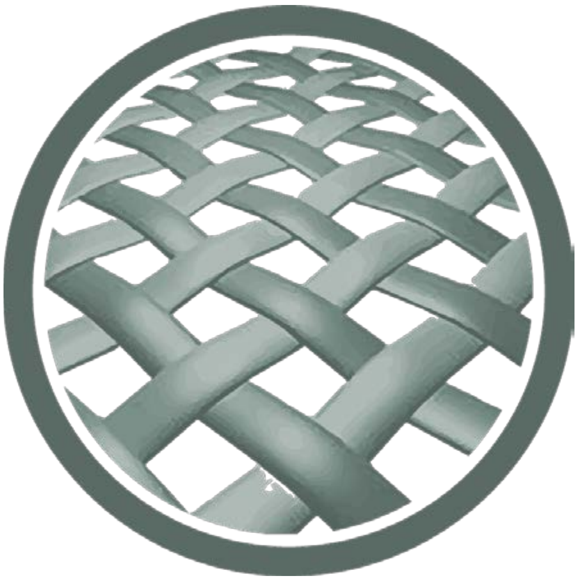

Science and Innovation

A Boeing/Teaching Channel Partnership

COMPOSITES

Teacher Handbook

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Composites

Day 4: Composites Everywhere

Grade Level	Grade 5
Lesson Length	One 50-minute session and a second optional 50-minute session

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:

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
- Disciplinary Core Ideas: ETS1.A Defining and Delimiting Engineering Problems, ETS1.Cptimizing the Design Solution, PS1.B Chemical Reactions
- 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.

Dimension	NGSS Element	Connections to Classroom Activity
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.* **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.*	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.
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.* **ETS1.C: Optimizing the Design Solution** • *Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.* **PS1.B: Chemical Reactions**	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. 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.

	• *When two or more different substances are mixed, a new substance with different properties may be formed.*	
Crosscutting Concepts	**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.* • *Substructures have shapes and parts that serve functions.*	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)

Required Preparation	Links/Additional Information
❑ Gather or purchase all required materials for the lesson	Refer to the Materials List below
❑ 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.	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.

❑ 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

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

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.

Video Link

- Daedalus and Icarus (Mimi the Storyteller, 6:31 minutes) [YouTube Link]

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:

________________ + ________________ = 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

Reinforcement ingredient + *Matrix ingredient* = 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

Reinforcement ingredient + *Matrix ingredient* = 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.*

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.

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

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.

NGSS Key Moment

Designing a fair test helps students begin to build an understanding for ETS1.C. Push students to think carefully about ways to control their testing protocol.

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.

NGSS Key Moment

Remember to link design considerations to 5-PS1-4. Have students consider the properties to the ingredients. Prompt students to predict what might happen when they combine ingredients. Students may find some unexpected results!

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?*

NGSS Key Moment

Continue to link the design outcomes to 5-PS1-4. Have students consider the properties of the composite and how they relate to the properties of the ingredients.

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

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

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