastic (GFRP). It is a composite of a glass fiber reinforcement in a plastic matrix. Fiberglass is used to create some types of bathtubs, water tanks, and roofing materials.
- Some types of laminate countertops are made from laminate composites.
- Metal matrix composites (MMC) are strong materials that combine a reinforcement (for example, carbon fibers) with a metal matrix (for example, aluminum or titanium).
- Glass reinforced plastics (GRP) are composites designed for high temperatures.
- Ceramic matrix composites (CMC) combines a reinforcement of ceramic fibers with a ceramic matrix, and are used in many different high temperature applications.

**Examples of Composites in Sports Equipment**

- Carbon fiber composites can be found in a variety of sports equipment to make the equipment lighter, stronger, and flexible. This includes certain types of baseball bats, golf club shafts, tennis racquets, fly fishing rods, skis, snowboards, hockey sticks, archery bows and arrows, canoe and kayak paddles, skateboards, surfboards, bicycle frames, helmets (bicycle, football, and so forth), and the interior parts of athletic shoes.
- Thermoplastic composites are also used in hockey sticks (and bullet-proof vests).
- Graphite composites can also be found in golf club shafts and sail boat masts.

**Examples of Composites in Vehicles**

- Fiberglass, or GFRP, as described above, is often used in the hulls of small boats, like sailboats, fishing boats, canoes, and rowboats.
- Mallite is a high performance composite used in some Formula One racing cars’ bodies.
Carbon fiber composites are used in some Formula One racing cars, yachts, as well as special edition cars manufactured by Porsche, Mitsubishi, Maybach, Chevrolet, Ford, and Bentley.

**Material Strength**

All materials possess three main types of materials strength:

- **Compressive Strength**: The maximum amount of compression (squishing, crunching, and so forth) that a material can handle before it fails. An example of compressive strength is stomping on an aluminum soda can.
- **Tensile Strength**: The maximum amount of loading that a material can handle before it fails. Some materials stretch before breaking. An example of tensile strength is piling pennies on top of a paper towel until the towel tears.
- **Shear Strength**: The maximum amount of stress along a plane that a material can handle before it fails. An example of shear strength is tearing a piece of fabric into strips. Shear strength can be measure across the width, length, and diagonal of a material.

*(Legends of Flight Informal Educator’s Toolkit: Background Science pg. 6)*

This is just the beginning when thinking about the properties and performance of materials. There are other types of strength (including yield, compressive, and impact). Material scientists and engineers are also concerned about loading, stress, strain, and failure. They also consider a material’s brittle and ductile properties.

**Material Science Background**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Web Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celebrating Engineering at Boeing</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Strange Matter Grades 5–8 Teacher’s Guide</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>A series of classroom lessons introducing students to the world of materials science</td>
<td></td>
</tr>
<tr>
<td>Strange Matter: Materials Smackdown</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>Animation that compares the effects of compression on different materials</td>
<td></td>
</tr>
<tr>
<td>Demoworks: The Fine Art of Materials Science Demonstrations</td>
<td>[Web Link]</td>
</tr>
<tr>
<td>40+ classroom demonstrations of materials science concepts</td>
<td></td>
</tr>
</tbody>
</table>
## 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><strong>carbon fiber composite</strong></td>
<td>A composite where the matrix is usually a polymer resin, such as epoxy, to bind the carbon fiber reinforcements together.*</td>
</tr>
<tr>
<td><strong>composite</strong></td>
<td>Made up of disparate or separate parts or elements; compound.</td>
</tr>
<tr>
<td><strong>composite engineer</strong></td>
<td>Engineers who design, fabricate, and test products made of composite materials.*</td>
</tr>
<tr>
<td><strong>compressive strength</strong></td>
<td>The capacity of a material or structure to withstand loads tending to reduce size.**</td>
</tr>
<tr>
<td><strong>constraint</strong></td>
<td>Limitation or restriction.</td>
</tr>
<tr>
<td><strong>criteria</strong></td>
<td>A standard of judgment or criticism; a rule or principle for evaluating or testing something.</td>
</tr>
<tr>
<td><strong>failure</strong></td>
<td>An act or instance of failing or proving unsuccessful; lack of success.</td>
</tr>
<tr>
<td><strong>fair test</strong></td>
<td>A testing process in which only one factor is changed at a time while keeping all other conditions the same.*</td>
</tr>
<tr>
<td><strong>materials science</strong></td>
<td>The study of the characteristics and uses of various materials, such as glass, plastics, and metals.</td>
</tr>
<tr>
<td><strong>matrix</strong></td>
<td>Fine material, such as cement, in which lumps of coarser material, such as an aggregate, are embedded.</td>
</tr>
<tr>
<td><strong>matrix ingredient</strong></td>
<td>Ingredients introduced into a fine material, such as cement.*</td>
</tr>
<tr>
<td><strong>optimize</strong></td>
<td>To make as effective, perfect, or useful as possible.</td>
</tr>
<tr>
<td><strong>performance</strong></td>
<td>A particular action, deed, or proceeding.</td>
</tr>
<tr>
<td><strong>prepregger</strong></td>
<td>A machine that assembles the dry fibers in a unidirectional pattern or weaves the fibers into a fabric followed by application of a matrix resin to make the prepreg.*</td>
</tr>
<tr>
<td><strong>property</strong></td>
<td>An essential or distinctive attribute or quality of a thing.</td>
</tr>
<tr>
<td><strong>prototype</strong></td>
<td>The original or model on which something is based or formed.</td>
</tr>
<tr>
<td><strong>reinforcement</strong></td>
<td>A system of internal structures embedded in a material to help absorb the tensile and shearing stresses.*</td>
</tr>
<tr>
<td><strong>shear strength</strong></td>
<td>The ability of a material to resist fracture along a plane as a result of forces acting parallel to the plane.**</td>
</tr>
<tr>
<td><strong>tensile strength</strong></td>
<td>The resistance of a material to longitudinal stress, measured by the minimum amount of longitudinal stress required to rupture the material.**</td>
</tr>
</tbody>
</table>

*Definition developed by module authors.

**Definition from Legends of Flight Informal Educator’s Toolkit.