Days 7 through 10: Composites Engineering Design Challenge

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

- Gather or purchase all required materials for the day
- Assemble a materials kit for each team, and organize kits in tubs, trays, or bags
- Review the recommended briefs for additional background information on working through design challenges with students

### Links/Additional Information

- Refer to the Materials List below
- Each kit should include:
  - Scissors (1 per student)
  - Ruler (1 per student)
  - Pennies, banker rolls (2 rolls)
  - Paper towels (at least 10 sheets)
  - Cellophane tape (1 roll or more)
  - Colored pens or pencils (assortment)

- Practice Brief 7: Learning STEM through Design—Students Benefit from Expanding What Counts as “Engineering.” [Web Link]
- Practice Brief 36: Failing Forward—Managing Student Frustration During Engineering Design Projects [Web Link]

### 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>
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<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.
• 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>
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<tr>
<th>Meeting the Needs of All Learners</th>
<th>Composites Teacher Handbook, Appendix B</th>
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Sources
