

# SciGirls Invent Engineer Your World



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# Engineer Your World

The process of designing and engineering requires creative thinking and problem solving. The activities in this book are designed to give girls experience sharing their inventive solutions to a variety of challenges.

These activities are based on the Emmy-Award winning, national PBS Kids television series **SciGirls**, which features groups of middle-school girls modeling authentic girl-friendly approaches to inquiry-based STEM (science, technology, engineering, and math) investigations.

These activities: follow the engineering design process (found on page 2); incorporate the **SciGirls Seven** strategies for engaging girls in STEM (outlined on page 3); connect to **SciGirls** videos and mentors from the show; and align to national standards.

All activities can be used alone, but we encourage you to enhance your girls' experience by using video to incorporate SciGirls as role models and mentors. Your girls can even take these activities to the next level by logging on to the **SciGirls** website, at [pbskidsgo.org/scigirls](http://pbskidsgo.org/scigirls), to create profiles and share their investigations with the online community.

Designing can involve a lot of struggle and initial failure. Encourage your girls to problem solve by asking them questions that tap their prior knowledge and help further the investigations. Then sit back and enjoy as your girls design and create their world!

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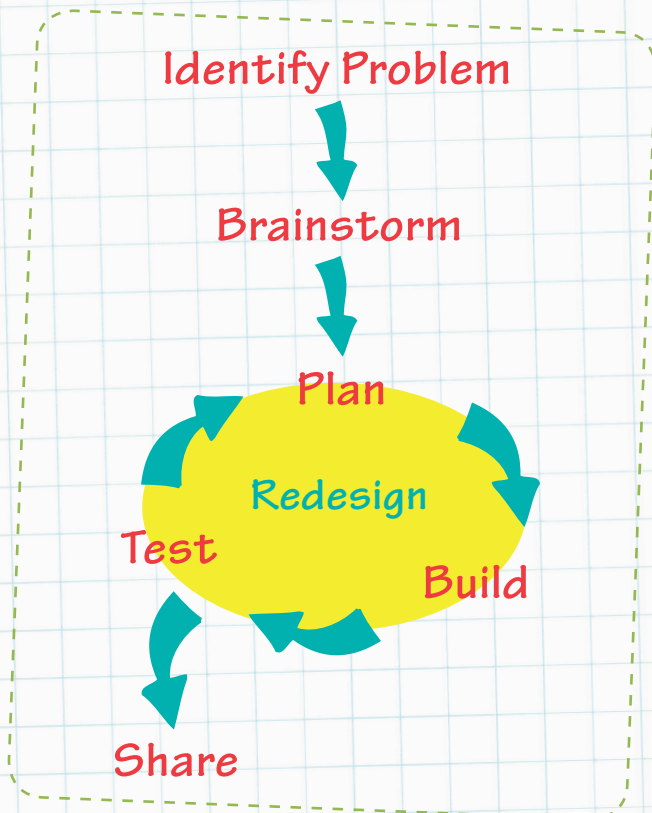
Standards Correlation **14**



# Think, Plan, Build!

## Engineering Design Process

Here is the **SciGirls'** engineering design process, the same steps that every engineer goes through when tackling a new problem. Encourage your girls to follow these steps as they approach each **SciGirls Challenge** in this activity booklet.



**Identify Problem** In our activities, the **SciGirls Challenge** lays out the goal, but girls should also discuss constraints they may have (e.g., supplies, time, and tools).

**Brainstorm** Girls can generate ideas by looking at other comparable designs or models, consulting experts, researching in books or on the Internet, or talking with one another.

**Plan** Each group must reach a consensus and choose *one* idea. Then they can use their math and science know-how to make a plan of attack, sketch a design, and identify the appropriate materials.

**Build** Girls should always start small by making a model or prototype and building one piece of the design before tackling the whole project.

**Test** After each test, girls need to evaluate their results. A failed test can still be a great test! There is something to learn from every experiment.

**Redesign** The design process is circular. After one cycle, girls may need to modify their original idea, revise their plan, and build and test again until they are ready to share their work.

**Share** Girls can learn from others by sharing their observations and results with each other, their parents, or on the **SciGirls** website. Learning is not a competition; it's a collaboration.

Throughout this guide, the projector points you to videos on the companion DVD.

Or you can watch online at [scigirlsconnect.org](http://scigirlsconnect.org)

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# The SciGirls Seven

## Strategies for Engaging Girls in STEM

The **SciGirls** approach is rooted in research on how to engage girls in STEM. A quarter of a century of studies have converged on a set of common strategies that work, and these have become **SciGirls**' foundation—aka the **SciGirls Seven**. All the activities in this booklet were created with the **SciGirls Seven** in mind and incorporate as many strategies as possible. We even mark the use of select strategies within each activity. (Look for superscript numbers and refer back to this page.) For additional information, please see our introductory booklet, *SciGirls Seven: How to Engage Girls in STEM*, which includes tips for implementing these strategies. You can download it for free at [scigirlsconnect.org](http://scigirlsconnect.org).

1. Girls benefit from collaboration, especially when they can participate and communicate fairly.
2. Girls are motivated by projects they find personally relevant and meaningful.
3. Girls enjoy hands-on, open-ended projects and investigations.
4. Girls are motivated when they can approach projects in their own way, applying their creativity, unique talents, and preferred learning styles.
5. Girls' confidence and performance improves in response to specific, positive feedback on things they can control—such as effort, strategies, and behaviors.
6. Girls gain confidence and trust in their own reasoning when encouraged to think critically.
7. Girls benefit from relationships with role models and mentors.



## Activity 1

# The Awesome Game Race

### DESIGN YOUR OWN GAME

What is a game? How is it different from a puzzle, a toy, or any other fun activity? People don't universally agree on what makes a game, but generally accepted components include: rules, decision making, goals, interaction, and potential for change each time the game is played. Your girls play games all the time. Now, SciGirls challenges them to create their own!

### SMART START:

- ★ Ask girls to bring in at least one of their favorite games from home<sup>2</sup> (including directions). Provide additional board games for those who don't bring them.
- ★ To be an effective facilitator, try to create your own game before introducing this activity to your girls.

### Here's how:

**1. Brainstorm.** Since the goal of this activity is to create a game, have girls work in small groups<sup>1</sup> to make observations about how games work. Before playing, decide which observations to record about the games you are playing. Some things to consider are:

- ★ **Mechanics** How things work or the rules in a game. In Candyland, when you draw a red card you move to the next closest red spot. But if you draw a gumdrop card, you move to the gumdrop spot. In Trivial Pursuit, if you roll the

### You'll Need:

*For each small group*

- ♦ paper and pencil
- ♦ sticky notes
- ♦ markers
- ♦ string
- ♦ tape
- ♦ scissors
- ♦ 3 in. x 5 in. index cards
- ♦ assorted game tokens for players
- ♦ paper, various sizes
- ♦ 2 different games with rules



dice and get a 5, you move 5 places.

- ★ **Goal** How you win a game or how a game ends. In Monopoly, your goal is for everyone else to run out of money before you do.
- ★ **Game pieces** Items that you use to play a game. (Not all games have pieces.) In Chess, you use six different pieces including a king, a queen, knights and pawns. In Monopoly, you use dice, player tokens, cards, houses and hotels, and money.
- ★ **Theme** The story told in a game. (Not all games have a theme.) In Clue, you investigate a murder and determine the culprit, the weapon, and the location of the crime.
- ★ **Dynamic** The main pattern of play that is

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<sup>1-7</sup> See **SciGirls Seven** strategies on page 3.



# The Awesome Game Race continued

characteristic of a game. In an exploration game like Clue or Battleship, you explore the game space. In a collection game like Hungry Hungry Hippos or Hi Ho! Cherry-O, you gather items as you play. In a race to the end game like Candyland or Chutes and Ladders, you want to get ahead of your opponents and be the first to finish.

**2. Research.** Distribute one game to each small group, and tell them to read the instructions even if they have played the game many times. Before they begin, have each girl in the group select one of the game components you brainstormed in step 1 to observe. Make sure each girl chooses a different component. As they play the game, the girls should record observations on their chosen component. After 15 minutes, ask the girls to stop playing and discuss:

- ★ Are the rules easy to understand? Do they make sense? What mechanics did you observe while playing?
- ★ Are there clear goals? How do you know when you win or the game is finished?
- ★ What types of game pieces did it use?
- ★ What was your game about? Did it have a theme?
- ★ Can you identify the dynamic in the game you played?
- ★ Is the game fun or interesting enough that you want to play it more than once?

**3. Present client information.** A company wants to make a new game for first and second graders that two to four children can play and that cannot

take more than 15 minutes to finish. Deliver the **SciGirls Challenge**: Create a game that meets the client's requirements.<sup>3</sup>

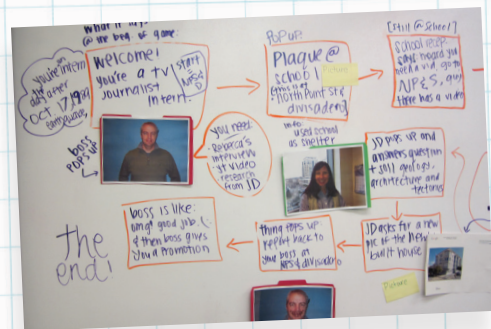
**4. Plan.** Have each group choose one dynamic and one mechanic for their game. Girls must come up with a:

- ★ **Theme** It should appeal to first and second graders. Encourage creativity!
- ★ **Goal** A goal can be how the game ends, instead of how a player wins.
- ★ **Game pieces** Remember not all games use game pieces—think of Tag!



**POINTER:** If girls are stuck on what kind of game to create, suggest they start with a game they know and alter it to fit their theme.

**5. Create Prototype 1 and test.** Create a prototype of the game using available materials.<sup>4</sup> This version should not be the final, refined game—it could be nothing more than pieces of paper. However, the prototype must include written directions so that another group can play. Each group should play their game before sharing it with others.



SciGirls game plan



# The Awesome Game Race continued

**6. Share.** Each group should now play another group's game. One girl from each group should stay with their game to hear feedback, take notes, and help the testing group if they are struggling. At the end of testing, have each group give feedback about the game they played. Is the game fun? Are the directions clear? What did they like about the game? What didn't they like? Can they think of any ways to improve it?

**7. Create Prototype 2.** Based on the feedback about the game, each group should refine their game by adding or removing different components, one at a time (mechanics, goal, games pieces, etc.). Groups should test their game after each change. Girls should add a title to the game and make sure the rules are clearly written out for anyone to pick up and play. (If there's time, you can test your directions by watching a new group play without helping them.)

**8. Playtime!** Set up a time for everyone to go around and play as many games as possible. Invite families! Celebrate each group's success and allow time for groups to share their process and struggles.<sup>5</sup>

The SciGirls and Kimberly discuss designing and building a game created to meet their clients' requirements, on the *SciGirls Invent* DVD. (Select *The Awesome App Race: Mentor Moment*.)<sup>7</sup>



## SciGirls Got Game!

SciGirls staffers have developed several games for young people. Check them out with the girls in your group and have them critique the games.

### brainSTEM

Face a variety of challenges in Science, Technology, Engineering and Mathematics in this board game. [scigirlsconnect.org/page/brainstem-game-1](http://scigirlsconnect.org/page/brainstem-game-1)

### SciGirls Dream Team

Play this cooperative game to learn more about working together to change the world! [scigirlsconnect.org/page/Dream-Team](http://scigirlsconnect.org/page/Dream-Team)

## Mentor Moment

Kimberly Bryant is an IT project manager who works with companies to create applications, or apps, for use on mobile devices. Most recently, she founded Black Girls CODE to introduce girls of color to digital technology and computer programming. Kimberly hopes to inspire a new generation of coders to become creators of technology.



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<sup>1-7</sup> See **SciGirls Seven** strategies on page 3.



## Activity 2

# Pedal Power

### FIND THE RIGHT GEAR TO HELP YOU SOAR ON YOUR BIKE!

Biking is fun for all ages, but can be tough unless you're in the right gear. A bike's gear system is designed to make pedaling more efficient on different terrains. The gear ratio measures how many times the back wheel turns for each rotation of the pedals.

#### SMART START:

Find a safe area where girls can ride their bikes. Determine the bike course; decide where to start and end. Try to include different features (e.g., flat surfaces, hills) and estimate the distance of the course.

#### Here's how:

**1. Introduce bikes and gears.** Divide girls into small groups<sup>1</sup> and have them discuss how bikes work. Visit [scigirlsconnect.org/page/pedalpower](http://scigirlsconnect.org/page/pedalpower) for background information.

**Watch SciGirls identify parts of a bike on SciGirls Invent DVD. (Select Pedal Power: Research.)**



**2. Brainstorm.** Ask each group to brainstorm ways to go faster on a bike (pedal quickly, change gears, bike design). Guide girls toward thinking about how gears affect speed. Then, deliver the **SciGirls Challenge:** Determine which gears will help you bike a set course in the shortest amount of time.<sup>3</sup>

### You'll Need:

*For each small group*

- ♦ bicycle with gears that can be changed
- ♦ helmet
- ♦ marker
- ♦ pencil and paper
- ♦ tape measure
- ♦ stopwatch
- ♦ chalk
- ♦ optional: calculator



**POINTER:** If you only have one bike for the whole group, first calculate the gear ratio as a large group. Then, have small groups make plans for the bike course and present them. Choose two or three plans to test and discuss results.

**3. Calculate gear ratio.** Help each group turn their bicycle upside down on the floor. Make sure it's stable. Use a marker to help count the teeth on the gears in the front (near the pedals) and in the back. Then, calculate each possible gear ratio. Rank them from highest to lowest and record data in a table. (See example table at [scigirlsconnect.org/page/pedalpower](http://scigirlsconnect.org/page/pedalpower).)

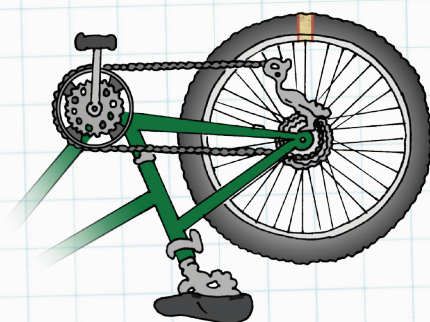
$$\text{gear ratio} = \frac{\text{number of teeth on front gear}}{\text{number of teeth on back gear}}$$

**4. Calculate tire revolutions.** Set the bike to its lowest gear (smallest gear in the front, largest



# Pedal Power continued

gear in the back). Mark a line on the back tire with chalk. Start with the pedal and tire marking at the 12 o'clock position as shown in the illustration below. Slowly move the pedal forward, clockwise, and make one full revolution. Count how many revolutions the back tire makes.



Record this number and compare it to the gear ratio. Try the highest gear (largest gear in front, smallest gear in back). What is the relationship between gear ratio and tire revolution? (Low gears have more tire revolutions, high gears have fewer tire revolutions.) How do tire revolutions relate to speed? (The more tire revolutions per pedal stroke, the faster you will go.) Would you want to be in a high or low gear when you go up a hill? Down a hill? Why?

**5. Plan and test.** Show the girls the course and give groups 10 minutes to decide the gears to test and who will ride. Encourage them to think about which gears will work best on the various landscapes (low gears for uphill, high gears for downhill, middle to high gears for flat stretches). Then, have groups take turns riding and recording their completion times. Each

girl's ability will be different so they should each ride the course several times.



**POINTER:** If there are girls in your group that can't ride bikes, assign them to be recorders.

**6. Share results.** Have each group discuss what gears they used, why they used them and their various completion times. Are gears the only factor in speed? Ask girls to share other ideas for how to ride faster. <sup>6</sup>

Watch Yvonne and the SciGirls design a pedal-powered ice cream maker on the *SciGirls Invent DVD*. (Select **Pedal Power: Mentor Moment**.) <sup>7</sup>



## Mentor Moment

Yvonne Ng is a mechanical engineer who began her career in automation design, creating computer systems that control equipment. She then began teaching at St. Catherine University in Minnesota and helped ramp up the school's STEM efforts. Yvonne recently founded Engineer's Playground to create resources that help K-12 instructors teach engineering ([engineersplayground.com](http://engineersplayground.com)).

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<sup>1-7</sup> See **SciGirls Seven** strategies on page 3.

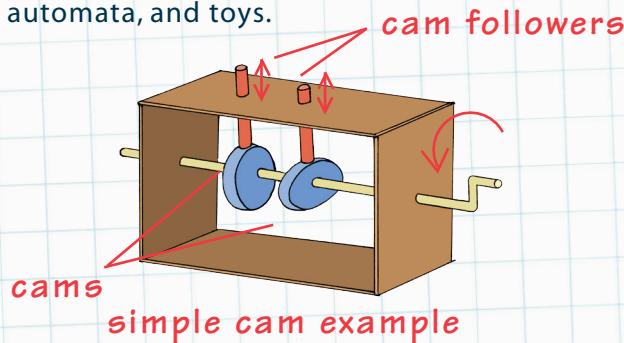


### Activity 3

# Crank It Up

## DESIGN AND CREATE YOUR OWN UNIQUE MOVING SCULPTURE!

Machines help us get work done; some are complex, with lots of moving parts, and others are simple. Cams are one example of a simple machine. They are like gears, but have no teeth and come in lots of different shapes. We use them to convert rotating motion (such as turning a crank) into back and forth motion (such as waving an arm). You'll find cams in everyday objects such as cars, music boxes, wooden automata, and toys.



## You'll Need:

- ◆ hot glue gun and hot glue sticks
- ◆ extra wooden skewers
- ◆ optional: decorative elements (e.g., construction paper, pipe cleaners, feathers, markers, cloth, tissue paper)

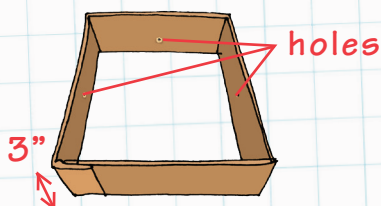
### For each small group

- ◆ small cardboard boxes (roughly 6 in. x 6 in. to 10 in. x 10 in.) or one shoebox
- ◆ 1 piece (at least 4 in. x 7 in.) of  $\frac{1}{4}$  in. (or 6 mm) thick foam (available at craft stores)
- ◆ 2 wooden skewers
- ◆ 1 plastic drinking straw
- ◆ masking tape
- ◆ ruler
- ◆ scissors
- ◆ pencil and paper

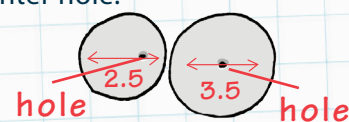
2+ hours

## SMART START:

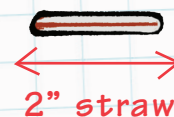
- ★ Before doing this activity with your girls, build your own machine and experiment with different size and shape cams to understand the possible variations.
- ★ Cut each box into frames at least 3 in. tall so there is one for each group. If extra support is needed, cut triangles for the corners.



Each prototype requires two foam circles (3.5 in., 2.5 in. in diameter). The 2.5 in. circle should have an off-center hole.



Each prototype needs a straw cut into 2 in. sections. Make sure to cut extras!





# Crank It Up continued

## Part 1 Build a prototype

Here's how:

**1. Introduce simple machines.** Allow girls time to play with or watch videos of automata that use cams. <sup>2</sup>Brainstorm a list of machines that use cams.



**POINTER:** Examples (or videos) of automata and cams can be found on the Exploratorium's Tinkering Studio page ([tinkering.exploratorium.edu/cardboard-automata/](http://tinkering.exploratorium.edu/cardboard-automata/)) or by searching "paper automata" on [youtube.com](http://youtube.com).

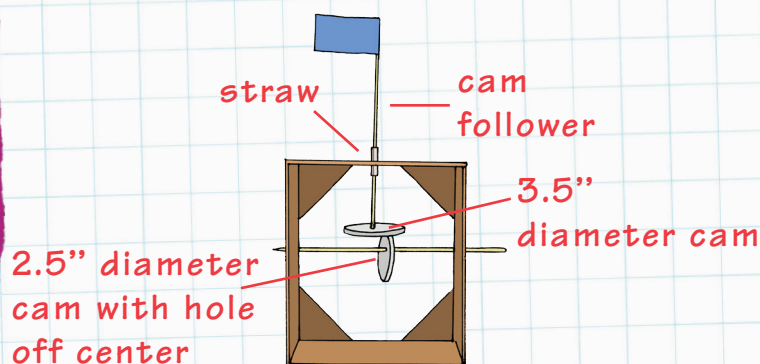
- ★ Try decorating the cam follower so the movement is easier to see.
- ★ Have your girls explore what happens when the cam is rotated.
- ★ Brainstorm what would happen if you change the shape of the cam, the placement of the hole, etc.

**3. Analyze.** Reconvene the girls into a large group to discuss the different parts of the prototypes. <sup>6</sup> What makes the cam follower rotate? What could you change to make the cam follower movement more interesting (the shape of the cam, the location, the number of cams, or the number of cam followers)?

## Part 2 Build a complex machine

Use care when working with hot glue.

**2. Build a Prototype.** Divide the girls into small groups <sup>1</sup> to build prototypes and learn about how cams and cam followers (a lever that follows the surface of the cam) work together. (See below.)



**4. Be creative.** Present the **SciGirls Challenge**: Using the prototype as inspiration, brainstorm and then build a moving sculpture that tells a story or performs a task. <sup>3</sup> Examples include machines that mix a cup of chocolate milk, illustrate a concept (a flower growing, a bee pollinating), move a pencil so that it draws on paper, or acts out a favorite story or poem.

**5. Share.** Have each group demonstrate how their moving sculpture works. Encourage the girls to have fun with the demonstration and use their imagination. <sup>4</sup> Make sure each group explains how the different parts work together in the final design. <sup>6</sup>

Adapted from the Exploratorium's cardboard automata activity at [tinkering.exploratorium.edu](http://tinkering.exploratorium.edu).

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<sup>1-7</sup> See **SciGirls Seven** strategies on page 3.



## Activity 4

# Grab and Go

### DESIGN AND BUILD A MECHANICAL ARM TO GIVE A SMALL ITEM A LIFT.

Robotic arms were first used in manufacturing in the 1950s. These arms were developed to help with dangerous jobs such as heavy duty welding, painting, and lifting large equipment. Today they are also used in scientific research, medical surgery, and to help people who have had amputations.

#### Here's how:

**1. Research.** Divide your girls into small groups<sup>1</sup> and ask them to research different types of robotic/mechanical/assistant arms on the Internet.<sup>2</sup> Have them create a table to compare the designs they find; they should include sketches or print out pictures. How do the designs differ? What kinds of designs are suitable for different purposes? What problems might arise with some of the designs?

Watch SciGirls research and design an underwater robot on the *SciGirls Invent DVD*. (Select *Aquabots: Research and Brainstorm*.)



#### 2. Brainstorm.

Deliver the **SciGirls Challenge**: Using the materials available, build an arm that can lift a paper cup from one foot away.<sup>3</sup> Share the following design constraints:

- ★ Only one person can operate the arm.
- ★ The mechanical arm is the only thing that can touch the cup.

### You'll Need:

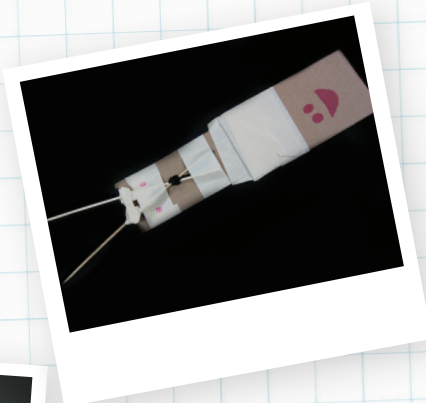
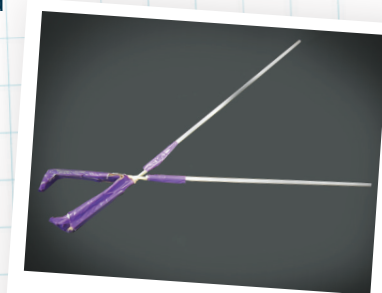
For each small group

- ◆ Styrofoam plates, Styrofoam trays (check your local grocery store), or craft foam
- ◆ craft sticks, wooden dowels, or wooden skewers in varying sizes and lengths
- ◆ plastic drinking straws
- ◆ string
- ◆ scissors
- ◆ permanent markers
- ◆ pencil and paper
- ◆ rubber bands
- ◆ tape
- ◆ 8 oz. paper cup
- ◆ ruler



- ★ The cup must be set back down and the arm removed when done.
- ★ The cup can't be damaged in the process of picking it up.

Examples of arms





# Grab and Go continued

**3. Plan and design.** Be sure to give the girls ample time to plan and design before they start to build.



**POINTER:** If groups are having difficulty, ask them to revisit the examples they researched. Suggest they break each design into simple pieces and build a similar version.

**4. Build and Test.** Throughout the building process groups should be testing their design and revising based on their results.

**5. Share.** Have each group share their design and demonstrate how it works by lifting the cup. What were the challenges? How did you overcome them? <sup>6</sup>

**6. Continue exploring.** Try adding weight to the cup and see if the arm still works. Brainstorm other things you can try picking up (stuffed animals, popcorn, pencils). How might you modify your design to address these new challenges? <sup>6</sup>

This activity is adapted from *The Case of the Physical Fitness Challenge* educator guide that is available in electronic format. A PDF version of the educator guide for NASA SCI Files™ can be found at the NASA SCI Files™ web site: [scifiles.larc.nasa.gov](http://scifiles.larc.nasa.gov). NASA SCI Files™ is produced by NASA's Center for Distance Learning, a component of the Office of Communication and Education at the NASA Langley Research Center, Hampton, VA. NASA's Center for Distance Learning is operated under cooperative agreement. Use of trade names does not imply endorsement by NASA.

## Mentor Moment

Commander Angela Schedel spent nine years flying helicopters for the U.S. Navy and discovered her passion for teaching while working as a helicopter flight instructor.

She is now an ocean engineering instructor at the U.S. Naval Academy. Angela is also the faculty advisor for the Academy's Concrete Canoe Team, which designs and builds a canoe entirely out of concrete to race against other universities!



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1-7 See **SciGirls Seven** strategies on page 3.



## Activity 5

# Deep Sea Diver

### THINK LIKE AN OCEAN ENGINEER AND DESIGN YOUR OWN MODEL DEEP SEA DIVER.

Buoyancy is the ability to float. When you put an object in water, it pushes water out of the way to make room for itself. An object floats when it weighs less than the water it displaces; an object sinks when it weighs more than the water it displaces.

#### SMART START:

Here's one way to start this activity. Get your girls thinking about buoyancy. Show them a group of objects and ask them to predict which will sink and which will float. Then, test their ideas using a plastic container filled with water. Do the girls' predictions match the results?

#### Here's how:

**1. Explore buoyancy.** Can you think of things that don't float on the water and don't sink to the bottom (scuba diver, submarine, fish, underwater research vehicles)? This is called "neutral buoyancy." Discuss what it means for an object to be neutrally buoyant. What are some situations where neutral buoyancy might be useful (snorkeling, using a submersible to study underwater creatures, taking measurements at different depths in the ocean)? <sup>6</sup>

Watch the SciGirls test a neutrally buoyant underwater robot on the *SciGirls Invent* DVD. (Select Aquabots: Test and Redesign 1.)



### You'll Need:

45 min

- ♦ items to adjust buoyancy (assorted metal washers, pennies, paper clips, binder clips, Styrofoam packing peanuts, small balloons)
  - ♦ items for the body of the diver (Styrofoam balls, plastic bendable drinking straws, craft sticks, wooden skewers, plastic eggs, ballpoint pen caps, sponge, craft foam)
  - ♦ items to hold the diver together (rubber bands, duct tape, or a hot glue gun)
  - ♦ optional: objects that sink or float (marbles, metal spoon, Ping Pong balls, sponges, plastic spoon, pieces of fruit)
- For each small group*
- ♦ sturdy clear container at least 6 in. x 6 in. that can hold water
  - ♦ water
  - ♦ scissors
  - ♦ paper and pencil

**2. Design and build.** Engineers will often build models before they design full scale. The models help them understand the factors that may be key to the success of the design. Deliver the **SciGirls Challenge**: Build a small diver (no larger than 3 in. by 3 in.) that is neutrally buoyant. In small groups, <sup>1</sup> have girls brainstorm what materials they'd like to use, then design and build their diver. <sup>3</sup>

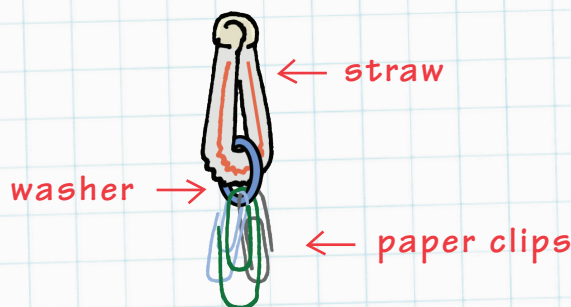
Use caution when working with hot glue.



# Deep Sea Diver continued



**POINTER:** If girls are having trouble try this model using a flexible straw. Bend it into a “U” shape. Cut the ends so they are even. Thread a washer onto the straw. Pinch ends of straw together (straw will form teardrop shape) and secure them with hot glue. Make sure the ends are sealed shut. Adjust weight by adding or removing paper clips.



**3. Test.** Place the diver into a container of water and test its buoyancy. Keep redesigning until the diver “hovers” in the center of the container of water.

**4. Share.** Have each group demonstrate their diver. Was it difficult to achieve neutral buoyancy? Why or why not? Have each group share their strategies for testing and redesigning.<sup>6</sup>

**5. Continue exploring.** Consider having the girls test their diver in salt water. They could even test whether the concentration of salt in the water makes a difference.

## Mentor Moment

Jaye Falls is a naval architect at the U.S. Naval Academy. Besides teaching, her interests include analyzing marine vessels and studying helicopter rotors to understand how they create lift. When not working, Jaye enjoys spending time with her two children.



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## Standards Correlation

The activities in this book align to national education standards including: Standards for Technological Literacy, Next Generation Science Standards and the Common Core Standards for Mathematics. To download the complete and most current alignments, please visit [scigirlsconnect.org](http://scigirlsconnect.org).

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1-7 See **SciGirls Seven** strategies on page 3.



# Every girl can be a SciGirl!



## Kids

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Watch Videos. Play games.  
Share projects. Make  
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## Parents

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Learn more about how  
to encourage your  
daughter in STEM!

## Educators

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Find ed resources: videos,  
hands-on activities, and  
the best in gender equitable  
STEM teaching  
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