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Smithsonian STEAM Readers—Grade 5

This sample includes the following:

Smithsonian

STEAM Readers

Science ▪ Technology ▪ Engineering ▪ Arts ▪ Mathematics

Management Guide

Grade 5

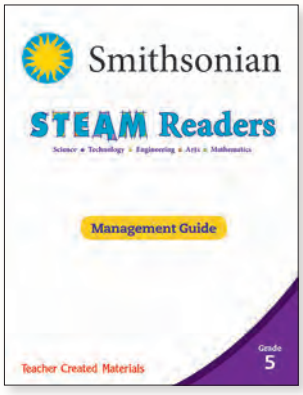
Teacher Created Materials

Table of Contents

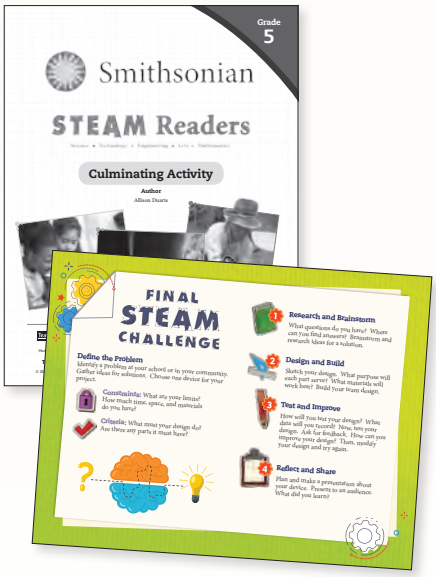
Kit Components

15 lesson plans with 6 copies of each book

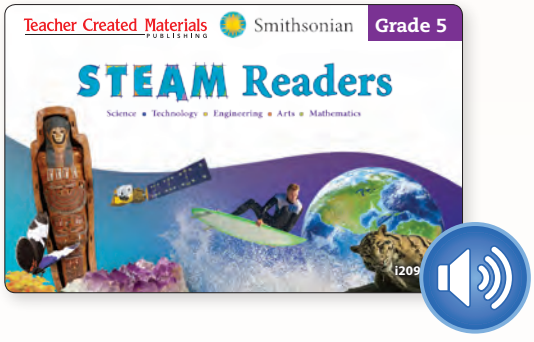
Management Guide



Culminating Activity



Digital and Audio Resources

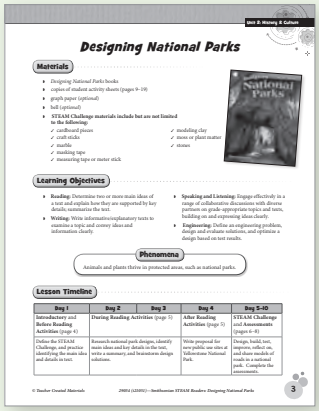


Lesson Plan Components

Each ten-day lesson sequence is organized in a consistent format for ease of use.

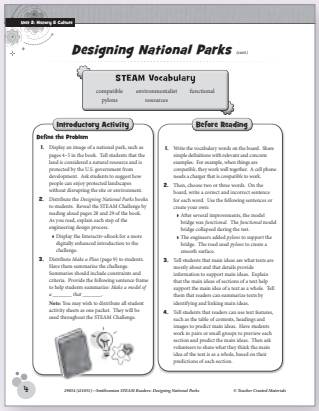
Overview

- The overview page includes learning objectives, a materials list, and a suggested timeline for lessons.



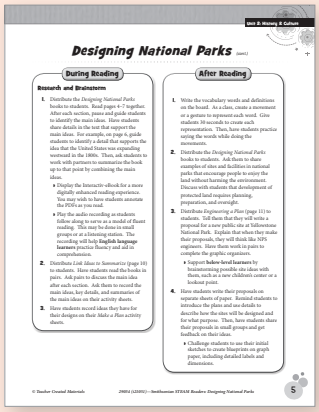
Day 1

- Students are introduced to the STEAM Challenge, vocabulary, and reading skill.



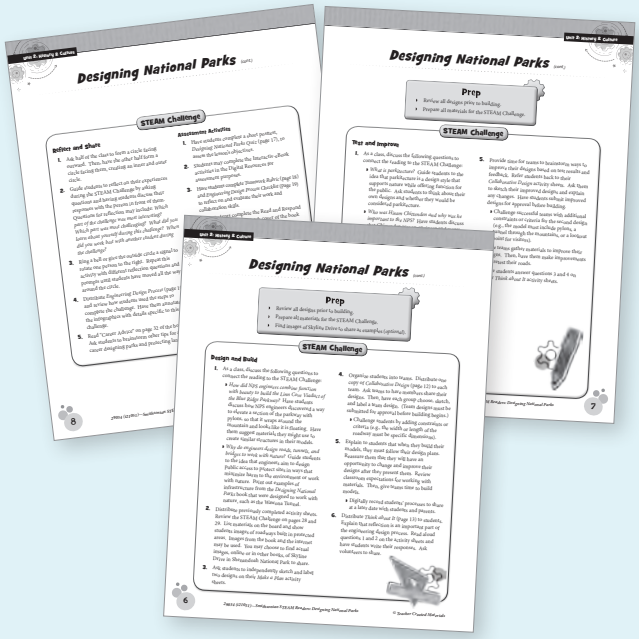
Days 2, 3, and 4

- Students complete reading and writing activities as they gain knowledge that will help them with the STEAM Challenge.



Days 5–10

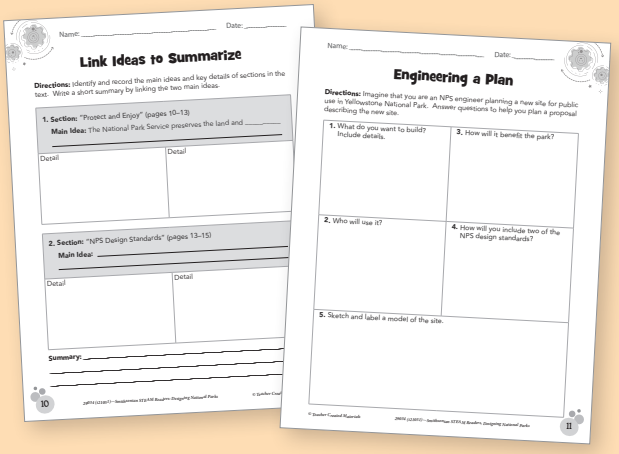
- Students take what they've learned and apply it to design, build, test, and improve a solution.
- Students reflect, share work, and take assessments.



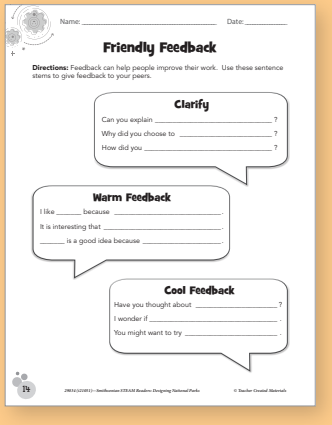
Lesson Plan Components *(cont.)*

Student Activity Sheets

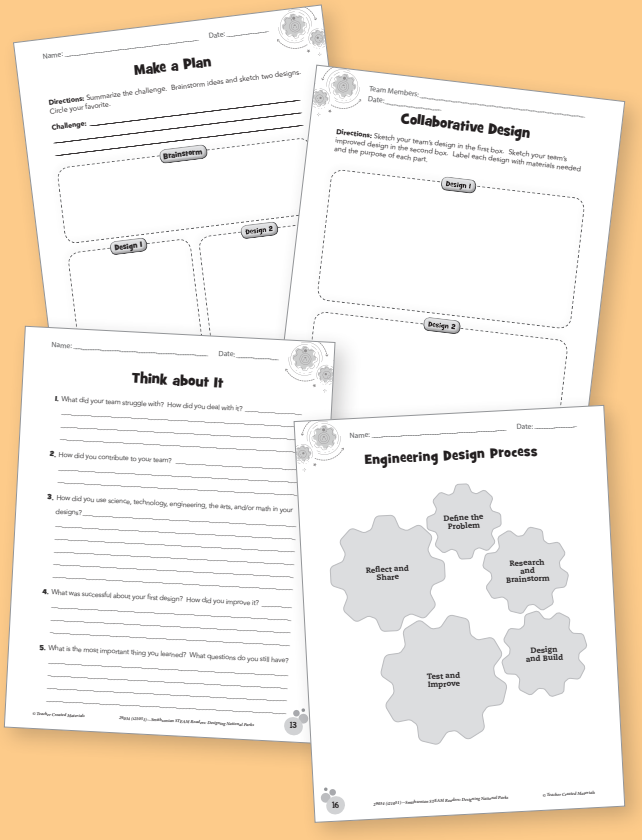
Literacy skills are supported with meaningful activities that **promote higher-order thinking skills**.



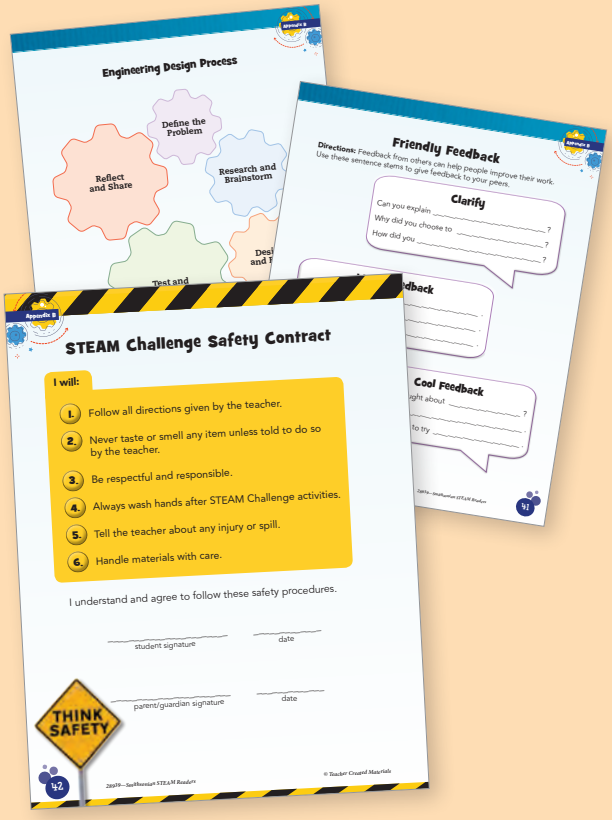
Effective feedback techniques are supported with **sentence frames** to help students provide feedback to peers and to facilitate productive classroom dialogue.



STEAM Challenge activity sheets support students throughout the **engineering design process**.



Appendix B includes quick reference sheets for students and teachers.



Assessments

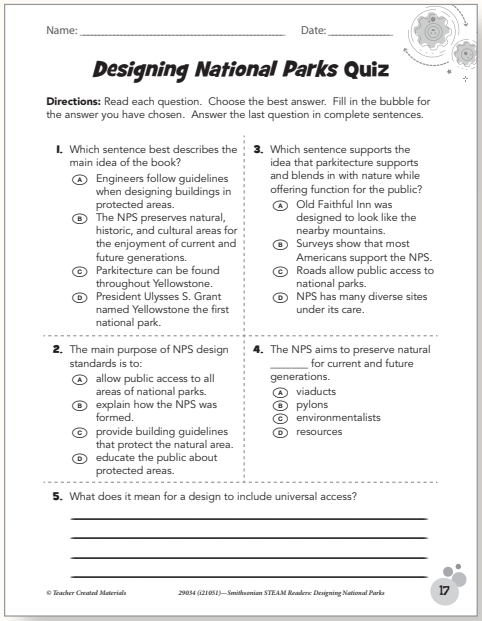
Assessment guides teacher decisions and improves student learning. *Smithsonian STEAM Readers* offers balanced assessment opportunities. Assessments require students to demonstrate analytical thinking, comprehend informational texts, and write evidence-based responses.

Quizzes

Each lesson plan includes a quiz with multiple-choice questions and a short-answer question. These assessments include text-dependent questions and may be used as open-book evaluations. Answer keys are provided on page 2 of each lesson.

STEAM Challenge

STEAM Challenges include a *Teamwork Rubric* and an *Engineering Design Process Checklist*. These guide students to reflect on and evaluate their work and collaboration skills.



Name: _____ Date: _____

Designing National Parks Quiz

Directions: Read each question. Choose the best answer. Fill in the bubble for the answer you have chosen. Answer the last question in complete sentences.

1. Which sentence best describes the main idea of the book?
- (A) Engineers follow guidelines when designing buildings in protected areas.
- (B) The NPS preserves natural, historic, and cultural areas for the enjoyment of current and future generations.
- (C) Parkitecture can be found throughout Yellowstone.
- (D) President Ulysses S. Grant named Yellowstone the first national park.

2. The main purpose of NPS design standards is to:
- (A) allow public access to all areas of national parks.
- (B) explain how the NPS was formed.
- (C) provide building guidelines that protect the natural area.
- (D) educate the public about protected areas.

3. Which sentence supports the idea that parkitecture supports and blends in with nature while offering function for the public?
- (A) Old Faithful Inn was designed to look like the nearby mountains.
- (B) Surveys show that most Americans support the NPS.
- (C) Roads allow public access to national parks.
- (D) NPS has many diverse sites under its care.

4. The NPS aims to preserve natural _____ for current and future generations.
- (A) viaducts
- (B) pylons
- (C) environmentalists
- (D) resources

5. What does it mean for a design to include universal access?

_____

_____

_____

_____

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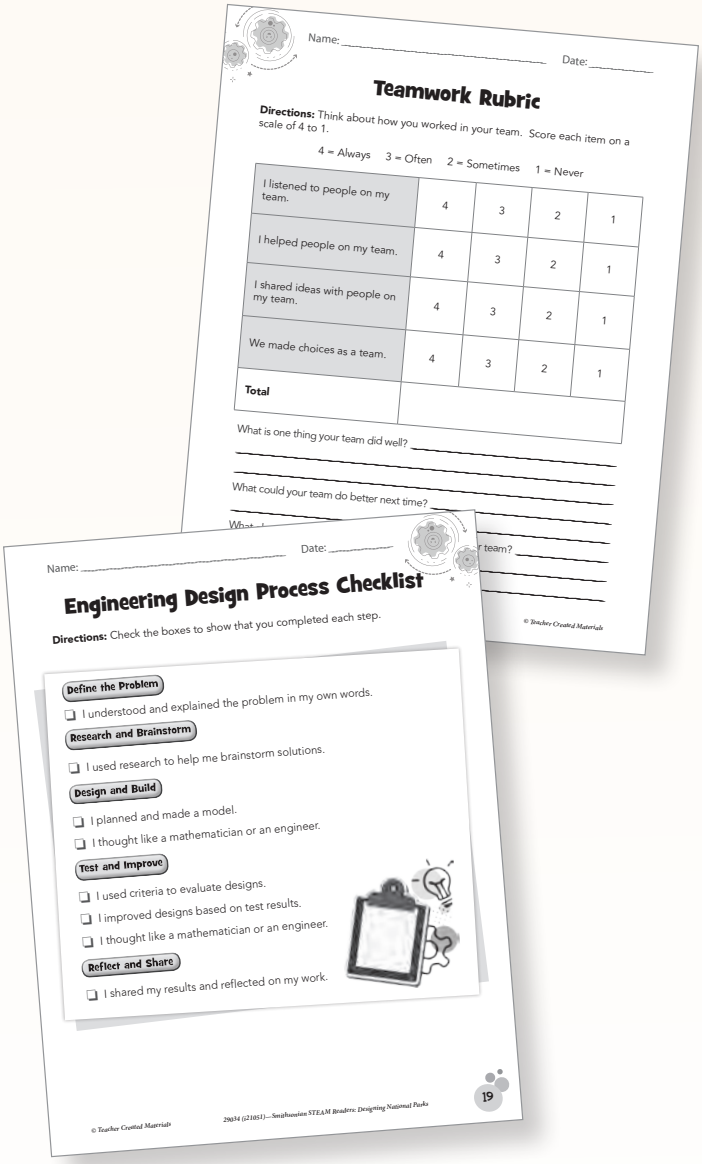

Name: _____ Date: _____

Teamwork Rubric

Directions: Think about how you worked in your team. Score each item on a scale of 4 to 1.

4 = Always 3 = Often 2 = Sometimes 1 = Never

I listened to people on my team.	4	3	2	1
I helped people on my team.	4	3	2	1
I shared ideas with people on my team.	4	3	2	1
We made choices as a team.	4	3	2	1
Total				

What is one thing your team did well? _____

What could your team do better next time? _____

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Name: _____ Date: _____

Engineering Design Process Checklist

Directions: Check the boxes to show that you completed each step.

Define the Problem
- ❑ I understood and explained the problem in my own words.

Research and Brainstorm
- ❑ I used research to help me brainstorm solutions.

Design and Build
- ❑ I planned and made a model.
- ❑ I thought like a mathematician or an engineer.

Test and Improve
- ❑ I used criteria to evaluate designs.
- ❑ I improved designs based on test results.
- ❑ I thought like a mathematician or an engineer.

Reflect and Share
- ❑ I shared my results and reflected on my work.

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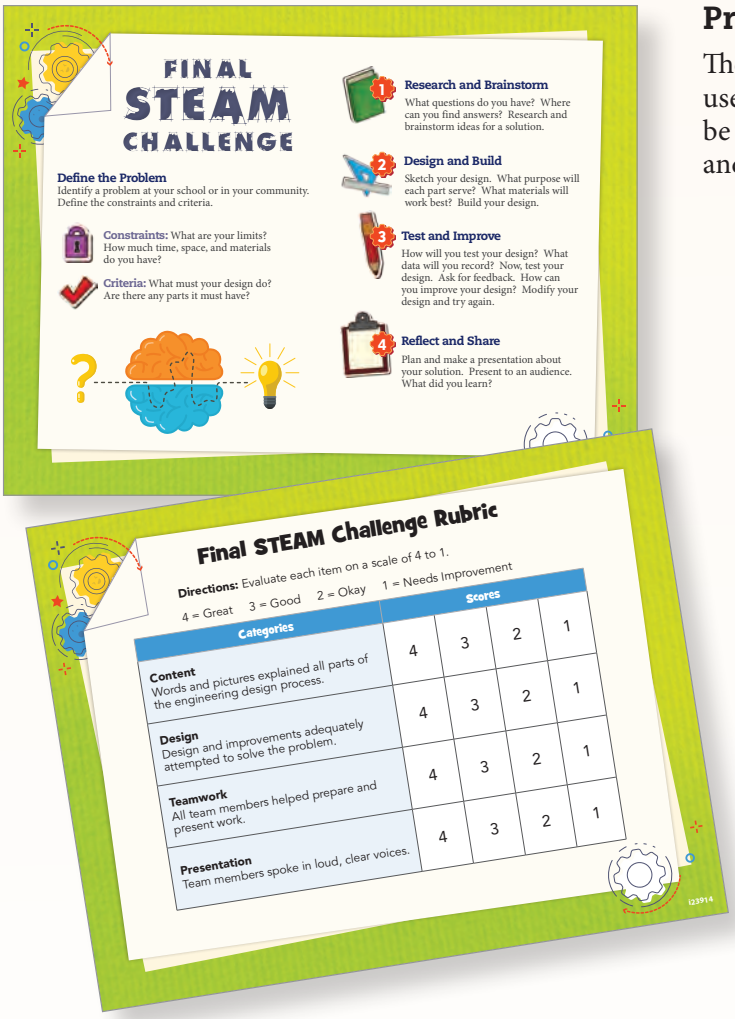
Assessments *(cont.)*

Culminating Activity

The Culminating Activity asks students to apply what they have learned in an engaging and interactive way. Students use what they have learned to solve real-world problems in a final STEAM Challenge.

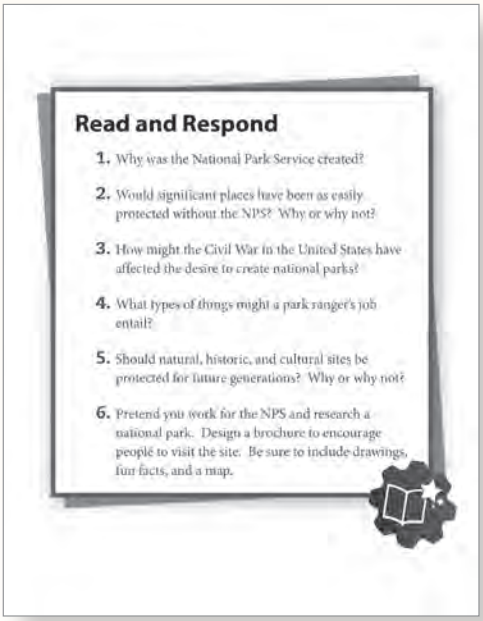


Read and Respond

Read and Respond questions can be found on the inside back covers of the books. Questions require various levels of critical thinking and can be used for instruction or assessment. Answer keys are provided in the digital resources.

Progress Monitoring

There are several points throughout each lesson when useful evaluations can be made. These evaluations can be based on group, paired, and individual discussions and activities.



Pacing and Instructional Setting Options

Smithsonian STEAM Readers is flexibly designed and can be used in tandem with a core curriculum within a science block/STEAM/STEM block, and/or literacy block. It can also be used in makerspaces to integrate literacy with the engineering design process. Teachers should customize pacing according to student need and the teacher's preferred instructional framework, such as Balanced Literacy.

***Smithsonian STEAM Readers* within the Balanced Literacy Framework**	
Modeled and Shared Reading/Writing	The Before, During, and After Reading activities in each lesson of this series offer opportunities for teachers to activate students' prior knowledge, as well as model fluency and metacognition as they read aloud from the text and guide students through reading and writing activities.
Small-Group Reading/ Workshop	The During Reading, After Reading, and STEAM Challenge activities in each lesson of this series can be completed during small-group instruction, in centers, or at workstations, depending on students' previous learning experiences and their need for teacher support.
Independent Reading	Professional audio recordings, PDFs of the books, and Interactiv-eBooks are provided to support independent reading at workstations and listening centers.
Assessment	This series offers multiple formative and summative assessment opportunities that can be used to guide instruction and assess learning (see pages 20–21 for details).

The following pacing and instructional setting options show suggestions for how to use this product. Two pacing options are provided.

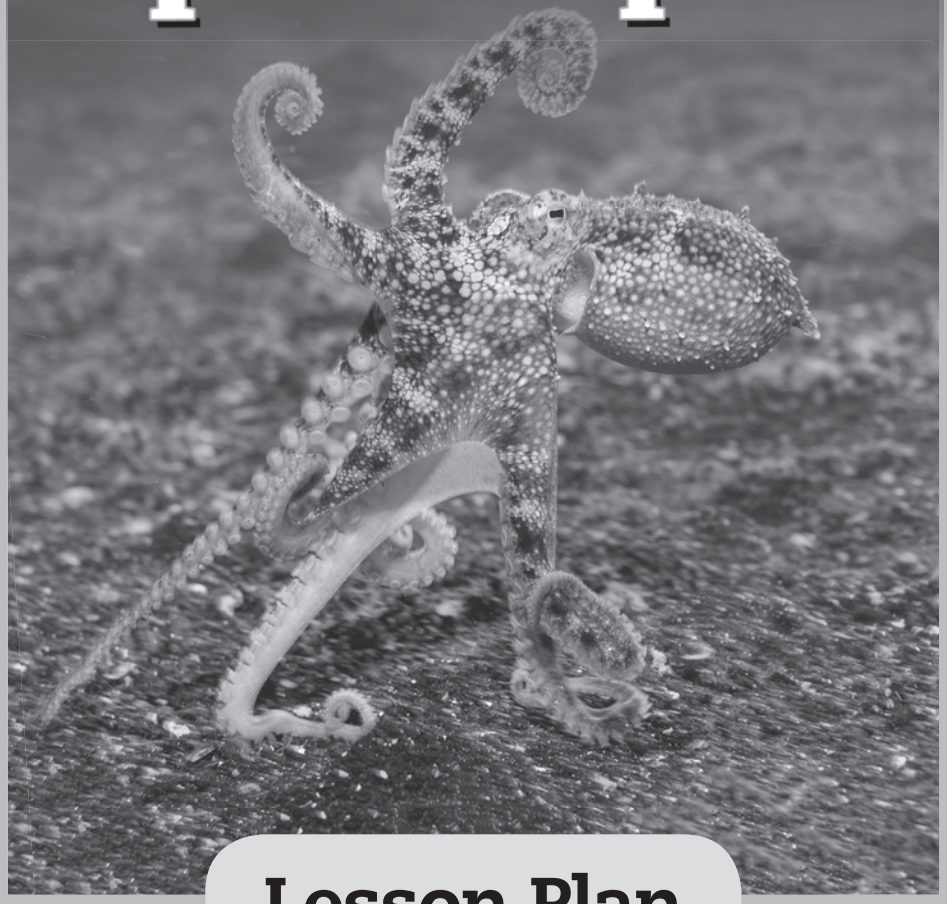
Option 1 includes both literacy and STEAM Challenge activities. This option spans 10 instructional days and requires approximately 30–45 minutes a day, for a total of 75–112.5 hours over the course of 150 days.

Day 1	Day 2	Day 3	Day 4	Days 5–10
Introductory and **Before Reading Activities**	**During Reading Activity**		**After Reading Activity**	**STEAM Challenge** and **Assessments**

Option 2 includes only literacy activities. This option spans five instructional days and requires approximately 30–45 minutes a day, for a total of 37.5–56.25 hours over the course of 75 days.

Day 1	Day 2	Day 3	Day 4	Day 5
Before Reading Activity	**During Reading Activity**		**After Reading Activity**	**Assessment Activities**

Color-Changing Cephalopods



Unit 3
Pushing the Limits

Lesson Plan

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Smithsonian STEAM Readers
Science ■ Technology ■ Engineering ■ Arts ■ Mathematics

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References to digital components are included for educators who purchased the full kit: *Smithsonian STEAM Readers: Grade 5*. Please disregard digital component references if this lesson was purchased in a different product configuration.

Answer Key: *Color-Changing Cephalopods*

page 10—Biomimicry

Responses will vary. Example:

1. color-changing ability; Scientists at the University of Illinois created a small piece of synthetic skin made of 256 black squares that change color between black and white when heated.
2. changing skin texture; Two professors created a material that can change texture and color when signaled by a change in voltage.
3. bioluminescence; Scientists are working to find a way to add light to city trees so that they can produce light during the night rather than using power sources.

page 11—All about Cephalopods

Responses will vary. Example:

Title Page: Copying Cephalopods, by Student Name

Introduction: Imagine being able to change colors whenever you want. Cephalopods can, and scientists at the University of Illinois are learning how to mimic this function.

Detail: They have created a small patch of synthetic skin that changes with heat.

Detail: The patch of skin is made of 256 tiny black squares and each have dye.

Detail: So far, they have been able to use heat to change the pattern of skin to spell UoI.

Closing: Cephalopods are amazing animals, and it is important that we continue to study and learn from them. Who knows what amazing technology they will inspire next?

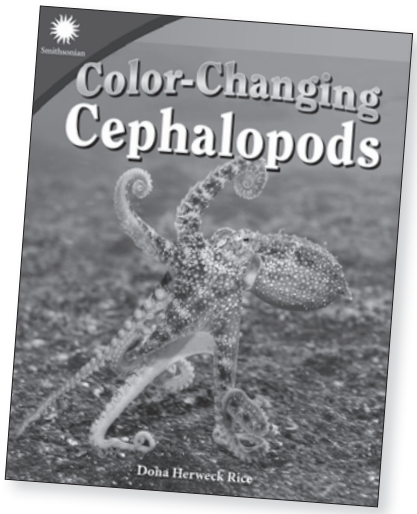
page 17—*Color-Changing Cephalopods* Quiz

1. B
2. A
3. B
4. C
5. Responses will vary. Example: The Octopus Gripper is designed to help robots grip objects. The design is related to the arms of octopuses, which have suckers all over them.

Color-Changing Cephalopods

Materials

- *Color-Changing Cephalopods* books
- copies of student activity sheets (pages 9–19)
- images of animals that use camouflage
- index cards
- pocket chart or chart paper
- **STEAM Challenge materials include but are not limited to the following:**
  - ✓ aluminum foil
  - ✓ cardboard pieces
  - ✓ cloth pieces, various sizes, textures, and colors
  - ✓ construction paper
  - ✓ glue
  - ✓ images and descriptions of Earth's various habitats
  - ✓ markers, colored pencils, or paint
  - ✓ masking tape
  - ✓ plant materials, such as leaves, moss, and bark
  - ✓ rubber bands
  - ✓ sticks, various sizes



Learning Objectives

- **Reading:** Explain the relationships or interactions between two or more individuals, events, ideas, or concepts in a historical, scientific, or technical text based on specific information in the text.
- **Writing:** With guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach.
- **Speaking and Listening:** Engage effectively in a range of collaborative discussions with diverse partners on grade-appropriate topics and texts, building on and expressing ideas clearly.
- **Engineering:** Define an engineering problem, design and evaluate solutions, and optimize a design based on test results.

Phenomena

Cephalopods can change their color, texture, and shape.

Lesson Timeline

Day 1	Day 2	Day 3	Day 4	Days 5–10
Introductory and **Before Reading Activities** (page 4)	**During Reading Activities** (page 5)		**After Reading Activities** (page 5)	**STEAM Challenge** and **Assessments** (pages 6–8)
Define the STEAM Challenge, and practice identifying how two concepts in the text are related.	Research cephalopods, identify how the structures and functions of cephalopods have influenced new technologies, and brainstorm design solutions.		Prepare digital slides for presentations about cephalopods at a biomimicry conference.	Design, build, test, improve, reflect on, and share pieces of camouflage clothing. Complete the assessments.

Color-Changing Cephalopods (cont.)

STEAM Vocabulary

camouflage cells chromatophores
crypsis tentacles

Introductory Activity

Define the Problem

1. Write a list on the board of animals that use camouflage, such as leopards, tree lizards, gray tree frogs, mountain hares, owl butterflies, brown vine snakes, leaf-tailed geckos, and day octopuses. Display images of each animal in their habitat. Ask students to share their observations and to suggest how all of the animals are similar. Guide students to the idea that some animals have the ability to blend in to match their environment. Challenge students to predict why this ability might be beneficial.
2. Distribute the *Color-Changing Cephalopods* books to students. Reveal the STEAM Challenge by reading aloud pages 28 and 29 of the book. Ask you read, explain each step of the engineering design process.
   - Display the Interactiv-eBook for a more digitally enhanced introduction to the challenge.
3. Distribute *Make a Plan* (page 9) to students. Have them summarize the challenge. Summaries should include constraints and criteria. Provide the following sentence frame to help students summarize: *Make* _____ *that uses* _____ *to* _____.

   Note: You may wish to distribute all student activity sheets as one packet. They will be used throughout the STEAM Challenge.

Before Reading

1. Write the vocabulary words on index cards. Discuss the meanings of the words. Create a word wall in a pocket chart or on chart paper. Have students help you arrange the words in a way that makes sense. Try several variations. Accept any arrangement as long as students can justify it. Continue to change and add to the word wall throughout the lesson.
2. Tell students that readers can find relationships to make sense of and deepen their understanding of texts. Explain to students that relationships may include how one thing impacts or influences another thing, how they compare and contrast, or how they are connected.
   - Support students by having them explain how various pairs of things are related, such as an apple and apple pie, a guitar and sheet music, and a bird and an airplane.
3. Tell students that you will read a passage about two related concepts. Read aloud the sidebar "Squids' Sight" on page 11 of the *Color-Changing Cephalopods* book, and ask students to identify the two related concepts (e.g., reflective eyes of squids and reflective technology for the military). Guide students to the idea that the concepts are related because the development of reflective technology is influenced by cephalopod eyes.

Color-Changing Cephalopods (cont.)

During Reading

Research and Brainstorm

1. Distribute the *Color-Changing Cephalopods* books to students. Read pages 4–11 aloud. Pause periodically to describe how ideas or concepts are related. For example, on page 8, have students explain how cuttlefish and squid are related by stating similarities and differences between the two animals.
   - Display the Interactiv-eBook for a more digitally enhanced reading experience. You may wish to have students annotate the PDFs as you read.
   - Play the audio recording as students follow along to serve as a model of fluent reading. This may be done in small groups or at a listening station. The recording will help **English language learners** practice fluency and aid in comprehension.
2. Distribute *Biomimicry* (page 10) to students. Have students read the books in pairs. Ask them to identify relationships between concepts and ideas as they read. Have them explain how scientists are developing technology related to cephalopod structures and functions on their activity sheets.
3. Have students record ideas they have for their designs on their *Make a Plan* activity sheets.

After Reading

1. Write the vocabulary words on the board and review the definitions. Have groups of students write meaningful sentences for each word. Use the following sentence stems or create your own:
   - When an animal is *camouflaged*, it_____ *(blends in with its environment).*
   - *Cells* make up _____ *(all living things).*
   - *Chromatophores* can change by _____ *(growing, shrinking, or restacking).*
   - Through *crypsis*, cephalopods can _____ *(change themselves to avoid detection).*
   - *Tentacles* are different from arms because _____ *(they have suckers just at the ends).*
2. Tell students that scientists and engineers often create presentations to share information with others. Explain to students that they give these presentations at meetings and conferences. Point out that the revision process, which includes feedback from colleagues, is an important part of producing scientific papers and presentations.
3. Distribute *All about Cephalopods* (page 11) to students. Ask students to imagine they have been asked to give a presenation on cehpalopods at a biomimicry conference. Have them plan slides for their presentations using the graphic organizers. Ask students to have partners review their slides and give feedback with the checklist on the bottom of the activity sheets. Allow time for students to revise their work after peer review.
4. Have students use their graphic organizers to create slide show presentations on computers or with a series of posters. Allow time for students to practice their presentations and receive peer feedback on their delivery. You may choose to have them present to groups of younger students.

Color-Changing Cephalopods (cont.)

Prep

- Review all designs prior to building.
- Prepare all materials for the STEAM Challenge.
- Identify and prepare materials that provide students with information, such as images and descriptions about Earth's various habitats.

STEAM Challenge

Design and Build

1. As a class, discuss the following questions to connect the reading to the STEAM Challenge:
   - *What does it mean for an animal to camouflage itself?* Have students recall that when an animal camouflages itself, the animal appears to blend with its environment.
   - *What are different ways animals can camouflage?* Discuss with students that animals can change their texture, shape, posture, or color to avoid detection.
2. Distribute previously completed activity sheets. Review the STEAM Challenge on pages 28 and 29. List materials on the board. Discuss with students various types of habitats, including tropical rainforests, deserts, temperate grasslands, and coniferous forests. Display images from books or the internet of the different habitat types. Encourage students to reference images and descriptions of the habitats as they design their clothing items.
   - Support students by explaining that texture is a characteristic of the surface of materials and refers to the way something feels. Discuss types of textures, including smooth, rough, sticky, fuzzy, and soft.
3. Ask students to independently sketch and label two designs on their *Make a Plan* activity sheets.
4. Organize students into teams. Distribute one copy of *Collaborative Design* (page 12) to each team. Ask teams to have members share their designs. Then, have each group choose, sketch, and label a team design. (Team designs must be submitted for approval before building begins.)
   - Challenge students by adding constraints or criteria (e.g., create a name and logo for the clothing line, write a pitch that would sell the item to consumers).
5. Explain to students that when they build their models, they must follow their design plans. Reassure them that they will have an opportunity to change and improve their designs after they present them. Review classroom expectations for working with materials. Then, give teams time to build the clothing item.
   - Digitally record students' processes to share at a later date with students and parents.
6. Distribute *Think about It* (page 13) to students. Explain that reflection is an important part of the engineering design process. Read aloud questions 1 and 2 on the activity sheets, and have students write their responses. Ask volunteers to share.

Color-Changing Cephalopods (cont.)

Prep

- Review all designs prior to building.
- Prepare all materials for the STEAM Challenge.

STEAM Challenge

Test and Improve

1. As a class, discuss the following questions to connect the reading to the STEAM Challenge:
   - *Why are scientists studying biomimicry?* Discuss with students that nature has found ways to exist that work well and are sustainable and how scientists can use solutions in nature to support humans.
   - *Why are scientists interested in cephalopods?* Have students discuss that scientists are particularly interested in cephalopods because their abilities to change might surpass any other creature.
2. Explain to students that teams not presenting their clothing will act as company representatives. Tell students that teams will offer feedback after each presentation. Use *Friendly Feedback* (page 14) to review best practices for giving feedback.
3. Distribute *Camouflage Clothing Test Results* (page 15) to students and ask them to record results for each team.
4. Allow time for teams to present their clothing. Have one member from each team wear the piece of clothing. Ask the team to present their design and describe how it functions to camouflage a person in two different habitats. A successful design uses both color and texture to camouflage a person in two different habitats. Ask volunteers to give friendly feedback.
5. Allow time for teams to brainstorm ways to improve their designs based on test results and feedback. Refer students back to their *Collaborative Design* activity sheets. Ask them to sketch their improved designs and explain any changes. Have students submit improved designs for approval before building.
   - Challenge successful teams with additional constraints or criteria for the second design (e.g., add an additional feature to the item, create a camouflage camera case to match the clothing item).
6. Have teams gather materials to improve their designs. Then, have them make improvements and present their clothing item again.
7. Have students answer questions 3 and 4 on their *Think about It* activity sheets.

Color-Changing Cephalopods *(cont.)*

STEAM Challenge

Reflect and Share

1. Discuss with students different situations in which they changed plans to adapt to new conditions. Connect this discussion to the STEAM Challenge by asking students to identify a way that they modified their initial design plan to improve their model. Ask each team to create a poster that represents the initial idea and how they modified their plans to adapt to new conditions. Invite teams to share their posters with the class.
2. Have students answer question 5 on their *Think about It* activity sheets.
3. Distribute *Engineering Design Process* (page 16) and review how students used the steps to complete the challenge. Have them annotate the infographics with details specific to this challenge.
4. Read "Career Advice" on page 32 of the book. Ask students to brainstorm other tips for a career studying animals and biomimicry.

Assessment Activities

1. Have students complete a short posttest, *Color-Changing Cephalopods Quiz* (page 17), to assess the lesson's objectives.
   - Students may complete the Interactiv-eBook activities in the Digital Resources for assessment purposes.
2. Have students complete *Teamwork Rubric* (page 18) and *Engineering Design Process Checklist* (page 19) to reflect on and evaluate their work and collaboration skills.
3. Have students complete the Read and Respond questions from the book.
   - Possible answers to the questions can be found in the Digital Resources (color_reproducibles.pdf).

Name: _____ Date: _____

Make a Plan

Directions: Summarize the challenge. Brainstorm ideas, and sketch two designs. Circle your favorite.

Challenge: _____

_____

_____

Brainstorm

Design 1

Design 2

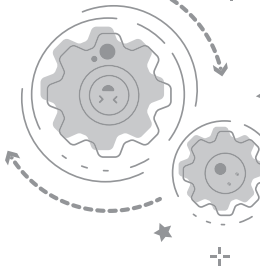
Name: _____ Date: _____

Biomimicry

Directions: Identify three cephalopod structures or functions, and describe the technologies they have inspired.

Cephalopod Structure or Function	Inspired Technology
1.	
2.	
3.	

Name: _____ Date: _____



All about Cephalopods

Directions: Choose one cephalopod-inspired technology to present at a biomimicry conference. Plan a presentation, and get feedback from a peer.

Title Page	**Introduction**
Detail	**Detail**
Detail	**Closing**

Ask a partner to review your slides. Have them check boxes to give feedback.

- ❑ engaging introduction
- ❑ vocabulary words used appropriately
- ❑ details clearly explain the topic
- ❑ correct spelling, grammar, and punctuation

Team Members:_____

Date:_____

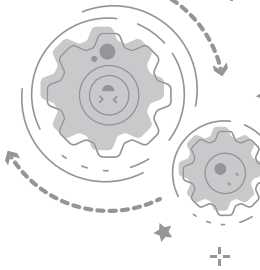
Collaborative Design

Directions: Sketch your team's design in the first box. Sketch your team's improved design in the second box. Label each design with materials needed and the purpose of each part.

Design 1

Design 2

Name: _____ Date: _____



Think about It

1. What did your team struggle with? How did you deal with it? _____

_____

_____

_____

2. How did you contribute to your team? _____

_____

_____

3. How did you use science, technology, engineering, the arts, and/or math in your designs? _____

_____

_____

_____

_____

_____

4. What was successful about your first design? How did you improve it? _____

_____

_____

_____

5. What is the most important thing you learned? What questions do you still have?

_____

_____

_____

_____

Name: _____ Date: _____

Friendly Feedback

Directions: Feedback can help people improve their work. Use these sentence stems to give feedback to your peers.

Clarify

Can you explain _____ ?

Why did you choose to _____ ?

How did you _____ ?

Warm Feedback

I like _____ because _____ .

It is interesting that _____ .

_____ is a good idea because _____ .

Cool Feedback

Have you thought about _____ ?

I wonder if _____ .

You might want to try _____ .

Name: _____ Date: _____

Camouflage Clothing Test Results

Directions: Write the type of clothing each team created. Describe the color and texture of items and tell whether they met design criteria. Then, answer the questions.

Team	Type of Clothing	Describe the color and texture	Does the clothing blend in with two different habitats?
		Color: Texture:	yes/no
		Color: Texture:	yes/no
		Color: Texture:	yes/no
		Color: Texture:	yes/no
		Color: Texture:	yes/no

Which team's clothing do you think would sell the most? Why?

_____

_____

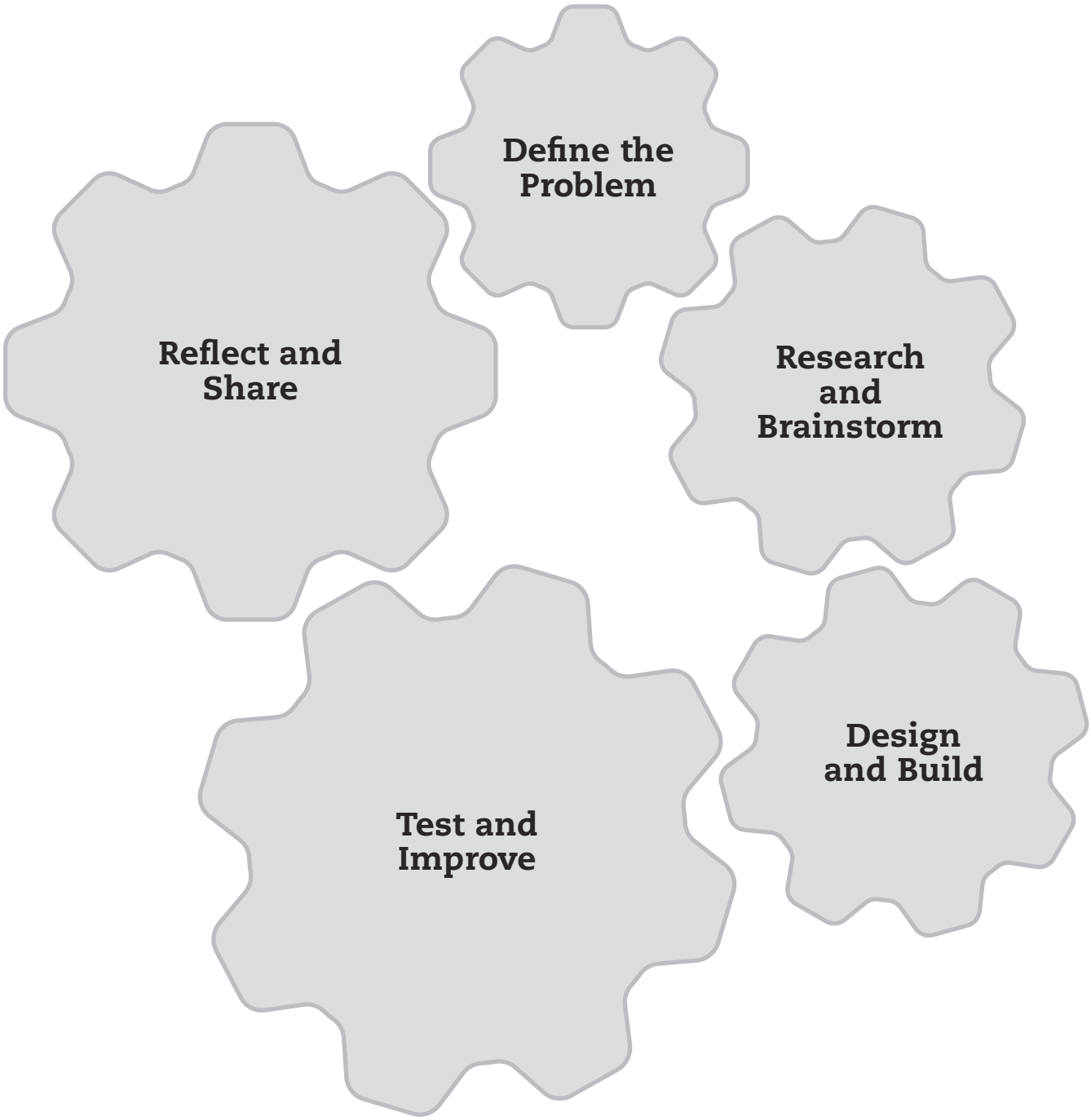
How will you use class data to improve your team's clothing?

_____

_____

Name: _____ Date: _____

Engineering Design Process



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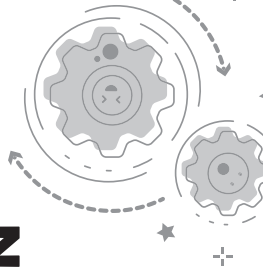

Color-Changing Cephalopods Quiz

Directions: Read each question. Choose the best answer. Fill in the bubble for the answer you have chosen. Answer the last question in complete sentences.

1. Cuttlefish are similar to octopuses in that

- (A) they both have shells.
- (B) they both belong to the mollusk group.
- (C) they both have hard bodies.
- (D) they both have human-like eyes.

2. Which cephalopod-inspired technology have experts successfully developed?

- (A) synthetic skin that changes color between black and white with heat
- (B) a boat that blends in with the ocean
- (C) clothing that blends in with different habitats
- (D) a building that uses bioluminescence to produce light at night

3. An octopus eye is different from a vertebrate's eye in that it lacks

- (A) pigment.
- (B) rods and cones.
- (C) pupils.
- (D) lenses.

4. A cephalopod can _____ itself by changing its texture.

- (A) contract
- (B) sustain
- (C) camouflage
- (D) analyze

5. How does the device on page 17 relate to the structures and functions of an octopus?

_____

_____

_____

_____

Name: _____ Date: _____

Teamwork Rubric

Directions: Think about how you worked in your team. Score each item on a scale of 4 to 1.

4 = Always 3 = Often 2 = Sometimes 1 = Never

I listened to people on my team.	4	3	2	1
I helped people on my team.	4	3	2	1
I shared ideas with people on my team.	4	3	2	1
We made choices as a team.	4	3	2	1
Total				

What is one thing your team did well? _____

_____

_____

What could your team do better next time? _____

_____

What else do you want your teacher to know about your team? _____

_____

_____

Name: _____ Date: _____

Engineering Design Process Checklist

Directions: Check the boxes to show that you completed each step.

Define the Problem

- ❑ I understood and explained the problem in my own words.

Research and Brainstorm

- ❑ I used research to help me brainstorm solutions.

Design and Build

- ❑ I planned and made a model.
- ❑ I thought like a mathematician or an engineer.

Test and Improve

- ❑ I used criteria to evaluate designs.
- ❑ I improved designs based on test results.
- ❑ I thought like a mathematician or an engineer.

Reflect and Share

- ❑ I shared my results and reflected on my work.

STEAM CHALLENGE

Define the Problem

Wildlife photographers need to hide to get good pictures of animals. A company has asked you to design clothing to help photographers blend in with two different habitats. Use what you know about camouflage to make an item of clothing the company can sell.

Constraints: Your design must use both color and texture to camouflage a person.

Criteria: A successful piece of clothing will adjust to blend in with two different habitats (rainforest, desert, etc.).

1 Research and Brainstorm

What are some of the different ways that cephalopods can camouflage themselves? What type of clothing would be most helpful to hide a person? How can you make your clothing change to camouflage a person in different habitats?

2 Design and Build

Find images in books or online of two habitats for your clothing. Sketch your design. What purpose will each part serve? Will you have any detachable parts? Build the piece of clothing.

3 Test and Improve

Have a friend wear the piece of clothing. Explain your design to them, and describe how it functions to camouflage a person in two different habitats. Did it work? Did it use both color and texture? How can you improve it? Modify your design, and try again.

4 Reflect and Share

Would your item be easy for a photographer to wear and move around in? Would it work in different weather conditions? How would you modify your design to be weather resistant?

Smithsonian

Color-Changing Cephalopods

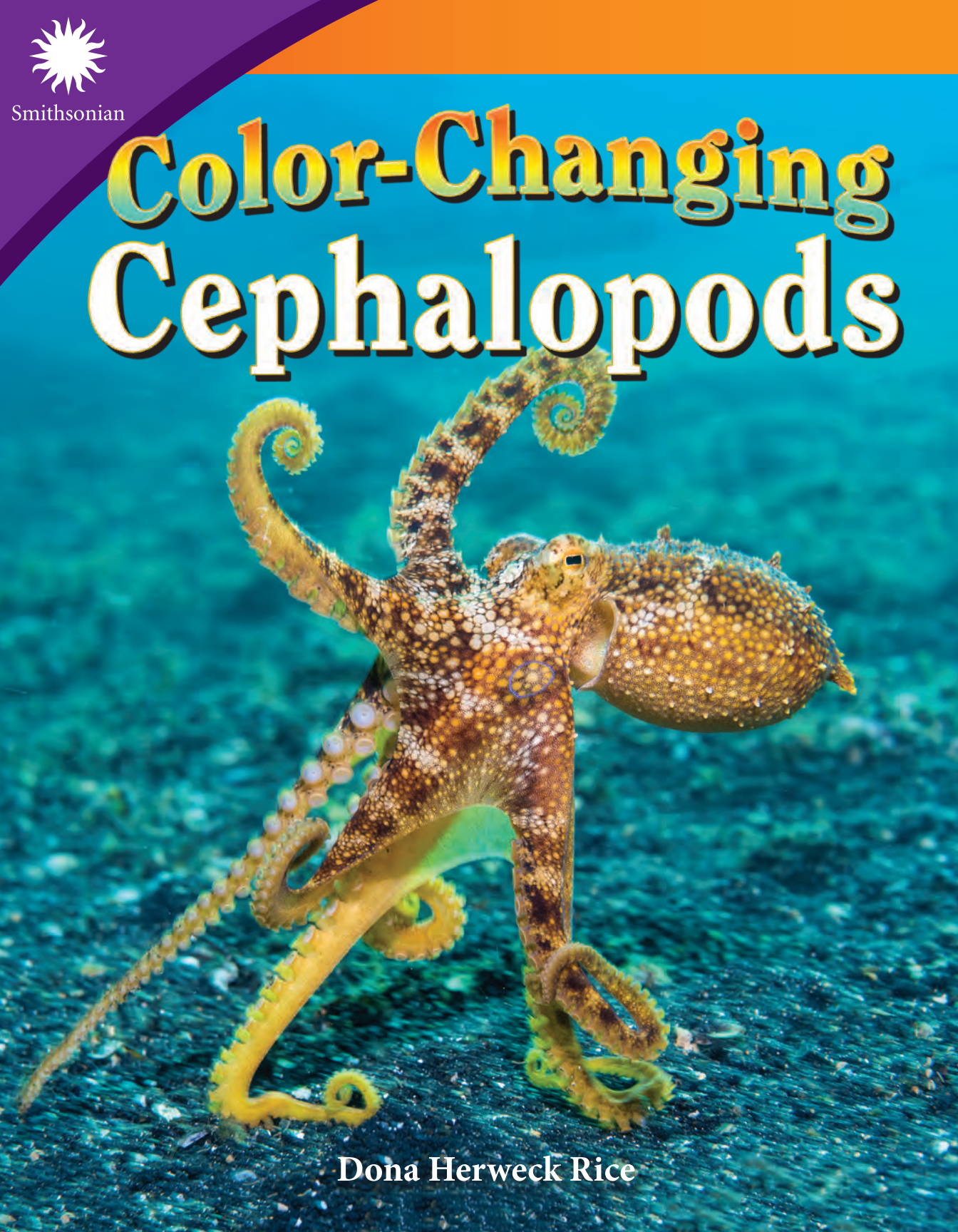

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Table of Contents

Vanished!

In the deep blue depths of the ocean, two divers explore the shimmering world around them. Through their masks, they look closely at the plants and animals below the surface. Each creature is more interesting than the next. And they have heard stories from other divers that octopuses live in the area. They hope they will be lucky enough to find one.

Just then, one diver spots a rocky outcrop below and signals the other diver to come explore it. Breathing through their scuba equipment, the two divers swim down. As they turn the corner, they see just what they hoped: an octopus! The happy divers turn to each other and grin, high-fiving each other. They quickly turn back to the octopus. But it has vanished! The divers have a wide-open view of the sea around them, and it seems impossible that the octopus just disappeared. Where could it be, and how in the world could they have missed it?

An octopus defends itself by inking as it flees from two scuba divers.

Cephalopods, such as octopuses, have long arms and complex heads. The word *cephalopod* comes from the ancient Greek words *kephale* (keh-PAH-leh), meaning "head," and *podos*, meaning "foot."

Hiding in Plain Sight

It is possible the octopus did not go anywhere at all! If the divers know where and how to look, they will see it right in front of them. The octopus, like other cephalopods, can blend with its environment. It can hide in plain sight. It does this through **crypsis**. This is a set of methods by which animals change themselves to avoid detection. They may change their texture, shape, posture, or color. Through a combination of these means, they can hide from predators or surprise their prey.

A day octopus changes its color and texture to blend into a dead coral reef.

A day octopus changes its color to match a coral reef.

SCIENCE

Can You See Me Now?

An octopus can **camouflage** itself by changing its texture. One way it does this is by raising papillae (puh-PIH-lee). Papillae are little bumps that sprout on the surface of the skin. When humans are cold or have a strong emotional reaction, they may grow papillae in the form of goose bumps.

A day octopus changes its texture to match a coral reef.

Fortunately, the divers know a thing or two about crypsis. Looking closely, they see a new blob on the rocky outcrop. It is the octopus blending into its environment. Its color and texture have changed in an instant!

Even knowing that the octopus can do this, the divers are amazed. How can it change in this dramatic way so quickly? Is it a **conscious** choice or an unconscious reaction? And since some animals can do it, what about humans? Is there any way for humans to produce this amazing ability in themselves?

Are They Magic?

Even if you do not have a chance to see cephalopods in person, a simple online search will bring up videos of them changing. The sight is remarkable every time. Viewers cannot help but wonder how they do it so quickly—or, in fact, how they do it at all. They can shift from one color or shape to another in under a second. For humans, this would be the work of a master magician. For cephalopods, it is simply in their DNA.


blue-ringed octopus

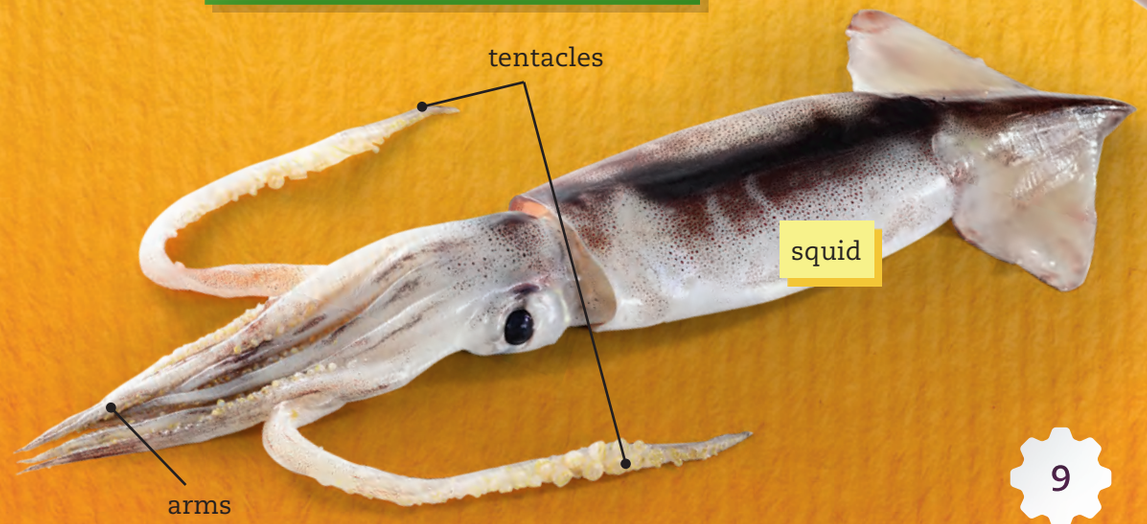
What Are Cephalopods?

The most common cephalopods are squid, octopods (including octopuses), and cuttlefish. Cephalopods belong to a group known as **mollusks**. Most mollusks, such as clams and snails, have shells. Cuttlefish have internal shells called cuttlebones. But squid and octopuses do not have shells, just soft bodies with lots of muscles. They have large brains and are known for their intelligence. Arms surround their mouths and are used to move and to grab prey. They also have large eyes and good vision, similar to a human's eyesight.


pharaoh cuttlefish


octopus with suckers on its arms

Despite what people may think, octopuses have arms, not **tentacles**! Arms have suckers all along them, but squid and cuttlefish tentacles have suckers just at the ends.



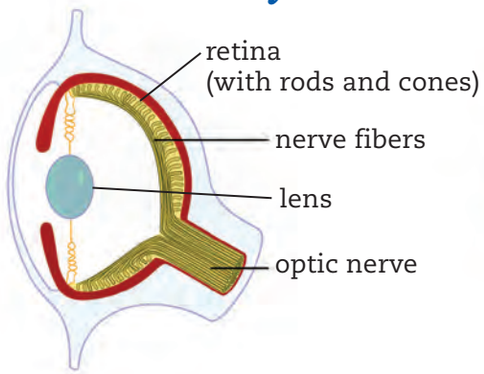
Eye See You!

The unique design and characteristics of cephalopod eyes are worth a mention. They have just one visual **pigment**. Vertebrates—which see in color—have two or more. Vertebrates also have rod and cone light receptors in their eyes. Cephalopods do not.

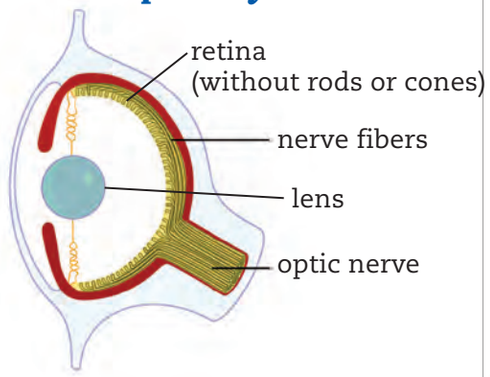
Each cephalopod's eye, like a human eye, has a single lens. Removed from the eye, humans can use this lens as a magnifying glass! This lens is fairly thick and strong and focuses light. Their pupils are U-shaped or W-shaped. These pupils may allow them to detect colors.

Cephalopods' pupils let in light from all directions. Some cephalopods' pupils are not round. When light hits these pupils, light diffracts, or bends. Different **wavelengths** of light bend different amounts. Cephalopods' retinas see this bent light as different parts of the color **spectrum**. This allows cephalopods to have a type of color vision.

Vertebrate Eye



Octopus Eye



TECHNOLOGY

Squids' Sight

Some squid have **reflective** eyes. There is a thin, mirror-like coating around their lenses. Predators have trouble seeing squids when they reflect light this way. It creates a type of camouflage. It is helpful to the squid—and it also appeals to the U.S. military! They are working to develop reflective technology based on cephalopod eyes. The hope is that it will allow soldiers to move without being seen.

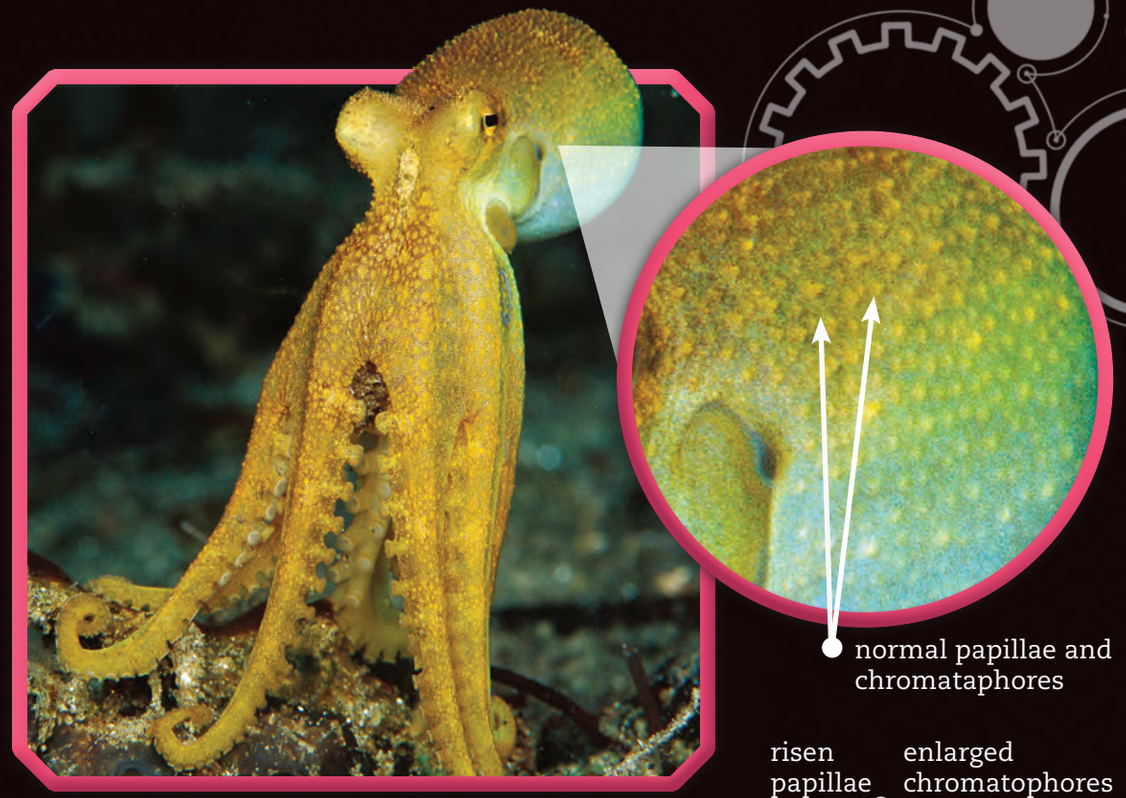
Cephalopods' eyes pick up visual cues from the area around them. They use these cues to adapt their colors, patterns, or even shapes and postures.

Scientists think cephalopods change for four main reasons. First, they change to resemble their backgrounds. Second, they try to blend with other living things. Third, they mask their true shape with a **countershading** pattern on their bodies. Lastly, they change their patterns to confuse predators. How can they do all these things? Cephalopods have **chromatophores**.

Chromatophores are tiny sacs filled with pigment. These pigments are yellow, red, black, or brown. Below the chromatophores are reflectors. These reflectors change reflected light into blues and greens.

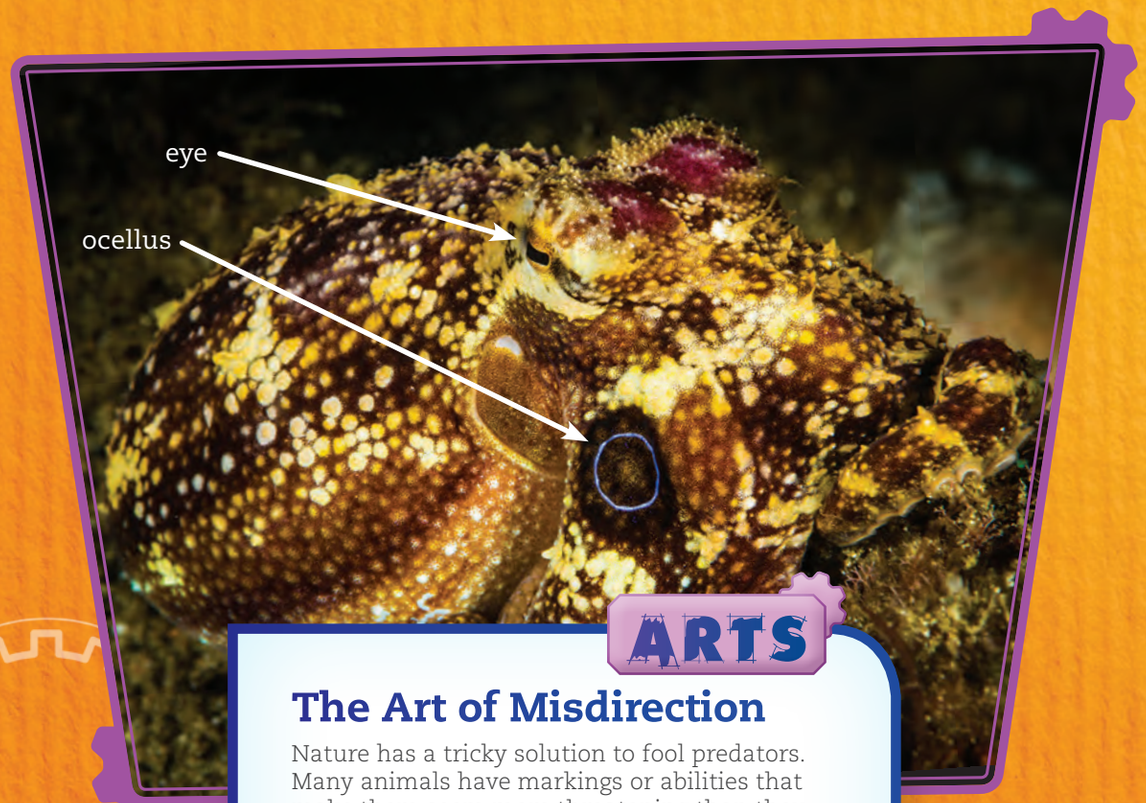
Cephalopods' skin have layers of **cells** that can stack upon each other. Chromatophores are cells that are just below the skin's surface. When they enlarge, shrink, or restack, the animals' appearances change.

What happens if an octopus is somehow placed inside a jar with the lid screwed on? It can get itself out by twisting off the cap from the inside!



Each chromatophore is connected to nerves. It is also surrounded by muscle. The nerves signal the muscles to **contract**. This forces the cells to expand. When they change shape or size, the creature changes its pattern, color, or both. Chromatophores can shrink, or they can grow 15 times their size. And they do it in under a second!

When chromatophores change, it is not automatic. The animal at some level has **analyzed** its environment. But the change happens so quickly that it can seem automatic. It is a sophisticated response to a wide range of input. The animal also has a goal. It may feel threatened and need to protect itself with camouflage. It may also be used to attract a mate or warn an enemy. Or it may be used to communicate something to its group.



ARTS

The Art of Misdirection

Nature has a tricky solution to fool predators. Many animals have markings or abilities that make them seem more threatening than they are. For example, **ocelli** (oh-SEH-lye) look like eyes but are not. Some cephalopods have them. An ocellus can trick a predator into attacking a less-important part of a cephalopod's body.

Where Did It Go?

There is no data to explain why a cephalopod cannot be seen well while in crypsis. Really, its color or brightness does not exactly match the area around it. It only seems to match. This suggests that its goal may not be to blend with the background so much as to fool whatever is looking at it.

A Caribbean reef octopus in crypsis changes to camouflage itself.

Biomimicry

Nature has answers that humans have not yet thought of. Nature adapts and thrives. It always has. By studying nature, people may solve age-old problems. Biomimicry is the science of studying nature to learn from and copy its solutions. It is "the process of looking at a leaf and trying to figure out how to make a better solar cell." So says Janine Benyus, founder of the Biomimicry Institute.

A scientist studies a giant Pacific octopus.

There are over 800 known species of cephalopods. Scientists believe there are more to find.

A biomimist displays his Octopus Gripper, designed to help robots grip objects.

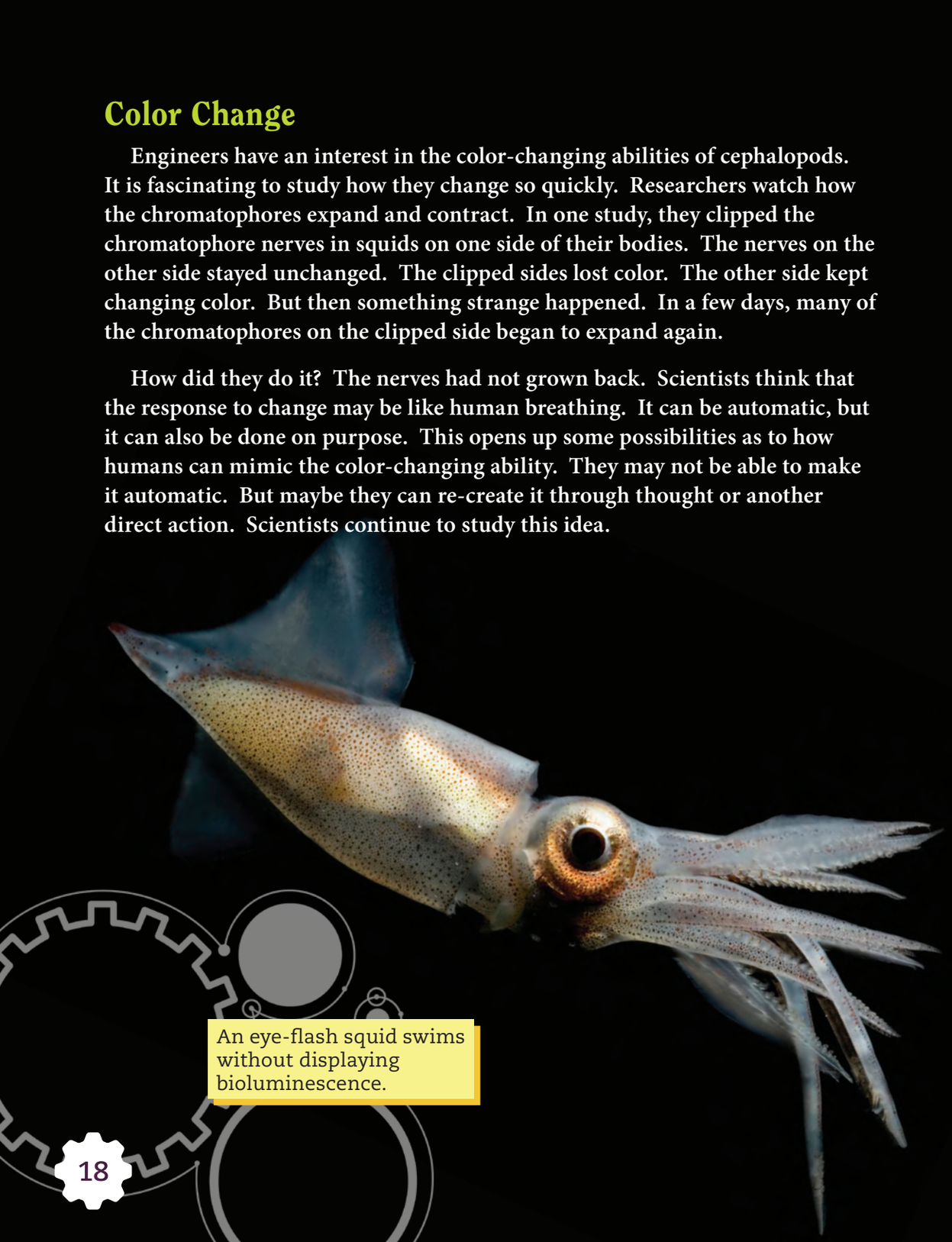
The idea is that nature has found ways to exist that not only work well but also are **sustainable**. By studying nature, humans can follow in kind. If it works for a plant or an animal, there is a good chance it will work for people, too!

Biomimists have turned their attention to cephalopods. They can do a lot of things that interest people. Above all, their ability to change is appealing. Are there ways to mimic what they do in the human world? Experts say yes! They have found many ways to copy nature's genius. And they think there is much more to learn.

Color Change

Engineers have an interest in the color-changing abilities of cephalopods. It is fascinating to study how they change so quickly. Researchers watch how the chromatophores expand and contract. In one study, they clipped the chromatophore nerves in squids on one side of their bodies. The nerves on the other side stayed unchanged. The clipped sides lost color. The other side kept changing color. But then something strange happened. In a few days, many of the chromatophores on the clipped side began to expand again.

How did they do it? The nerves had not grown back. Scientists think that the response to change may be like human breathing. It can be automatic, but it can also be done on purpose. This opens up some possibilities as to how humans can mimic the color-changing ability. They may not be able to make it automatic. But maybe they can re-create it through thought or another direct action. Scientists continue to study this idea.



An eye-flash squid swims without displaying bioluminescence.

A firefly squid swims while displaying bioluminescence.

ENGINEERING

Bioluminescence

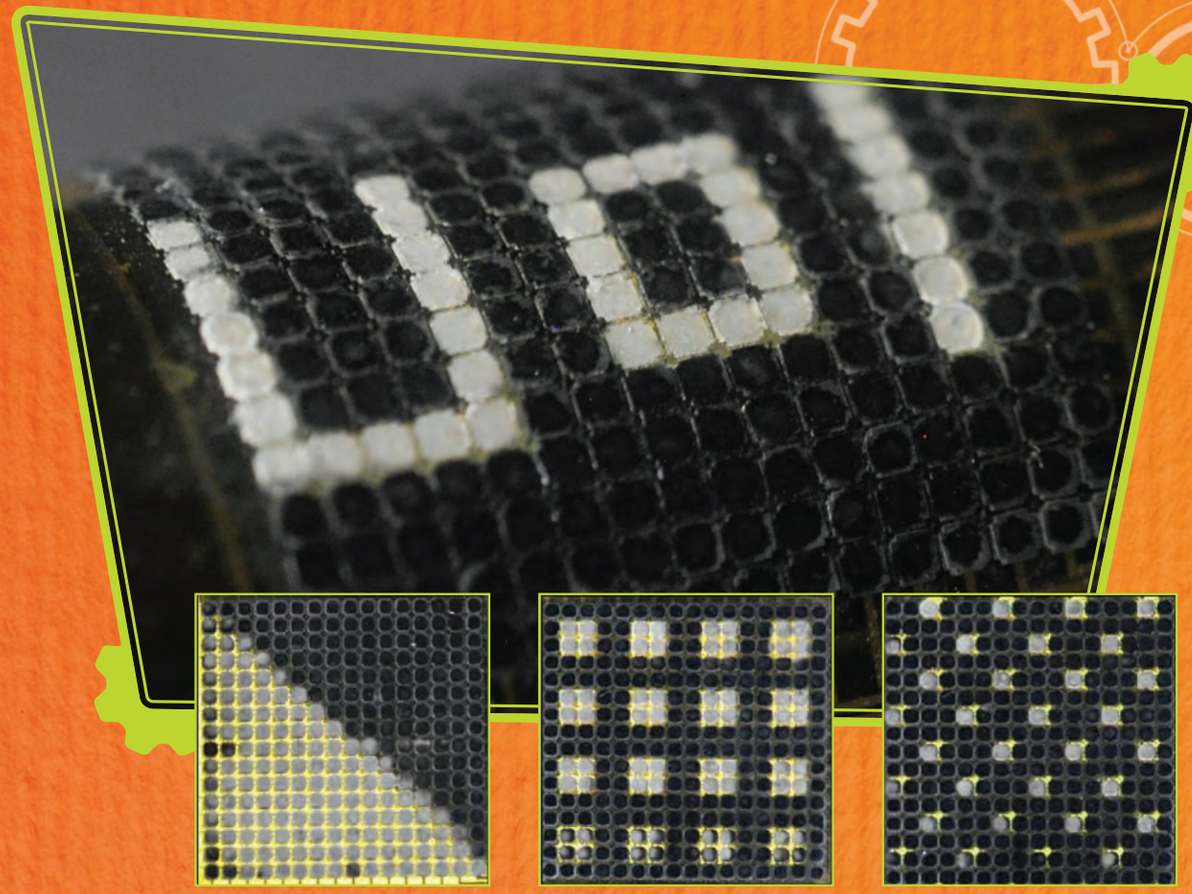
Some squid can produce light. This is called bioluminescence. Engineers are studying it to help develop new technologies. They are working on a way to add it to trees! This way, trees could give light at night throughout cities instead of using costly and limited power sources. They are also trying to use it as a way to study the human body. With it, body processes may be closely observed to gain insight into how to cure diseases.

Cephalopod Skin

John Rogers was working as a researcher at the University of Illinois when he had an idea. He worked with a team to re-create cephalopod skin. After a lot of hard work, the team successfully made a small piece of **synthetic** skin.

Rogers said the team's purpose was to "build devices that can respond and adapt to the lighting and coloration of whatever environment they are in." They see a future in which clothing, buildings, ships, and more can transform and blend.

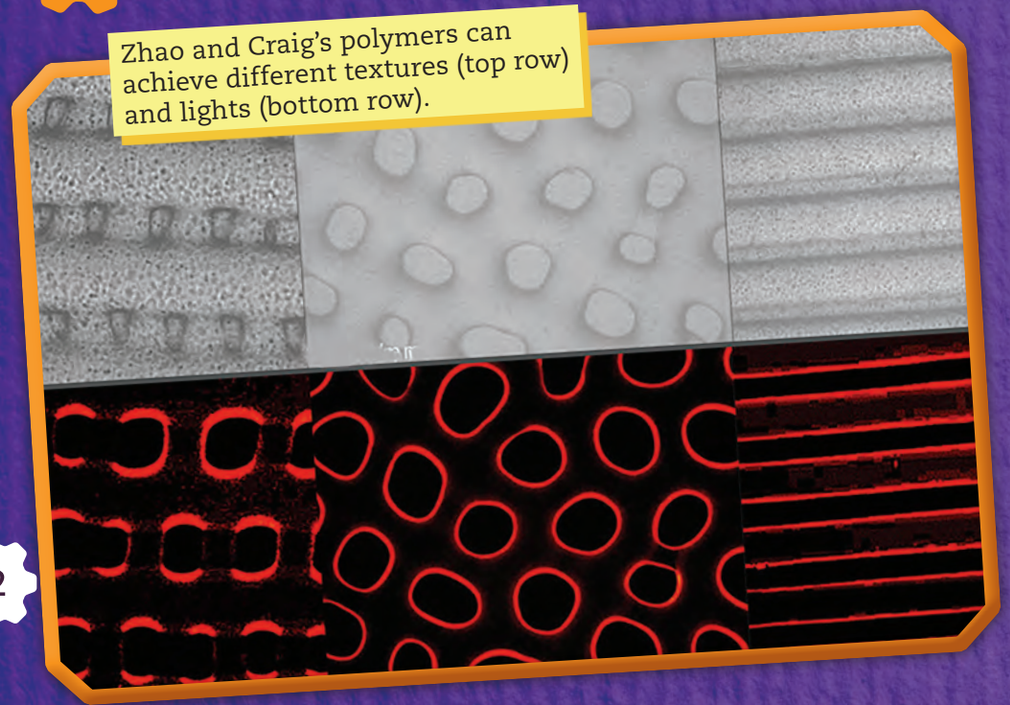
A cephalopod's skin is filled with millions of chromatophores. The UoI success is just a small fraction of what the true skin can do.



Roger Hanlon is a well-known scientist who has studied these animals for years. He has worked closely with Rogers to take what he knows and translate it into human experience.

The small patch of skin they made has 256 black squares. Each square is the size of a tiny poppy seed. There is dye in each one. With heat, the square changes between black and white. A reflective layer is below the dye layer. Below this is the heating grid. The team used heat controlled by a computer to trigger the patch of skin to shift its pattern. So far, they have succeeded in making it spell out "UoI." (This stands for University of Illinois.)

A giant Pacific octopus changes its texture to match surrounding plants.



Zhao and Craig's polymers can achieve different textures (top row) and lights (bottom row).

Texture Change

Engineers are also actively studying how cephalopods change their skin textures. They look to a future in which materials can change textures too. There are many uses for this. Perhaps boat surfaces can change to shun **barnacles**. Maybe display screens can bend and fold. The military has many ideas as to how changing textures can help their missions. The ideas are endless.

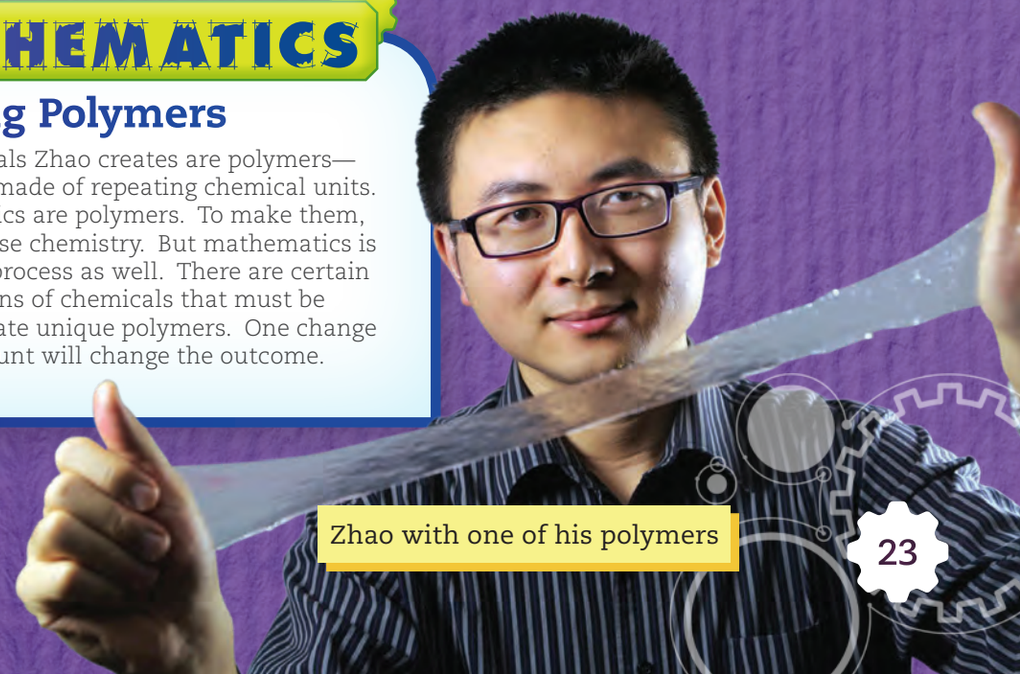
Two professors are in charge of a team that has been successful in making a texture-changing material. Xuanhe Zhao (SHWAN-huh JOW) is at MIT, and Stephen Craig is at Duke University. Their product can alter and stretch when signaled. The signal comes as a change in **voltage**. The material responds in a snap. It shifts from one texture to another. It also changes color.

One drawback is that the new material is limited in how it can change. It is far more limited than cephalopod skin is. It also needs a direct signal from a person. But this team and others continue their work. They are sure they can expand on what can be done. The kind of physical changes people make in sci-fi movies may be science *non*fiction one day! And that day may not be far away.

MATHEMATICS

Making Polymers

The materials Zhao creates are polymers—molecules made of repeating chemical units. Many plastics are polymers. To make them, scientists use chemistry. But mathematics is key to the process as well. There are certain combinations of chemicals that must be used to create unique polymers. One change in the amount will change the outcome.



Zhao with one of his polymers

More to Know

Scientists continue to study cephalopods to see what they can learn. Their abilities to change, some say, surpass any other creature. And the list of what they can do goes on and on. For example, suckers on their limbs let them grab very small objects. The fluid motion of their bodies lets them move across surfaces and through water with little disturbance. The ability to reshape their bodies, into and through tiny spaces, seems impossible. The multiple ways in which they can ward off predators offer them a wide range of protection. The stretch of their skin goes far beyond what it "should," due to the structure of the skin itself. They can communicate through reflected light, colors, and textures. These are just some of the things they are known to do!

Scientists are ready to learn from them. In time, they may find ways to copy and use all of their abilities. Now, they have just scratched the surface. There is so much more to learn.

Cephalopods are found in fossil records from about 500 million years ago.

What Nature Teaches Us

Cephalopods have evolved with a strong set of skills. These skills allow them to survive well in the world. And, of course, every species that thrives today has its own skill set. These facts lead to a simple question. What skills do humans have that help us prosper and thrive in the world? A second question may be this: Do humans use these skills in the same sustainable way that cephalopods and other creatures do?

These can be interesting questions to think about. Perhaps there is no single correct answer to them. It may be worthwhile, though, for us to study nature's biggest lessons when exploring its wonders. These are the lessons that have helped the rest of nature survive and thrive for eons. Using what nature teaches us, will we be able to do the same? Perhaps there is much more to learn from cephalopods than what passes before our eyes.

STEAM CHALLENGE

Define the Problem

Wildlife photographers need to hide to get good pictures of animals. A company has asked you to design clothing to help photographers blend in with two different habitats. Use what you know about camouflage to make an item of clothing the company can sell.

Constraints: Your design must use both color and texture to camouflage a person.

Criteria: A successful piece of clothing will adjust to blend in with two different habitats (rainforest, desert, etc.).

1 Research and Brainstorm

What are some of the different ways that cephalopods can camouflage themselves? What type of clothing would be most helpful to hide a person? How can you make your clothing change to camouflage a person in different habitats?

2 Design and Build

Find images in books or online of two habitats for your clothing. Sketch your design. What purpose will each part serve? Will you have any detachable parts? Build the piece of clothing.

3 Test and Improve

Have a friend wear the piece of clothing. Explain your design to them and describe how it functions to camouflage a person in two different habitats. Did it work? Did it use both color and texture? How can you improve it? Modify your design and try again.

4 Reflect and Share

Would your item be easy for a photographer to wear and move around in? Would it work in different weather conditions? How would you modify your design to be weather resistant?

Glossary

analyzed—studied closely and made a determination

barnacles—small crustaceans that attach themselves in clusters to rocks, piers, and boats

camouflage—make something appear to blend with its environment

cells—the very small parts that together form all living things

chromatophores—color-changing cells below the surface of cephalopod skin that allow them to transform

conscious—refers to an awareness

contract—reduce in size

countershading—a pattern of dark and light color that is used to trick predators

crypsis—the way in which an animal remains undetected by other organisms

mollusks—large group of animals with no backbone and soft bodies

ocelli—spots on animals' bodies that look like eyes but are not

pigment—a color compound that can change the color of other things

reflective—causing light to bounce off

spectrum—the group of colors that light can be separated into, including red, orange, yellow, green, blue, indigo, and violet

sustainable—able to be used without being used up or doing harm to a system

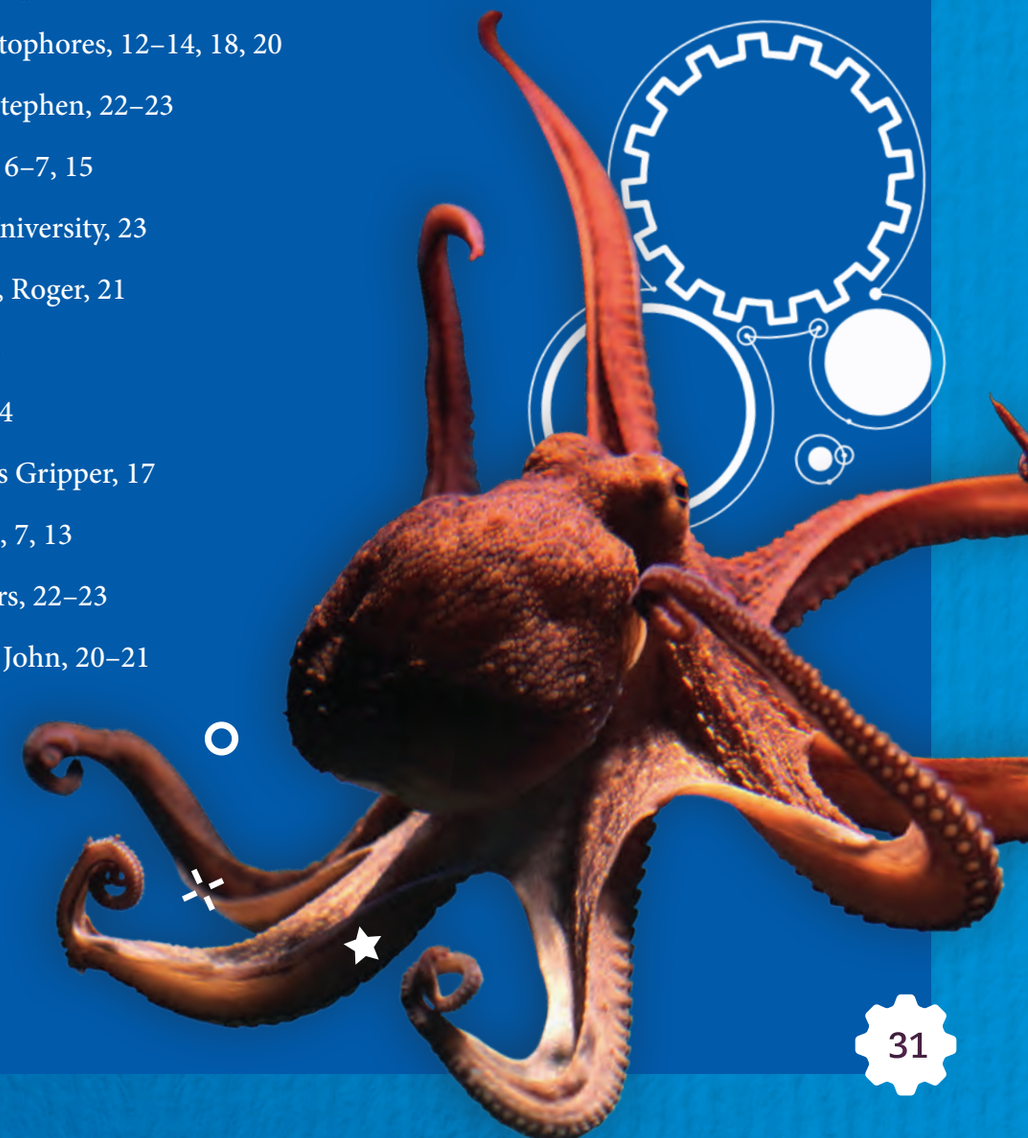
synthetic—artificial

tentacles—long, flexible parts on certain animals that are used for grabbing things and moving

voltage—the force of a current of electricity

wavelengths—the distances between light waves, which represent different colors

Index



CAREER ADVICE
from Smithsonian

Do you want to study cephalopods?
Here are some tips to get you started.

"I earned college degrees in math and economics. My last year of college, I took a class that captured my imagination about the history of life on Earth. Open yourself up to new experiences and learn as much as you can about cephalopods. That will give you a head start in your career." —***Dr. Allen Collins, Invertebrate Zoologist***

"Pay attention to nature and study hard in all your courses. For example, I use English all the time in writing and speaking about science. Remember science is not just about what is already in books. It is about discovering new things about nature, and if you become a scientist there will be lots of stuff left to discover." —***Michael Vecchione, Research Zoologist***

Read and Respond

1. How do cephalopods change color?
2. How might cephalopods benefit from their color-changing abilities?
3. How are octopus eyes different from human eyes?
4. In what ways can biomimicry provide sustainable solutions for people's problems?
5. How would communication be different if humans communicated through lights like squids do? What would be its benefits and drawbacks?
6. Brainstorm a product that biomimicry engineers can create based off cephalopods. Draw a diagram of what it is, label its parts, and explain how it might be used.