DISCOVERY ENGINEERING IN PHYSICAL SCIENCE

Case Studies for Grades 6–12

M. GAIL JONES • ELYSA CORIN • MEGAN ENNES
EMILY CAYTON • GINA CHILDERS

NSTApress
National Science Teachers Association

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This book is dedicated to all the youth who remind us that the smallest things can be the most important.

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About the Authors

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A STICKY SITUATION

Gecko Feet Adhesives

A Case Study Using the Discovery Engineering Process

Introduction

Geckos are a type of lizard found all around the world. (See Figure 5.1.) Scientists have been studying the feet of geckos since it was discovered that the reptiles could hang by one toe from a piece of glass. The secret to how they were able to do so was a mystery until recently. Scientists have discovered how to make an adhesive that mimics the properties of a gecko foot. This has allowed them to develop products that can be used in a variety of situations where traditional adhesives may not work or would damage objects.

FIGURE 5.1

Gecko

Lesson Objectives

By the end of this case study, you will be able to

- Describe how van der Waals forces work.
- Analyze the tack (stickiness) of different adhesives.
- Design a new use for gecko-inspired adhesives.

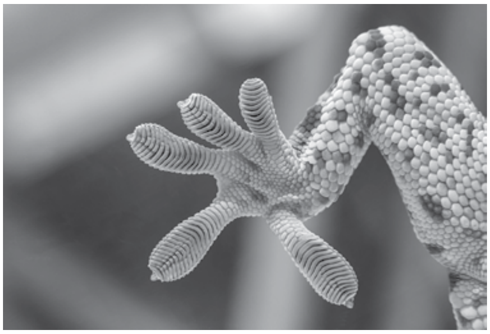
The Case

Read the following summary of an adhesive developed using the same principles as those used by gecko feet.

Since the time of the Romans, scientists have been studying the feet of geckos. In the early 2000s, researchers learned that gecko feet have microscopic hairs called setae (see Figure 5.2). These hairs attach to objects through the use of van der Waals forces. Van der Waals forces are relatively weak electric forces that involve the attraction of neutral atoms or molecules. These forces are distance-dependent and weaker than covalent, ionic bonds, and metallic bonds. Covalent bonds are formed when electrons are shared between atoms. Ionic bonds are formed when one atom gives up one or more electrons to another atom. Metallic bonds hold metals together and are formed by the attraction of fixed, positively charged metallic atoms and mobile electrons that move around the entire structure.

FIGURE 5.2

Up-Close Photo of a Gecko Foot



Even though scientists had discovered that geckos use van der Waals forces to climb and hang from surfaces, they struggled with how to use that information to make new forms of adhesives. Researchers at the University of Massachusetts Amherst were studying the problem from two angles. A biologist named Duncan Irschick was investigating how geckos can cling to various objects. At the same time, a polymer scientist named Alfred Crosby was trying to make adhesives using the principle of van der Waals forces. The two began working together to develop a solution.

Dr. Irschick discovered that the setae on gecko feet had stiff tendons connected to them under the skin. Dr. Crosby was able to use this information to develop a new adhesive made up of stiff fibers attached to a flexible polymer. The fibers drape over surfaces, which allows them to bond through van der Waals forces. A slight pull in a different direction releases the adhesive. Their new product, named Geckskin, allows objects that weigh as much as 700 pounds to be attached vertically to smooth surfaces like glass with as little as a note card–size piece of adhesive.

Recognize, Recall, and Reflect

1. What structural feature of a gecko's feet allows the reptile to stick to walls?
2. How are van der Waals forces different from other forces?

3. How did the two researchers from the University of Massachusetts Amherst work together to create a gecko-inspired adhesive?

Investigate

While gecko-inspired adhesives are not currently available to the public, many other adhesives are on the market for consumers. In this activity, you will test the tack, or stickiness, of these different products to explore their adhesive properties. Record your observations on the Adhesive Testing Chart (p. 77).

Materials

For each group of students:

- 1 ruler
- 2 chairs
- 1 quart-size plastic bag
- Pennies or small weights
- 2 adhesive bandages
- Masking tape
- Cellophane tape
- Duct tape
- First-aid tape
- Electrical tape
- Packing tape
- Scissors

Safety Note: Do not allow your feet or other parts of the body to remain under the plastic bag while testing the tack of the different adhesives.

Create, Innovate, and Investigate

- Begin by examining each of the adhesives. Look at their shapes, colors, and textures. What properties do you notice?
- Next, cut a small piece from each of the different types of tape.
- Touch each of the adhesives. What do you observe about the tack, or stickiness, of each one? Predict which materials are stickiest based on your initial observations, rating them on a scale of 1 to 7 on your chart (with 1

being the stickiest and 7 being the least sticky). Once you have made your predictions, you will test each material.

- Set two chairs back-to-back, about 6 inches apart.
- Balance a ruler on the backs of the two chairs so it forms a bridge.
- Cut a 4-inch strip of each adhesive.
- You will test each adhesive, one at a time. Attach the first adhesive to the top edge of a plastic bag, using one inch at the strip's end. (*Note:* Use a new strip of tape, *not* the one you examined earlier.)
- Then attach the bag to the ruler using one inch of the other end of the adhesive. The bag should remain open.
- Gently place the pennies or weights in the bag, one at a time, until the bag falls from the adhesive. Write the number of pennies or weights it took to pull the bag from the adhesive on your chart.
- Repeat the activity with each of the other adhesives.
- Once you have collected your data, compare your results to your initial prediction as to which adhesive was strongest.

Adhesive Testing Chart

Name: ____________________

Material	Initial Observations	Stickiness Ranking	Stickiness Prediction	Number of Pennies
Adhesive bandage				
Masking tape				
Cellophane tape				
Duct tape				
First-aid tape				
Electrical tape				
Packing tape				

Questions for Reflection

1. What did you observe about the different types of adhesives?
2. Which adhesive was strongest? Were you surprised? Why or why not?
3. Which adhesive was weakest? Were you surprised? Why or why not?
4. How would you decide which type of adhesive to use in the future?
5. Why is it important to know what type of adhesive to use?

Apply and Analyze

The concept of gecko-inspired materials is quickly being adopted for new areas of research and commercial applications. Watch this video on how the gecko-inspired adhesive created by Irschick and Crosby works: *www.youtube.com/watch?v=9ZJYbcG0Ts0*. Next, visit the links below to explore a set of articles and videos created by *Science* magazine, which show how researchers are developing new products that mimic gecko feet. After you're done reading the articles and watching the videos on these web pages, answer the questions that follow.

- Watch astronauts play catch with a gecko-inspired gripper: *www.sciencemag.org/news/2017/06/watch-astronauts-play-catch-gecko-inspired-gripper.*
- See how gecko-inspired adhesives allow people to climb walls: *www.sciencemag.org/news/2014/11/gecko-inspired-adhesives-allow-people-climb-walls.*

1. How many times can someone use Geckskin before it loses its adhesive properties?
2. Why are you unable to use traditional adhesives in space?
3. The inventors using gecko-inspired adhesives believe the technology can be used to create robots that assist astronauts in space or hold heavy objects on vertical surfaces. What are some other new applications that you can imagine for gecko-inspired adhesives in your classroom?

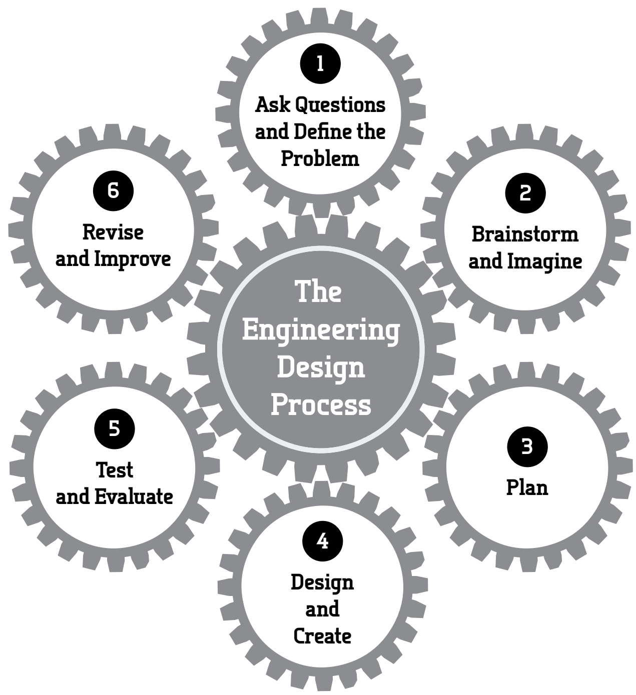
Design Challenge

Engineering is the application of scientific understanding through creativity, imagination, problem solving, and the designing and building of new materials to address and solve problems in the real world. You will be asked to take the science you have learned in this case and design a process or product to address a real-world issue of your choosing.

Engineers use the engineering design process as steps to address a real-world problem (see Figure 5.3). You will now use this process as you come up with a new way to use a gecko-inspired adhesive. In this case, you are asking the question (Step 1) of how you can design a new use for a gecko-inspired adhesive. Drawing on your creativity, you will then brainstorm (Step 2) a new product that uses a gecko-inspired adhesive to solve a problem. Afterward, you will create a plan (Step 3) for this new product. Next, you will create a sketch and/or model of your product (Step 4). Then, you will work with your classmates to think about how you would test (Step 5) and refine (Step 6) your product.

FIGURE 5.3

The Engineering Design Process



1. Ask Questions

Based upon your previous research, consider a new problem that may be addressed or product that could be created by using materials inspired by gecko feet. Think about applications where you need a material that can stick, be easily removed, and not damage the material to which it is sticking. What problem could be solved with a material like this?

2. Brainstorm and Imagine

Brainstorm a specific application for a gecko-inspired adhesive that could help solve a problem. (For example, perhaps such an adhesive could be used to hang wall art so that the art doesn't damage the wall.)

3. Create a Plan

Create a plan for your product. Consider: (1) What is the purpose of the product? (2) What are benefits to using this product? (3) What are the limitations of using this product? (For example, if you were to create a gecko-inspired adhesive that could be used to hang wall art, you'd have to come up with the pros and cons of the product.) Use the Product Planning Graphic Organizer to help you.

4. Design and Create

Consider the following questions and considerations for your product and its design.

- How would incorporating a gecko-inspired adhesive into your design make the product better?
- Are there any limitations or drawbacks to using a gecko-inspired adhesive? If so, how would you overcome them?
- What technologies might need to be developed to create or manufacture this design?
- What are any constraints or drawbacks you can foresee with implementing this design?
- Would there be any safety concerns regarding your product?

Now, create a sketch of your product design. Make sure your design incorporates your previous research and exploration.

5. Test and Evaluate

Working with your classmates, come up with a way to test your design to see its effectiveness.

6. Revise and Improve

Give your plans to one of your classmates for review. Listen to his or her feedback on your design. What are some ways you can use the input to refine your design? Take some time to revise and make improvements.

Reflect

1. What technologies might need to be developed to create or manufacture this design?
2. What are any constraints or drawbacks you can foresee with implementing this design?
3. Would there be any environmental or human health concerns about this design?

Product Planning Graphic Organizer

Proposed Product Idea	
Pros (Benefits)	**Cons (Limitations)**

TEACHER NOTES

A STICKY SITUATION

GECKO FEET ADHESIVES

A Case Study Using the Discovery Engineering Process

Lesson Overview

In this lesson, students explore gecko foot–inspired adhesives. Geckos are able to hang by one toe from a smooth surface and researchers have finally unlocked the reason why. They are using this information to develop new adhesive products.

Lesson Objectives

By the end of this case study, students will be able to

- Describe how van der Waals forces work.
- Analyze the tack (stickiness) of different adhesives.
- Design a new use for gecko-inspired adhesives.

The Case Study Approach

This lesson uses a case study approach. Explaining the purpose of case studies will encourage your students to relate to the material and engage with the problem. At the heart of each case study in this book is a true story, one that describes how someone in his or her everyday life or during a routine workday made an observation or did a simple experiment that led to a new insight or discovery. Case studies are designed to get students actively engaged in the process of problem solving. The narrative of the case supplies authentic details that place the student in the role of the inventor and provide scaffolds for critical thinking and deep reflection. A case is more than a paragraph to read or a story to analyze but rather a way of framing problems, synthesizing what is known, and thinking creatively about new applications and solutions. In this lesson, students consider how adhesives inspired by gecko feet were discovered and work together to think about new applications for such adhesives to solve real-life problems.

Use of the Case

Due to the nature of these case studies, teachers may elect to use any section of each case for their instructional needs. The sections are sequenced in order (scaffolded) so students think more deeply about the science involved in the case and develop an understanding of engineering in the context of science.

Curriculum Connections

Lesson Integration

You could use this case as a way to integrate engineering into a lesson on atomic structure or bonds. It may be useful to review the properties of atomic forces.

Related Next Generation Science Standards

PERFORMANCE EXPECTATIONS

- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

SCIENCE AND ENGINEERING PRACTICES

- Analyzing and Interpreting Data
- Engaging in Argument From Evidence
- Constructing Explanations and Designing Solutions

CROSSCUTTING CONCEPT

- Structure and Function

Related National Academy of Engineering Grand Challenge

- Engineer the Tools of Scientific Discovery

Lesson Preparation

You will need to make copies of the entire student section for the class. Students will need internet access at various points in the lesson. Alternatively, you can project videos or print and distribute copies of online content for the class. Look at the Teaching Organizer (Table 5.1) for suggestions on how to organize the lesson.

Materials

For each group of students:

- 1 ruler
- 2 chairs
- 1 quart-size plastic bag
- Pennies or small weights
- 2 adhesive bandages
- Masking tape
- Cellophane tape
- Duct tape
- First-aid tape
- Electrical tape
- Packing tape
- Scissors

Safety Note for Students: Do not allow your feet or other parts of the body to remain under the plastic bag while testing the tack of the different adhesives.

Time Needed

55 minutes

TABLE 5.1

Teaching Organizer

Section	Time Suggested	Materials Needed	Additional Considerations
The Case	5 minutes	Student packet	Could be read in class or as a homework assignment prior to class
Investigate	10 minutes	Student packet, 1 ruler, 2 chairs, 1 quart-size plastic bag, pennies or small weights, 2 adhesive bandages, masking tape, cellophane tape, duct tape, first-aid tape, electrical tape, packing tape, scissors	Small-group activity. During the investigation, students may choose to add additional types of adhesives. They may also want to investigate what effect heat, cold temperatures, or water have on the adhesives.
Apply and Analyze	10 minutes	Student packet, internet access	Small-group or individual activity
Design Challenge	30 minutes	Student packet	Small-group activity

Teacher Background Information

It may be helpful to review the properties of atomic forces. Students often also have questions about bonding. These resources from the National Science Teachers Association may be of use:

- Book chapter on chemical bonds
  http://common.nsta.org/resource/?id=10.2505/9780873552738.9
- SciGuide on atomic structure and chemical bonding
  http://common.nsta.org/resource/?id=10.2505/5/SG-07
- E-book on quantitative evaluation
  http://common.nsta.org/resource/?id=10.2505/PKEB237X

Vocabulary

- adhesive
- covalent
- ionic
- setae
- tack
- van der Waals forces

Teacher Answer Key

Recognize, Recall, and Reflect

1. **What structural feature of a gecko's feet helps the reptile to stick to walls?**

   Gecko feet have tiny hairs called setae attached to tendons under the skin that help them to stick to walls.

2. **How are van der Waals forces different from other forces?**

   Van der Waals forces—electric forces that involve the attraction of neutral atoms or molecules—are relatively weaker than other forces.

3. **How did the two researchers from the University of Massachusetts Amherst work together to create a gecko-inspired adhesive?**

   Dr. Irschick discovered that the setae on gecko feet had stiff tendons connected to them under the skin. Dr. Crosby was able to use this information to develop a new adhesive made up of stiff fibers attached to a flexible polymer.

Questions for Reflection

1. **What did you observe about the different types of adhesives?**

   Answers will vary.

2. **Which adhesive was strongest? Were you surprised? Why or why not?**

   Answers will vary.

3. **Which adhesive was weakest? Were you surprised? Why or why not?**

   Answers will vary.

4. **How would you decide which type of adhesive to use in the future?**

   Answers will vary.

5. **Why is it important to know what type of adhesive to use?**

   Answers will vary but may include that you sometimes need stronger adhesives and sometimes weaker ones depending on what objects you're trying to stick together.

Apply and Analyze

1. **How many times can someone use Geckskin before it loses its adhesive properties?**

   You can use it over and over again.

2. **Why are you unable to use traditional adhesives in space?**

   Suction won't work, because most of the universe is a vacuum, and you can't use suction in a vacuum. Other traditional adhesives that use sticky chemicals are degraded by the extreme temperatures of Earth's orbit.

3. **The inventors using gecko-inspired adhesives believe the technology can be used to create robots that assist astronauts in space or hold heavy objects on vertical surfaces. What are some other new applications that you can imagine for gecko-inspired adhesives in your classroom?**

   Examples for uses may include holding a television on the wall that can be moved as the classroom is rearranged or installing movable dry erase boards.

Reflect

1. **What technologies might need to be developed to create or manufacture this design?**

   Answers will vary depending on the students' designs.

2. **What are any constraints or drawbacks you can foresee with implementing this design?**

   Answers will vary depending on the students' designs.

3. **Would there be any environmental or human health concerns about this design?**

   Answers will vary depending on the students' designs.

Assessment

The Design Challenge can be assessed using the rubric in the appendix (p. 377).

Extensions

This lesson can be combined with the case in Chapter 10, "A Sticky Discovery: The Invention of Post-It Notes" (p. 153).

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Note: Page references in **boldface** indicate information contained in figures or tables.

"A number of amazing innovations have resulted from someone making an observation of a phenomenon or trying an experiment just to 'see what will happen.'"

—From the introduction to *Discovery Engineering in Physical Science*

DISCOVERY ENGINEERING IN PHYSICAL SCIENCE

Case Studies for Grades 6–12

Show your students how amazing it can be to just "see what will happen" when they blend science, engineering, and serendipity. Focusing on innovations sparked by accidental observations, the case studies in this resource are a lively way to integrate engineering and experimentation into your physical science classes. Middle and high school students will learn fundamental science processes while using their natural curiosity to explore ideas for new engineering applications and products. They'll also find out that gecko feet inspired scientists to develop a stickier adhesive, cocklebur in dog fur led to Velcro, and the invention of safety glass was a total accident.

The book's 22 easy-to-use investigations help you do the following:

- **Use real-world case studies to bring accidental inspiration to life.** Each investigation starts with an actual scientific discovery that students explore through primary documents or historical accounts.
- **Let students be the innovators.** The investigations task your classes to investigate physical materials, do research, examine data, create models, and use their own personal ideas to design new products or problem-solving applications.
- **Apply the content in flexible, interesting ways.** You can implement the investigations in part or as a whole, and you can use them to teach one or more science concepts while exposing students to the unpredictable nature of science. Students will be intrigued by investigations with titles such as "By the Teeth of Your Skin: Shark Skin and Bacteria" and "From Ship to Staircase: The History of the Slinky."

Discovery Engineering in Physical Science is not only ideal for the classroom but also perfect for informal education at STEM camps, science centers, and more. You'll help your students see that just as there is not one way to do science, there are many paths that lead to innovations in engineering. And who knows what might happen? Maybe your students will engineer the next amazing designs inspired by gecko feet!

Grades 6–12

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