DESIGN SQUAD

as built on TV

ACTIVITY GUIDE

ENGINEERING CHALLENGES FOR 9- TO 12-YEAR-OLDS

DESIGN SQUAD
INSPIRING A NEW GENERATION OF ENGINEERS

PBS

Dear Educators,

Intel welcomes you to Season 2 of PBS's reality competition series, *Design Squad*™! Our sponsorship is a component of our commitment and active involvement in today's education to inspire tomorrow's innovators. In the past decade, Intel has invested over one billion dollars and Intel employees have donated over two million hours toward improving education in 50 countries. *Design Squad*, with its substantive focus on math, science, and the design process, is closely aligned with our mission of engaging young people's curiosity about the world and developing their skills to become the next generation of innovators.

In Season 1, *Design Squad* set out to increase kids' interest in engineering by showcasing engaging, real-life applications of engineering. And it worked! After researching the impact of the TV series, Web site, and educator guides, an independent evaluator found a significant jump in kids' learning and a uniformly positive, enthusiastic response from viewers, educators, and kids. For example:

Afterschool program leaders:

- reported that the guides were easy to use and contained everything they needed.
- said they will use the guides again and recommend them to others.
- felt the guides' background materials and leader notes enabled them to talk confidently about the science and engineering in the challenges.
- developed a strong understanding of the design process and how to help kids put it into action.

Kids in afterschool programs:

- loved the engineering challenges.
- learned the science concepts in the challenges.
- increased their understanding of engineering and the design process.

We encourage you to use *Design Squad* to bring the possibilities of engineering to life for young people and inspire them to investigate and solve challenging problems that could change the world!

Sincerely,

Brenda B. Musilli

Brenda Musilli
President, Intel Foundation

WHAT'S IN THIS GUIDE

This guide offers five hands-on challenges that bring engineering to life for kids aged 9–12. They offer anyone running afterschool programs, workshops, or events engaging, effective ways to get kids thinking like engineers. The challenges are versatile—they don't require much facilitation, use modest amounts of readily available materials, give kids many ways to succeed, and are manageable with large numbers of kids. Use them for ongoing programs AND events.

Introducing the Design Process **2**

Talking to Kids about Engineering **4**

Fit *Design Squad* into any Program **5**

Web Resources **6**

Hosting a *Design Squad* Event **7**

Sources for Materials **7**

Science and Technology Content Standards **8**

Challenge 1: Watercraft **9**
Find out if you can build an unsinkable boat out of straws and plastic wrap.

Challenge 2: Paper Table **13**
See how strong a table you can build out of paper.

Challenge 3: Zip Line **17**
Test how quickly you can get a Ping Pong ball to the bottom of a zip line string.

Challenge 4: Paddle Power **21**
Check out how fast a boat can paddle itself across a container of water.

Challenge 5: Helping Hand **25**
See how many objects you can grab with a homemade "bionic" arm.

The reproducible challenge sheets are also available online in both English and Spanish at pbs.org/designsquad/parentseducators.

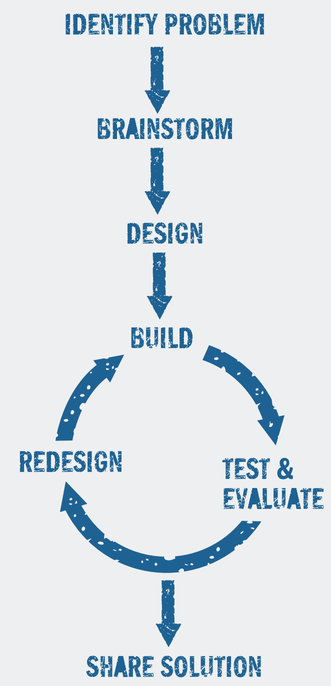
Photo: Lauren Feinberg

WANT MORE CHALLENGES LIKE THESE?

There are 12 more like them in the *Design Squad* Educator's and Event guides. Download the guides from **pbs.org/designsquad/parentseducators.**

INTRODUCING THE DESIGN PROCESS

When engineers solve a problem, their first solution is rarely their best. Instead, they try different ideas, learn from mistakes, and try again. The series of steps engineers use to arrive at a solution is called the ***design process***.



INTEGRATE THE DESIGN PROCESS INTO ACTIVITIES

As kids work through a challenge, use the questions below to tie their work to specific steps of the design process.

Brainstorming

- At this stage, all ideas are welcome, and criticism is not allowed. How creative can you be?
- What specific goal are you trying to achieve, and how will you know if you've been successful?
- What are some ways you can start tackling today's challenge?

Designing

- Time to get realistic. Talk through the brainstormed ideas. What's really possible given your time, tools, and materials?
- It's not cheating to look at other kids' projects. What can you learn by looking at them?

Building, testing, evaluating, and revising

- Does your design meet the criteria for success?
- What is the hardest problem to solve as you build your project?
- Why do you have to do something a few times before it works the way you want?

Sharing solutions

- What do you think is the best feature of your design? Why?
- What are some things everyone's designs have in common?
- What would you do differently if you had more time?
- What were the different steps you had to do to get your project to work the way you wanted?

THE DESIGN PROCESS

The design process is a great way to tackle almost any task. In fact, you use it each time you create something that didn't exist before (e.g., planning an outing, cooking a meal, or choosing an outfit).

Photo: Anthony Tieuli

Design Squad host, Nate Ball, looks at the Purple Team's design sketch before they begin building.

EACH CHALLENGE REINFORCES THE DESIGN PROCESS

Each section of the leader notes and kids' challenge sheets is built around the steps of the design process. Point out to kids that the titles on a challenge sheet are the steps of the design process.

- **Introduce the challenge**—Offers simple demonstrations and presents questions (and answers) about the activity's key concepts. This quick review introduces the activity's important ideas and terms.
- **Brainstorm and design**—Raises discussion questions to help kids think about different ways to tackle a challenge. Since challenges offer kids many ways to succeed, this section helps jump-start their thinking about various approaches and possibilities. At this stage, the more ideas, the better. But before moving to the "build" step, be sure that each kid narrows the list of ideas and settles on something specific to design.
- **Build, test, evaluate, and redesign**—Lists common issues that surfaced when the challenges were field tested as well as strategies to use with kids who are facing these issues.
- **Discuss what happened**—Provides questions (and answers) to review the activity's key concepts and to help kids reflect on how they used the design process in the challenge.
- **For events**—Offers tips on setting up and running the challenge in an event setting.
- **Kids' challenge sheets**—Each section of a challenge sheet correlates with a different design process step. After completing a few challenges, kids see that the design process lets them think creatively about a problem and produce a successful result.

HOW TO REINFORCE THE DESIGN PROCESS WITH KIDS

Open-ended challenges have no single right answer, so kids are inspired to come up with their own solutions. Use these tips to help kids explore!

- As kids progress through a challenge, point out the steps of the design process that they're doing.
- Encourage kids to come up with several ways of solving a problem before they move ahead with one idea.
- Avoid giving too much direction; it discourages kids from thinking for themselves.
- When something fails, encourage kids to try again. Mistakes are opportunities for learning. In fact, the *Design Squad* motto is, "Fail fast—succeed sooner."
- Guide kids by asking questions. To help kids discover answers for themselves, ask: What have you tried? How did it work? Why do you think it didn't work? What else could you do?
- Engineers communicate visually as well as verbally. Have kids keep design notebooks to sketch their ideas and results.
- Engineers present their work to colleagues to show how they solved a problem. You can do the same by reviewing each challenge with your kids.

IF AT FIRST...

...you don't succeed, try, try again. This saying is at the heart of the design process. Testing a design and then revising it based on what you've learned is an important key to success.

Photo: Lauren Feinberg

Photo: Lauren Feinberg

As kids progress through a challenge, point out the steps of the design process that they're doing.

TALKING TO KIDS ABOUT ENGINEERING

Few kids can say what engineering is or what an engineer does. Yet once they find out, many are hooked! You can be the one to help a young person discover his or her dream job. As you work with kids, use the information below to talk with them about engineering.

WHAT'S AN ENGINEER?

Engineers dream up creative, practical solutions and work with other smart, inspiring people to invent, design, and build things that matter. They are changing the world all the time.

WHAT DO ENGINEERS DO AT WORK?

Think creatively. Engineering is an ideal outlet for imagination and creative problem solving—the perfect field for independent thinkers.

Work with great people. Engineering takes teamwork. As an engineer, you'll be surrounded by smart, creative, inspiring people.

Solve problems and design things that matter. Engineers improve peoples' lives by tackling problems, improving current designs, and coming up with solutions no one else has thought of.

Change the world and make a difference. Among many other pursuits, engineers develop systems that save lives, prevent disease, reduce poverty, and protect our planet.

HOW DO ENGINEERS MAKE THE WORLD A BETTER PLACE?

Here are some things engineers do to help improve people's lives.

- Create more fuel-efficient cars
- Design a lighter bike frame
- Invent a more powerful superglue
- Create satellites that detect drought around the world
- Develop state-of-the-art cell phones
- Invent artificial retinas for the blind
- Develop a feather-light laptop
- Design clothing that repels mosquitoes

FIND OUT MORE

For more great reasons to become an engineer, fun projects, and profiles of engineers doing innovative work, visit the following Web sites:

- Engineer Your Life at engineeryourlife.org
- Discover Engineering at discoverengineering.org/home.asp

WHAT'S ENGINEERING?

Engineers get to imagine the future and design for it.
Marisa Wolsky, *Design Squad* Executive Producer

Engineering is about thinking through problems, finding solutions, and helping people.
Daniele Lantagne, Environmental engineer

The best part of being an engineer is the creativity that's involved and the satisfaction that comes from solving hard problems.
Jananda Hill, Computer Science engineer

Every day I see things that could be made better by just applying some good engineering know-how.
Jessica Miller, Biomedical engineer

Photo: Renée Mattier

The *Design Squad* motto is, "Fail fast—succeed sooner." If a design doesn't work as planned, encourage kids to try again.

FIT DESIGN SQUAD INTO ANY PROGRAM

Design Squad offers educators a total of 17 hands-on challenges in three great resources—this guide and the Educator's and Event guides. Find all three guides online at pbs.org/designsquad.

FOR AN EVENT OR OTHER ONE-TIME OCCASION

Design Squad challenges use simple, readily available materials and are open-ended with multiple solutions that engage a wide variety of ages and ability levels. The challenges are perfect for events and for science and engineering days. Take *Design Squad* to a museum, library, mall, or university near you and spark kids' interest and confidence in engineering with a lively, fun-filled event. Get signs, handouts, and a detailed checklist for planning and running an event in the Event Guide at pbs.org/designsquad/parentseducators.

FOR CLASSROOM, AFTERSCHOOL, CLUBS, AND OTHER ONGOING PROGRAMS

The challenges offer kids fun ways to apply the design process and core science concepts. They are excellent ways for kids to exercise their creativity and practice important skills, such as problem solving, teamwork, and critical thinking. Yet, each one is distinct, so kids do something different in every challenge. For step-by-step assistance in setting up a *Design Squad* club, check out the Educator's Guide at pbs.org/designsquad/parentseducators.

Photo: Ellen Robinson

DO CHALLENGES INDIVIDUALLY OR IN TEAMS

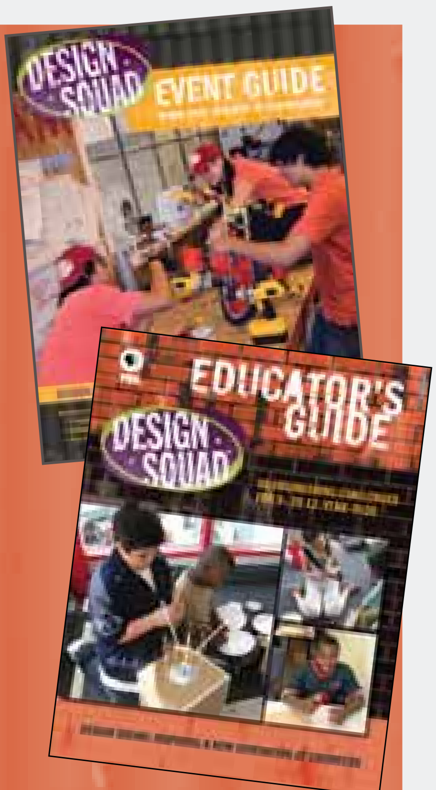
Engineers work both ways. Kids can work individually and share results or work in teams from the beginning.

SPREAD THE WORD

If you like *Design Squad* challenges, help get more people involved.

- Encourage others to do *Design Squad* challenges with kids.
- Publish a story about your successful event or program.
- Link your Web site to the *Design Squad* Web site at pbs.org/designsquad.

WEB RESOURCES



WATCH DESIGN SQUAD ONLINE

- *Episodes:* Watch all the episodes for free. Read the online descriptions to find a show that relates to what you're doing or a topic that your kids like.
- *D Squad profiles:* View short videos of engineers who showcase diverse, creative career paths in engineering.
- *Program-viewing tips:* Use these great before-, during-, and after-watching ideas to enhance kids' experience of watching a *Design Squad* episode.

GET MORE HANDS-ON, OPEN-ENDED ENGINEERING CHALLENGES

- *The Educator's Guide:* Has ten challenges with leader notes, discussion questions, and reproducible challenge sheets in English and Spanish.
- *The Event Guide:* Contains five challenges with reproducible activity sheets in English and Spanish, a list of sources for materials, a detailed event checklist, and an evaluation form to help make your event a great success.

PROMOTE THE DESIGN SQUAD VISION

- *The Design Process:* More tips on how to reinforce the design process with kids.*
- *Setting Up a Club:* Guide for launching a multi-session *Design Squad* club.*
- *Engineering in Action:* Ideas for ways to share with kids your enthusiasm for engineering.**
- *Working with Kids:* Pointers on engaging kids in engineering activities, using questions to guide their work, and solving problems that come up when doing open-ended challenges.**
- *E-newsletter:* Sign up for news about the show, Web site, resources, and events and trainings.

* See Educator's Guide *Introduction* ** See Event Guide's *Designing Your Event*

HOST DESIGN SQUAD EVENTS

- *How-to guide:* A detailed guide and step-by-step checklist to make your event a success. See pages 6–14 of the Event Guide.
- *Signage:* Get all the signs you need for use at an event, workshop, or *Design Squad* club.
- *Products:* Buy *Design Squad* T-shirts, pencils, and balloons. For purchase information, go to eweek.org.
- *T-Shirt transfers:* Download these iron-on transfers. Create your own *Design Squad* apparel.
- *Volunteer certificate:* Acknowledge people who have helped at an event, workshop, or club.

Find all these Web resources online at pbs.org/designsquad.

HOSTING A DESIGN SQUAD EVENT

GENERAL EVENT TIPS

Do the challenge(s) yourself to anticipate the quantities of materials required and where kids might need help.

Review the leader notes and challenge sheet, focusing especially on how to respond to questions that might come up.

Make photocopies of the kids' challenge sheet(s) and set them out, one per kid.

Use signs to mark activities. Download and print activity signs from the *Design Squad* Web site. Mount each on a firm backing and set on tabletops to advertise the activities you're doing.

Establish testing zones separate from building areas to ease overcrowding in any one area. Download, print, and mount the Testing Zone sign from the *Design Squad* Web site and set it in the area devoted to testing.

CALCULATING HOW MANY MATERIALS TO BUY

Estimate how many kids will be at your event. Then add 20%. This figure will help to accommodate a larger-than-expected crowd (and kids who just LOVE tape!).

Use the "per person" guidelines in each activity's materials list. Multiply the per person recommendation by the number you arrived at above.

Don't consider "common" materials to be "shareable." If you're doing several activities that use similar materials, stock each area fully.

Gather materials in advance, and get extra! It's better to have too many materials. You can return unopened extras or save them for next time.

SOURCES FOR MATERIALS

Most of the required materials are easy to find at local stores. If you are buying small quantities, try: **hardware stores** for metal washers; **office supply stores** for corrugated cardboard and chipboard; **grocery stores** for wooden skewers; and **sporting goods stores** for Ping-Pong balls. Large quantities of these items are available online at:

Chipboard
8 ½ x 11 inch
Item #S-6416
$40 per case (960 sheets)
uline.com

Corrugated cardboard
11 x 17 inch
Item #S-3585
28 cents per piece
uline.com

Flat washers
SAE standard steel
Inside diameter: ½ inch
Outside diameter: 1 inch
Item #2980
14 cents each
boltdepot.com

Ping-Pong balls
Item #GS29
$1.95 per dozen
ustoy.com

Wooden skewers
Item #05700
$1.29 for 100
netgrocer.com

Sources listed are examples of vendors who offer these items. We encourage you to research the sources that best fit your needs.

ATTEND A DESIGN SQUAD TRAINING SESSION

Photo: James Tkatch

WGBH and its outreach partners host a series of nationwide trainings for engineers and informal educators on how to connect kids to engineering, organize an event or workshop, find volunteers, work with kids, and train others. Interested? Send an e-mail to designsquad_feedback@wgbh.org.

Photo: Lauren Feinberg

SCIENCE AND TECHNOLOGY CONTENT STANDARDS

Massachusetts Curriculum Frameworks Science and Technology/Engineering Standards

	Grades 3–5										Grades 6–8									
	Materials and Tools			Engineering Design				Physical Science			Materials, Tools, and Machines		Engineering Design					Physical Science		
Challenge	1.1	1.2	1.3	2.1	2.2	2.3	2.4	1	4	5	1.1	1.2	2.1	2.2	2.3	2.4	2.5	8	11	13
Watercraft	●	●		●	●	●		●			●	●	●	●	●	●	●			
Paper Table	●	●		●	●	●		●			●	●	●	●	●	●	●			
Zip Line	●	●		●	●	●		●			●	●	●	●	●	●	●	●	●	
Paddle Power	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●		●	●
Helping Hand	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●			

ITEA National Study of Technology Content Standards

	Grades K–12										
	The Nature of Technology			Technology and Society	Design			Abilities for a Technological World		The Designed World	
Challenge	1	2	3	6	8	9	10	11	12	18	20
Watercraft	●	●	●	●	●	●	●	●	●	●	
Paper Table	●	●	●	●	●	●	●	●	●		●
Zip Line	●	●	●	●	●	●	●	●	●	●	
Paddle Power	●	●	●	●	●	●	●	●	●	●	
Helping Hand	●	●	●	●	●	●	●	●	●		

National Science Education Standards

	Gr. 3–5			Grades 6–8			
Challenge	Science as Inquiry	Properties of Materials	Technological Design	Motions and Forces	Technological Design	Science and Technology	Technology in Society
Watercraft	●	●	●	●	●	●	●
Paper Table	●	●	●	●	●	●	●
Zip Line	●	●	●	●	●	●	●
Paddle Power	●	●	●	●	●	●	●
Helping Hand	●	●	●	●	●	●	●

WATERCRAFT

CHALLENGE 1
LEADER NOTES

The Challenge

Build a boat that can hold 25 pennies for at least ten seconds before sinking.

In this challenge, kids follow the design process to build a boat that can stay afloat and upright while weighed down with a heavy load of pennies. (If metal washers are easier to get, use 15 metal washers [one inch in diameter] instead of 25 pennies.)

1. **Introduce the challenge** (5 minutes)
Begin by telling kids the challenge. Then get them thinking about why things float. Ask:
   - If you take two empty, *capped* soda bottles—one big and one small—and push them underwater, which one will be harder to keep down? (*The big one*) Why? (*Both bottles displace [i.e., push aside] some water. The displaced water pushes back on the bottles. The upward push of the water on an object gets bigger as more water is displaced. The big bottle displaces more water than the small one does. So there's more force pushing it up, and it floats better.*)
   - Tell kids that buoyancy is the term for describing the force pushing back up on the bottle. The more **buoyancy** something has, the higher it floats in the water.
   - How can you make a boat that's very buoyant? (*Make sure it displaces a lot of water.*)

2. **Brainstorm and design** (10 minutes)
Show kids the materials and ask, "What kinds of boats can you make using these materials? How can you design them to carry a heavy load?" After discussing their ideas, have them sketch their designs on a piece of paper or in their design notebooks.

3. **Build, test, evaluate, and redesign** (35 minutes)
Distribute the challenge sheet and have kids begin building. If any of the following issues come up, ask kids questions to get them thinking about how they might solve their problems.
   - The boat doesn't float well. *Increase its buoyancy by making its interior space bigger (i.e., making a very wide boat with high sides). Or trap a lot of air in the straws, cups, or frame used to build the boat.*
   - The boat leaks. *See if the straws are filling with water. If so, use tape to seal them. Also, check the plastic wrap. Press it tightly or use tape to form a watertight barrier.*
   - The boat tips and takes on water. *Make sure the weight is well distributed—spread it evenly across the bottom. Also, a boat can tip when the load is up high. Place the pennies in the lowest part of the boat. Or build a boat with a V-shaped (i.e., triangular) hull, which is generally a more stable design than a flat-bottomed boat.*
   - The boat can't support 25 pennies. *Increase its buoyancy by increasing its size and depth.*

DESIGN SQUAD

SHOW KIDS THE RELATED TV EPISODE


Photo: Helen Tsai

In Watercraft, kids figure out how to carry a heavy load in a boat. Show them the PVC Kayak episode in which *Design Squad* teams compete to build kayaks that the team members can maneuver around a slalom course. Get it online at pbs.org/designsquad.


Photo: Lauren Feinberg

Encourage kids to come up with several ways of solving a problem before they move ahead with one idea.

Photo: Lauren Feinberg

Have kids test the buoyancy of their boats by carefully loading them with pennies or washers.

Photo: Lauren Feinberg

A boat that can displace a lot of water can support a lot of weight.

- Someone's design just isn't working. *Suggest making a different kind of boat. With these materials, kids can make platform boats and open boats. Make a platform boat by taping straws together to form a floating platform. Make an open boat by covering a frame of straws with plastic wrap. The open boat design generally supports a heavier load.*

4 **Discuss what happened** (10 minutes)
Have kids talk about their designs and how they solved any problems that came up. Emphasize the key themes in this challenge—buoyancy and supporting a load—by asking questions such as:

- What are some things that all the boats have in common? (*They float by displacing water, are waterproof, stay upright when floating, and carry a load.*)
- Which held more pennies, a platform raft or a boat built over a frame? (*Generally, a boat built over a frame will hold more pennies than a similar-sized platform of straws will. Its hull displaces more water before starting to sink; it is therefore more buoyant.*)
- How did knowing about buoyancy influence the design of your boat? (*In general, the more water that a boat can displace, the more weight it can support.*)

FOR EVENTS

- Draw kids into your area by asking, "Can you build an unsinkable boat?"
- Kids may be tempted to make huge rafts out of straws or to use large quantities of plastic wrap to waterproof their boats. Limit materials to those listed on the activity sheet unless someone gives good reasons for needing more.
- Provide one container of water per five kids.
- Keep the supply of pennies in the testing area. Kids only need them when they're testing.
- Have towels on hand to mop up spills.

To determine how many materials you'll need for different-sized events, for information on obtaining large quantities of materials, and for other general event tips, see page 7.

WATERCRAFT

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YOUR CHALLENGE

Design and build a boat out of straws and plastic wrap that can hold 25 pennies for at least ten seconds before sinking.

BRAINSTORM & DESIGN

Look at your materials and think about the questions below. Then sketch your ideas on a piece of paper or in your design notebook.

1. How will you make a boat that floats well enough to support a heavy load without sinking?
2. Should your boat be a platform (e.g., a raft or barge) or an open boat (e.g., a rowboat or canoe)?
3. What's the best way to make your boat waterproof?
4. How big do you need to make your boat to hold 25 pennies?

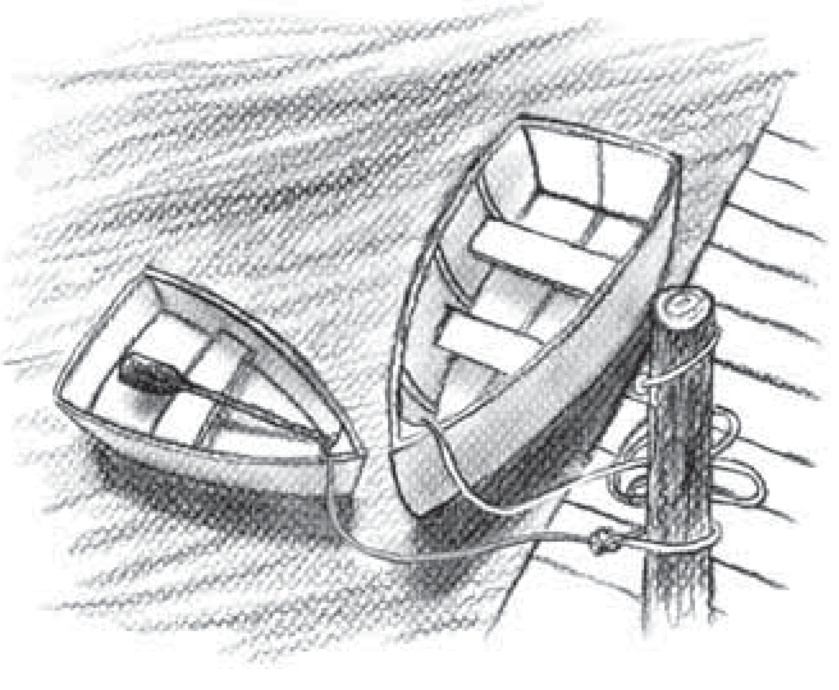
BUILD, TEST, EVALUATE & REDESIGN

Use the materials to build your boat. Then test it by floating it in a container of water and adding pennies, one at a time. When you test, your design may not work as planned. When engineers solve a problem, they try different ideas, learn from mistakes, and try again. The steps they use to arrive at a solution is called the ***design process.*** Study the problems and then redesign. For example, if the boat:

- sinks easily—*Increase its ability to float. When you set your boat in water, notice how it sinks down a bit, pushing aside some water. The water pushes right back, pressing on the boat's bottom and sides. The force from these pushes is called* ***buoyancy****. To change your boat's buoyancy, experiment with the boat's width and the height of its sides.*
- leaks a lot—*See if the straws are filling with water or if the plastic wrap is separating.*
- tips easily—*Check how near the weights are to each other. A boat can get tippy when one part is heavier than another.*

MATERIALS (per person)

- container filled with water (e.g., bucket, sink, plastic tub)
- duct tape
- paper cups (8-ounce or larger)
- 10-inch strip of plastic wrap
- 10 straws
- towels (paper or cloth)
- 25 pennies (or 15 standard, flat steel washers, at least 1 inch in diameter)



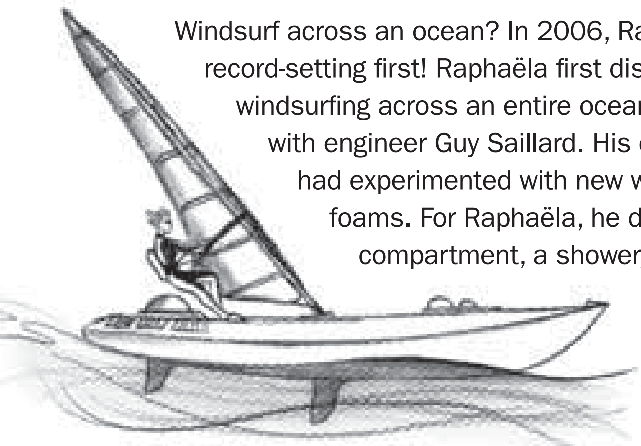
TAKE IT TO THE NEXT LEVEL

- Ready for some heavy lifting? Change your boat so it holds 50 pennies for at least ten seconds before sinking.
- Less is more! Build another boat that can hold 25 pennies, but use only half the amount of materials that you used for your first boat.

MAKE IT ONLINE

Underwater boat?
Build a self-propelled submarine out of 2 soda bottles, a rubber band, and 2 paper clips. See how on Make Magazine's project page at makezine.com/designsquad.

ENGINEERING IN ACTION



Windsurf across an ocean? In 2006, Raphaëla le Gouvello windsurfed 3,541 miles across the Indian Ocean—a record-setting first! Raphaëla first discovered windsurfing while on a family vacation. Soon, the idea of windsurfing across an entire ocean caught her imagination. To turn her dream into reality, she teamed up with engineer Guy Saillard. His challenge was to make her a sailboard she could live on. For years, Guy had experimented with new ways to use durable hi-tech materials such as epoxy resin, carbon fiber, and foams. For Raphaëla, he designed a strong, lightweight, 25-foot-long sailboard. It has a sleeping compartment, a shower, and its own satellite communication system—all the comforts of home. Or not! The cabin was only 8 feet long, 20 inches wide, and 31 inches high (slightly bigger than a coffin). If an engineer could build you the boat of your dreams, would you want to take a trip like Raphaëla's? Here's a snapshot:

- **Length of trip:** Two months.
- **Time sailed each day:** Seven hours.
- **Time spent sleeping:** Seven hours.
- **Weight of her first-aid kit:** 26 pounds.
- **Other things she did each day:** Send e-mail, check her course, get weather reports, talk to her support team by radio, relax, and make and eat meals.
- **Amount of water she used per shower:** A half gallon. The average shower in the US uses 18 gallons! Her boat only holds five gallons, but it has a solar-powered device that makes fresh water by taking the salt out of seawater.

Watch the DESIGN SQUAD PVC Kayak episode on PBS or online at pbs.org/designsquad.

Major funding for *Design Squad* is provided by the Corporation for Public Broadcasting and the Intel Foundation. Additional funding is provided by the National Council of Examiners for Engineering and Surveying, United Engineering Foundation (ASCE, ASME, AIChE, IEEE, AIME), Noyce Foundation, Northrop Grumman Foundation, the IEEE, and the Intel Corporation.

PAPER TABLE

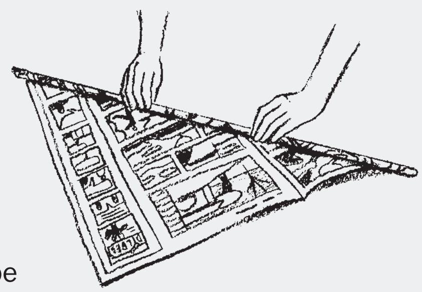
CHALLENGE 2
LEADER NOTES

The Challenge
Use tubes of newspaper to make a table that's at least eight inches tall and strong enough to hold a heavy book.

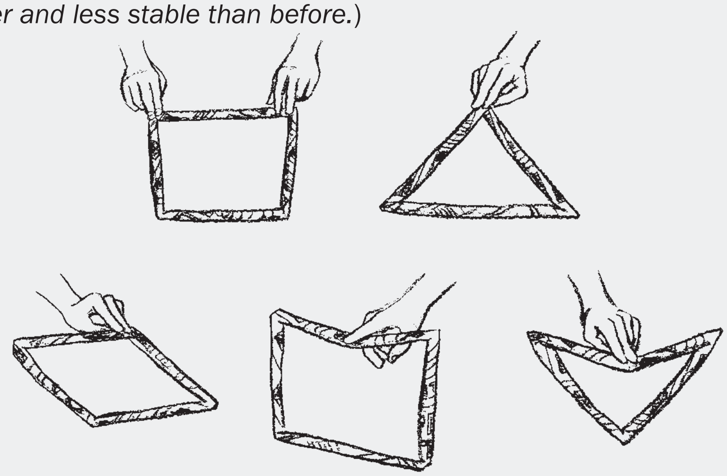
In this challenge, kids (1) follow the design process to build a sturdy table out of paper tubes; (2) make paper support more weight by changing its shape; and (3) figure out ways to keep the table legs from buckling.

1 **Introduce the challenge** (5 minutes)
Begin by telling kids the challenge. Then get them thinking about ways to get paper to support a lot of weight. Ask:

- How can you make a piece of paper support a lot of weight? *(You can fold, roll, layer, or reinforce it. In this activity, kids use sheets of newspaper rolled into tubes. To make a strong tube, roll it tight. Demonstrate how to do this. Start at one corner and roll diagonally toward the other corner. Your first roll should be about the diameter of a straw. Tape the tube closed with a strip or two of tape. Wave it around to show how stiff it is.)*



- Tables and chairs have supports to keep their legs from tilting or twisting. Look at the furniture in this room. How would you describe the supports you see? (*Table legs often use rods for support. The rods often form a triangle with the leg. Take two newspaper tubes. Bend one into a triangle and the other into a square. Tape them closed and set them on the floor. Push down on them and rock them side to side. The triangle will withstand more force and be more stable than the square. However, orientation matters. If you turn it so it rests on a point, the triangle will be weaker and less stable than before.*)



2 **Brainstorm and design** (10 minutes)
Show kids the materials and ask, "How can you use these materials to make a paper table that's at least eight inches tall and strong enough to hold a book?" After discussing their ideas, have them sketch their designs on a piece of paper or in their design notebooks.

DESIGN SQUAD

SHOW KIDS THE RELATED TV EPISODE


Photo: Anthony Tieuli

In Paper Table, kids figure out ways to use paper to make strong tables. Show them the Cardboard Furniture episode in which *Design Squad* teams compete to build cardboard furniture that is modern, comfortable, innovative, and functional. Get it online at pbs.org/designsquad.


Photo: Renée Mattier

It takes much more force to crumple paper when it's rolled into a tube than when it's in a flat sheet.

Photo: Ellen Robinson

In general, the more triangles kids use in their tables, the stronger and more stable they will be.

Photo: Renée Mattier

Changing the shape of a material affects its strength. Any shape that distributes the force of a load increases a material's strength.

3 **Build, test, evaluate, and redesign** (35 minutes)
Distribute the challenge sheet and have kids begin building. If any of the following issues come up, ask kids questions to get them thinking about how they might solve their problems.

- The table legs tilt or twist. *Support the legs by running tubes between them.*
- A tube buckles when weight is applied. *See if the tube is loosely rolled. If so, re-roll it tighter and tape it securely closed. Also, dents and creases weaken a tube. Add a support or reinforce the weak area or replace the damaged tube with a new one.*
- The table wobbles. *Make sure that the table isn't lopsided, that there are adequate supports, and that the tubes are undamaged. Also, a table becomes tippier as its height increases. If a table is very tall and reinforcing the legs doesn't work, suggest reducing its height.*
- The table collapses. *Check that the base of the table is truly sturdy. Remind kids that engineers often put materials together in triangular arrangements to increase their strength and stability. In general, the more triangles kids use to build their table, the stronger it will be.*

4 **Discuss what happened** (10 minutes)
Have kids talk about their designs and how they solved any problems that came up. Emphasize the key themes in this challenge—making paper support more weight by changing its shape, and designing a stable, strong table base—by asking questions such as:

- How were you able to support a heavy book on just pieces of newspaper? (*Kids changed the paper's shape. A tubular shape distributes a load well and increases the amount of weight the paper can support. With a tube, the book's weight pushes on every part of the paper, not just one section of it. A tubular shape also resists buckling.*)
- How did knowing that certain arrangements of materials (like triangles) are stronger than others influence the design of your table? (*Answers will vary.*)
- What helped your table be especially strong? (*Kids may mention the use of good bracing, sturdy frames, triangles, and keeping the table as compact as possible.*)

FOR EVENTS

- Draw kids into your area by asking, "Do you think you can build a table out of newspaper?"
- To avoid spending time teaching each person how to make a tube out of newspaper, make samples that illustrate the process described in the Introduce the Challenge section. For example, take three pieces of newspaper. With the first, show how tight the first roll needs to be. With the second, show the paper rolled halfway up. With the third, show a finished tube. Tape these samples to a piece of poster board and label them accordingly.

To determine how many materials you'll need for different-sized events, for information on obtaining large quantities of materials, and for other general event tips, see page 7.

PAPER TABLE

DESIGN SQUAD
PBS
as built on TV
pbs.org/designsquad

YOUR CHALLENGE

Design and build a table out of newspaper tubes. Make it at least eight inches tall and strong enough to hold a heavy book.

MATERIALS (per person)

- 1 piece of cardboard or chipboard (approximately 8 ½ x 11 inches)
- heavy book (e.g., a textbook or telephone book)
- masking tape
- 8 sheets of newspaper

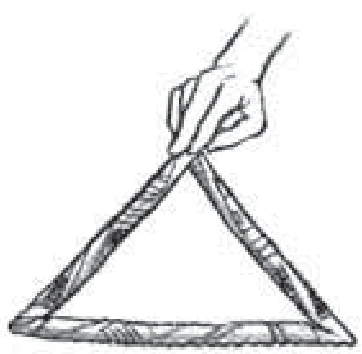
BRAINSTORM & DESIGN

Look at your materials and think about the questions below. Then sketch your ideas on a piece of paper or in your design notebook.

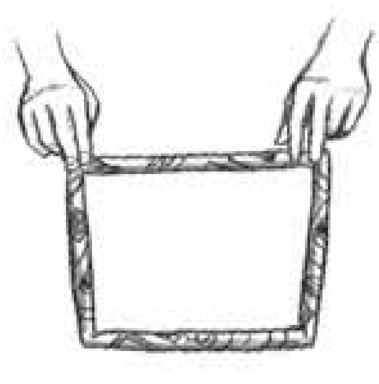
1. How can you make a strong tube out of a piece of newspaper? (This challenge uses tubes because it takes more force to crumple paper when it's shaped as a tube.)
2. How can you arrange the tubes to make a strong, stable table?
3. How can you support the table legs to keep them from tilting or twisting?
4. How level and big does the table's top need to be to support a heavy book?

BUILD, TEST, EVALUATE & REDESIGN

Use the materials to build your table. Then test it by carefully setting a heavy book on it. When you test, your design may not work as planned. If things don't work out, it's an opportunity—not a mistake! When engineers solve a problem, they try different ideas, learn from mistakes, and try again. Study the problems and then redesign. For example, if:



- the tubes start to unroll—*Re-roll them so they are tighter. A tube shape lets the load (i.e., the book) push on every part of the paper, not just one section of it. Whether they're building tables, buildings, or bridges,* **load distribution** *is a feature engineers think carefully about.*
- the legs tilt or twist—*Find a way to stabilize and support them. Also check if the table is lopsided, too high, or has legs that are damaged or not well braced.*
- a tube buckles when you add weight—*Support or reinforce the weak area, use a wider or thicker-walled tube, or replace the tube if it's badly damaged. Changing the shape of a material affects its strength. Shapes that spread a load well are strong. Dents, creases, and wrinkles that put stress on some areas more than others make a material weaker.*
- the table collapses—*Make its base as sturdy as possible. Also, a table with a lot of triangular supports tends to be quite strong. A* **truss** *is a large, strong support beam. It is built from short boards or metal rods that are arranged as a series of triangles. Engineers often use trusses in bridges, buildings, and towers.*



TAKE IT TO THE NEXT LEVEL

- If a little is good, a lot is better! Build a table that can hold two or more heavy books.
- The sky's the limit. Build a table that can hold a heavy book 16 inches above the ground.
- Matching furniture! Build a chair out of newspaper.

MAKE IT ONLINE

Paper guitar?
Build a great-sounding guitar out of a box, string, wood, and wire. See how on Make Magazine's project page at makezine.com/designsquad.

ENGINEERING IN ACTION

A paper house? Better leave your matches outside! Check out these items that engineers made out of paper. Then choose from the list and see if you can figure out the year each item was invented.

Years these items were invented: 1922; 1931; 1967; 1995; 2004; 2007

_______ **A. Paper Church**
After a big earthquake in Japan, engineers quickly made a building by stretching a paper "skin" across 58 paper tubes, each over 16 feet long. The church was only meant to be a temporary place of worship. But it's still standing today.

_______ **B. Paper Video Disc**
This disc holds more than three times as much data as a standard DVD and is much better for the environment. But you'll have to stay tuned—there's no release date set.

_______ **C. Paper House**
An engineer built a vacation home out of newspaper. He glued newspapers into one-inch-thick slabs and then used them to make the walls. It's still standing!

_______ **D. Paper Towels**
By mistake, a factory made rolls of paper that were too thick for toilet paper but too weak for most other uses. But where others see problems, engineers see possibilities. The paper was sold as "Sani-Towels," which soon became known as paper towels.

_______ **E. Paper Batteries**
They're smaller than a postage stamp but can power a light bulb! And they decompose in landfills. Engineers are still figuring out how to get them to work with all our gadgets.

_______ **F. Paper Dresses**
Engineers created paper outfits that could be printed with designs. They were sold in boutiques and in stationery stores, where you could get a tablecloth to match!

(Answers: A: 1995; B: 2004; C: 1922; D: 1931; E: 2007; F: 1967)

Watch the DESIGN SQUAD Cardboard Furniture episode on PBS or online at pbs.org/designsquad.

Major funding for *Design Squad* is provided by the Corporation for Public Broadcasting and the Intel Foundation. Additional funding is provided by the National Council of Examiners for Engineering and Surveying, United Engineering Foundation (ASCE, ASME, AIChE, IEEE, AIME), Noyce Foundation, Northrop Grumman Foundation, the IEEE, and the Intel Corporation.

ZIP LINE

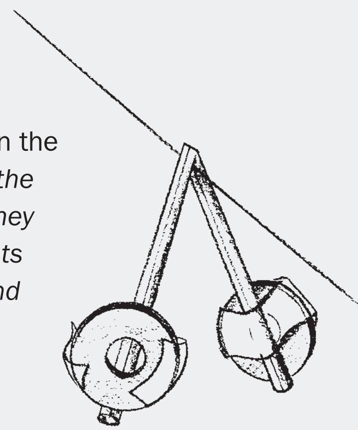
CHALLENGE 3
LEADER NOTES

The Challenge
Design and build something to carry a Ping-Pong ball from the top of a zip line to the bottom in four seconds (or less!).

In this challenge, kids (1) follow the design process to build a Ping-Pong ball carrier that slides quickly down a zip line string; (2) figure out how to keep something balanced; and (3) identify ways to reduce friction.

1 **Introduce the challenge** (5 minutes)
Before the session starts, run a four-foot length of fishing line between the back of a chair and a stack of books on the floor. Tie the line so that the chair end is about two feet higher than the book end. (It should slant at about 30 degrees.) Begin by telling kids the challenge and that the slanted fishing line is called a zip line. Then rest a straw on top of the zip line. Hold it across the line so that the line touches the straw at its middle. To get kids thinking about balance, ask:

- What will happen if I let go of this straw? (*It will fall. When the straw is straight, it's hard to balance it on the line.*)
- What can we do to help the straw stay balanced on the line? (*Try any ideas kids suggest, such as bending the straw in half and setting the crease on the line. If they don't suggest adding weight, show them how weights can balance the straw. Tape a washer onto each end of the straw. Bend the straw in half and set the crease on the line. The two washers will balance the straw.*)



- How do the washers help the straw stay on the line? (*The washers pull the straw down, keeping it firmly on the line. Also, when there is the same amount of weight on each side of the straw, the washers balance each other and keep the straw stable.*)

2 **Brainstorm and design** (10 minutes)
Show kids the materials and ask, "How can you use these materials to make a device that carries a Ping-Pong ball quickly down a zip line? The ball carrier should also be easy to put on and take off the line." After discussing their ideas, have them sketch their designs on a piece of paper or in their design notebooks.

3 **Build, test, evaluate, and redesign** (35 minutes)
Distribute the challenge sheet and have kids begin building. If any of the following issues come up, ask kids questions to get them thinking about how they might solve their problems.

- The ball carrier doesn't balance. *Check that each side is equally weighted and that the middle of the carrier touches the line. Also, make sure kids used enough weight. It can be hard to stay balanced if there's too little weight holding the carrier down, especially once there's a ball on it. Finally, the Ping-Pong ball carrier will be more stable the lower the weights hang, so make sure the weights hang well below the zip line.*

DESIGN SQUAD

SHOW KIDS THE RELATED TV EPISODE

Photo: Helen Tsai

In Zip Line, kids figure out ways to safely slide a Ping-Pong ball along a line. Show them the Backyard Thrill Ride episode in which *Design Squad* teams compete to build an exciting zip line-based amusement ride for a kid's backyard. Get it online at pbs.org/designsquad.

Photo: Lauren Feinberg

Open-ended challenges have no single right answer, so kids are inspired to come up with their own solutions.

Photo: Lauren Feinberg

Ball carriers go faster when they're evenly weighted and when there's little friction between the sliding surface and the line.

Photo: Lauren Feinberg

Kids can extend the activity by building a ball carrier that can hold several Ping-Pong balls.

- The ball falls off the ball carrier. *Make sure the carrier has a big enough place to hold the ball. Kids can use tape, a cup, several cups, or a platform to keep the ball on the carrier.*
- The carrier goes slowly or stops partway down. *See if kids have reduced friction as much as possible. To do this, they can: (1) make the part of the carrier touching the line as slippery as possible by using a smooth, hard material like plastic; or (2) adjust how hard the carrier presses on the zip line by hooking it on the zip line at two or more points.*
- The zip line sags. *Check the tension of the line. Tighten, if necessary. If a kid's carrier is very heavy, encourage him or her to find ways to lighten it.*

4 **Discuss what happened** (10 minutes)
Have kids talk about their designs and how they solved any problems that came up. Emphasize the key themes in this challenge—balance and friction—by asking questions such as:

- What helped your Ping-Pong ball carrier travel quickly down the zip line? (*Ball carriers go faster when they're evenly weighted and when there is little friction between the sliding surface of the ball carrier and the line.*)
- How did you minimize friction in your Ping-Pong ball carrier? (*Answers will vary.*)
- What was the hardest part of making a Ping-Pong ball carrier with good balance? With little friction? With a secure way to carry the ball? (*Answers will vary.*)

FOR EVENTS

- Draw kids into your area by asking, "How quickly do you think you can get a Ping-Pong ball to the bottom of our zip line?"
- Provide one zip line per eight kids.
- Four to five feet is the recommended length for the zip line. If it's much shorter, the ball carrier's ride goes too quickly. If it's much longer, the line begins to sag.
- Fishing line can be hard to see. Mark off the testing area so that people don't accidentally run into the lines you set up.
- To minimize distractions, give kids Ping-Pong balls only when they're in the testing area. Put out just a few at a time. Have kids leave them in the testing area once they've finished.

To determine how many materials you'll need for different-sized events, for information on obtaining large quantities of materials, and for other general event tips, see page 7.

ZIP LINE

DESIGN SQUAD as built on TV
pbs.org/designsquad

YOUR CHALLENGE

Design and build something that can carry a Ping-Pong ball from the top of a zip line string to the bottom in four seconds (or less!).

BRAINSTORM & DESIGN

Look at your materials and think about the questions below. Then sketch your ideas on a piece of paper or in your design notebook.

1. Using these materials, what can you design that can carry a Ping-Pong ball down a zip line?
2. How will your Ping-Pong ball carrier stay on the zip line as it goes from the top to the bottom?
3. What kinds of materials should be in contact with the zip line so that the carrier slides quickly?

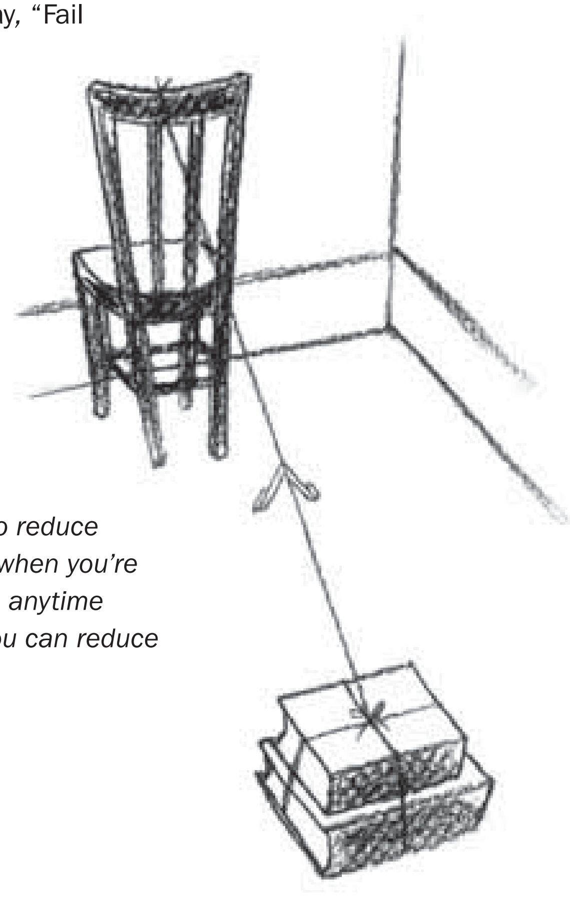
BUILD, TEST, EVALUATE & REDESIGN

Use the materials to build your Ping-Pong ball carrier. Then make a zip line. Run the line between the back of a chair and a stack of books. Make sure the high end is about two feet above the low end. Test the carrier by putting it on the line. When you test, your design may not work as planned. The design process is all about "if at first you don't succeed, then try, try again." On *Design Squad,* we say, "Fail fast—succeed sooner!" Study the problems and then redesign. For example, if your Ping-Pong ball carrier:

- keeps dropping the ball—*Check that it has a big enough place to hold the ball.*
- stops partway down—*Make sure there's nothing blocking your carrier where it touches the line.*
- doesn't balance well—*Adjust the weights. Add weights or move them so they are farther below the zip line. Doing this changes the carrier's* **center of gravity**, *the point within an object where all parts are in balance with one another. See how changing the numbers and positions of washers affects the carrier's balance.*
- takes longer than four seconds to travel the zip line—*Find ways to reduce friction. Yes, there's* **friction**—*the force that resists motion—even when you're dealing with something as smooth as fishing line. You'll find friction anytime things rub together. Experiment with different materials to see if you can reduce friction and speed up the Ping-Pong ball carrier.*

MATERIALS (per person)

- chipboard (from a cereal box or back of a notepad)
- 2–4 small paper cups (i.e., 3-ounce)
- Ping-Pong ball
- 4 plastic straws
- scissors
- single-hole hole punch
- 4 feet of smooth line (e.g., fishing line or unwaxed dental floss)
- tape (duct or masking)
- 4 standard, flat steel washers (1 inch in diameter or larger)
- 4 wooden skewers



TAKE IT TO THE NEXT LEVEL

- Slow down! Build a carrier that takes ten seconds to travel the length of the zip line.
- Piggyback time. Make a carrier that can hold several Ping-Pong balls at the same time.
- Blast off! Find a way to launch the Ping-Pong ball when the carrier gets to the end of the zip line.
- On your mark. Get set. Go! Set up two zip lines and race different ball carriers.

MAKE IT ONLINE

Travel by blimp, anyone?
Build a jet-propelled blimp that can travel across a large room. Make it out of 2 balloons, 2 straws, and some clay and tape. See how on Make Magazine's project page at makezine.com/designsquad.

ENGINEERING IN ACTION

Ever want to zip up the side of a building like Batman or Spiderman? Now this superpower can be yours, thanks to engineer Nate Ball, host of *Design Squad*, and his friends. For a contest, they designed and built a climbing device that could carry a person 50 feet up the side of a building in less than five seconds. After months of work, the team tested their climber by lifting a 150-pound load of tires. Nate recalls, "After a few seconds, there was an awful sound. The gearbox exploded. The tires smashed to the ground with a huge crash." After analyzing the ruined climber, they made lots of changes and ended up winning third prize in the contest. Ultimately, they patented the climber and started a company to sell it. Today, soldiers, firefighters, and rescue workers around the world use the team's climber to fly up buildings. Now, those are *real* superheroes.

Watch the DESIGN SQUAD Backyard Thrill Ride episode on PBS or online at pbs.org/designsquad.

Major funding for *Design Squad* is provided by the Corporation for Public Broadcasting and the Intel Foundation. Additional funding is provided by the National Council of Examiners for Engineering and Surveying, United Engineering Foundation (ASCE, ASME, AIChE, IEEE, AIME), Noyce Foundation, Northrop Grumman Foundation, the IEEE, and the Intel Corporation.

PADDLE POWER

The Challenge
Build a boat that paddles itself using a rubber band as its power source.

In this challenge, kids (1) follow the design process to make a boat out of cups; (2) design and build working paddles; (3) use rubber bands to store and release energy; and (4) figure out ways to attach their paddles to their boats.

1 **Introduce the challenge** (5 minutes)
Begin by looping a rubber band over your thumb and index finger. Slide a 1 x 2-inch piece of chipboard through the rubber band and wind it up. Let go so the chipboard spins. Begin by telling kids the challenge. Tell them that they'll be using this kind of rubber-band-powered paddle to drive a boat across a container of water. Then get them thinking about storing and releasing energy. Ask:

- Where was the energy stored that made the paddle spin? (*In the rubber band*)
- Tell kids that the term for stored energy is **potential energy**. Ask, "How can you increase a rubber band's potential energy?" (*Wind it up more.*)
- How can you tell when potential energy stored in the rubber band is being used? (*Something moves.*)
- Tell kids the term for motion energy is **kinetic energy**. Ask, "What are some examples of kinetic energy that occur when a paddleboat moves through the water?" (*The rubber band unwinds; the paddle spins; the boat moves; waves spread out*)

2 **Brainstorm and design** (10 minutes)
Show kids the materials and ask, "How can you use these materials to make a boat that paddles itself through the water using a rubber band as its power source?" After discussing their ideas, have them sketch their designs on a piece of paper or in their design notebooks.

3 **Build, test, evaluate, and redesign** (35 minutes)
Distribute the challenge sheet and have kids begin building. If any of the following issues come up, ask kids questions to get them thinking about how they might solve their problems.

- Kids are all doing the exact same design. *Suggest different boat designs, such as: (1) Seal a cup by putting tape over the opening and floating it on its side; (2) Cut a cup in half lengthwise and tape the halves together to form an open boat; (3) Tape several cups together to make a raft; and (4) Use the chipboard for the boat's bottom and sides.*
- Water leaks into the cup. *Seal openings with duct tape.*
- The paddles are hard to attach to the cup. *(1) Tape straws or wooden skewers along the sides of a cup (or poke them through the sides and bottom) so they stick out far enough to loop a rubber band over them. (2) Build a frame out of straws or wooden skewers and mount it between two cups. Attach the rubber band and paddle to this frame.*

DESIGN SQUAD

SHOW KIDS THE RELATED TV EPISODE

Photo: Parrish Kennington

In Paddle Power, kids figure out how to power a boat through the water. Show them the Aquatic Robotics episode in which *Design Squad* teams attempt to build a radio-controlled underwater robot. Get it online at pbs.org/designsquad.

A paddleboat moves when the rubber band's stored (***potential***) energy is converted into motion (***kinetic***) energy and spins the paddle.

Testing in a large container of water lets the boats paddle a good distance before hitting a side.

- The chipboard paddle warps when it gets wet. *Protect it by wrapping it in duct tape.*
- The paddle hits the frame that holds it. *Reposition the rubber band; widen or lengthen the frame; make the paddle smaller.*
- The frame holding the rubber band bends when the rubber band is wound tight. *Make sure the frame is securely taped to the cup. See if adding a crosspiece can help stiffen the frame. Also, move the rubber band toward the cup. The closer it is to the cup, the harder it will be to bend the frame. Finally, use wooden skewers. They're stronger than straws.*
- The boat tips and does not let the paddle hit the water properly. *Add weight to the boat to control its position. Tape a washer or two to the bottom of the hull. Weight used to keep a boat upright is called **ballast**.*

4 Discuss what happened (10 minutes)
Have kids talk about their designs and how they solved any problems that came up. Emphasize the key themes in this challenge—potential and kinetic energy—by asking questions such as:

- What are some examples of potential and kinetic energy in your paddleboat? (*An example of potential energy is the wound rubber band. Examples of kinetic energy include the things that moved, like the paddle, rubber band, boat, and water.*)
- How can you store a lot of energy in your boat? (*Wind up the rubber band tighter, or use more than one rubber band.*)
- What was the hardest problem to solve when building your boat? (*Answers will vary, but perfecting the paddles and attaching them to the cup is often quite challenging.*)

FOR EVENTS

- Draw kids into your area by asking, "How quickly can you get a boat to power itself through the water?"
- It's hard to make boats that float well with cups smaller than 8 ounces. If you want to give kids more design options, offer them two different-sized cups, such as 8- and 12-ounce cups.
- Test boats in large containers. Kiddie pools, underbed storage containers, or wallpaper trays offer kids longer, more satisfying travel times for their boats. In addition, even when a boat doesn't go straight, it can still go reasonably far before hitting a side.
- To avoid overcrowding, provide one kiddie pool per 20 participants expected, one underbed storage container per 10 kids expected, or one wallpaper tray per 4 kids expected. Since kids won't all be testing at once, these numbers will provide plenty of open water for testing.
- Large containers filled with water are heavy and awkward. Put the container where you want it on the floor of the testing area. Then use a bucket to fill and empty it.
- Have towels on hand to mop up spills.

To determine how many materials you'll need for different-sized events, for information on obtaining large quantities of materials, and for other general event tips, see page 7.

PADDLE POWER

DESIGN SQUAD

PBS

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YOUR CHALLENGE

Design and build a boat that paddles itself across a container of water using a rubber band as its power source.

BRAINSTORM & DESIGN

Look at your materials and think about the questions below. Then sketch your ideas on a piece of paper or in your design notebook.

1. How can you use these materials to make a boat that floats well?
2. How will you attach a rubber band and paddle to your boat?
3. How big a paddle do you need so that it reaches the water and drives the boat?
4. How will you make sure your boat doesn't sink, tip, or roll over?

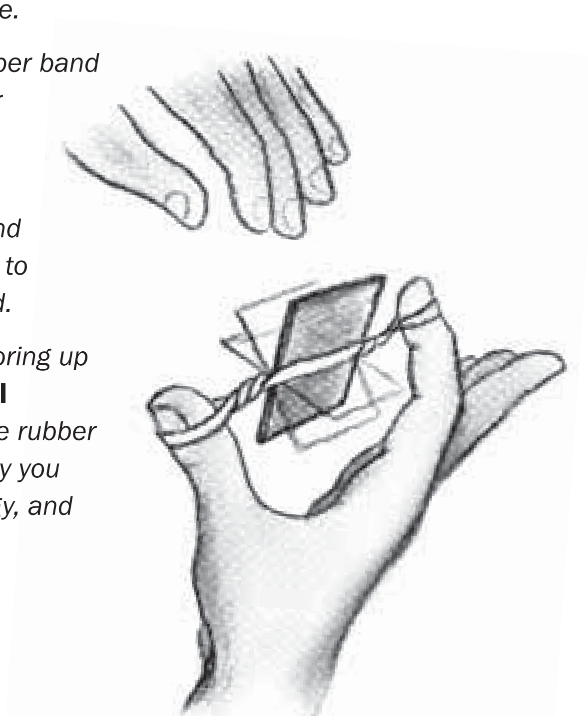
BUILD, TEST, EVALUATE & REDESIGN

Use the materials to build your paddleboat. Then test it by winding it up, putting it in the container of water, and releasing it. When you test, your design may not work as planned. The saying, "If at first you don't succeed, try, try again," is at the heart of the design process. Testing a design and then revising it based on what you've learned is a key to success. Study the problems and then redesign. For example, if your paddleboat:

- tips—*Add some weight to the bottom of the boat to help keep it upright.*
- has a warped paddle—*Think of some ways to waterproof the paddle.*
- has a paddle that hits the frame holding it—*See if moving the rubber band makes a difference. Also consider changing the size of the frame or the paddle.*
- has parts that bend when the rubber band is wound tight—*Make sure parts are taped on securely. Also, see if moving the rubber band makes a difference. The closer it is to the boat, the harder it will be to bend things. Finally, find ways to add support to any parts that bend.*
- doesn't make it across the container—*Experiment with ways of storing up more energy. Your boat moves by changing stored energy (***potential energy***) into motion energy (***kinetic energy***). The more you wind the rubber band (or the more rubber bands you use), the more potential energy you store. When you let go, this potential energy turns into kinetic energy, and the boat moves.*

MATERIALS (per person)

- chipboard (8 ½ x 11 sheet)
- wide container partially filled with water (e.g., kiddie pool, bathtub, underbed storage container, wallpaper tray)
- duct tape
- 2 paper cups (8 ounce or larger)
- 5 rubber bands
- scissors
- towels (paper or cloth)
- 4 straws
- washers (1-inch or larger)
- 4 wooden skewers



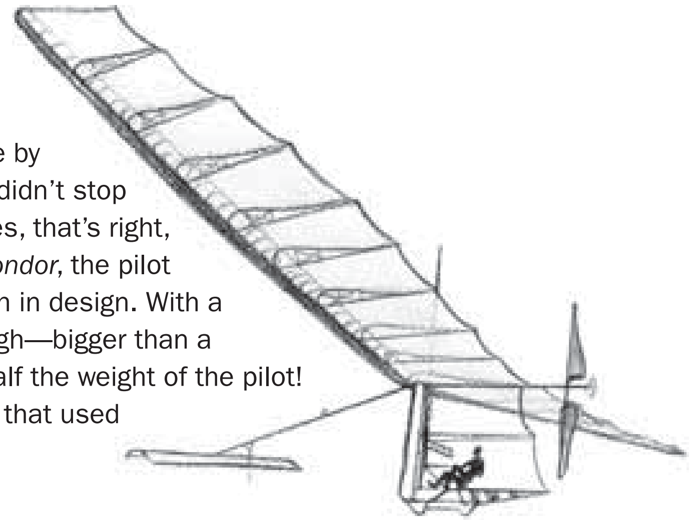
TAKE IT TO THE NEXT LEVEL

- Watch your fingers! Add an on-off switch so you can start and stop the paddle.
- Ready. Set. Go! Experiment with the paddle, the rubber band, or the boat's shape to increase its speed. Then race other paddleboats.
- Tugboat time! Carry or tow a Ping-Pong ball from one side of the container to the other.

MAKE IT ONLINE

Is that a bird or a plane? Build an airplane that flies by flapping its wings out of wood, wire, tissue paper, rubber bands, and glue. See how on Make Magazine's project page at makezine.com/designsquad.

ENGINEERING IN ACTION



Engineer Paul MacCready was always intrigued by the way birds soared through the air. As an adult, he brought his passion to life by building gliders that won contests and set records. His success didn't stop with gliders—he built the world's first human-powered aircraft. Yes, that's right, *human* powered! In one of MacCready's planes, the *Gossamer Condor*, the pilot pedaled a modified bike to spin a propeller. It was a breakthrough in design. With a wingspan of 96 feet, the *Condor* was 30 feet long and 18 feet high—bigger than a tractor-trailer truck. And it weighed only 70 pounds—less than half the weight of the pilot! MacCready made his planes light and strong with clever designs that used materials in new ways. His motto was "do more with less."

Look at the materials below. MacCready used all but one to build the Condor. Guess which one wasn't a part of his incredible flying machine?

A. Mylar® plastic (like in silver balloons)
B. Aluminum tubes
C. Bicycle parts
D. Cardboard
E. Titanium panels
F. Piano wire
G. Clear household tape
H. Styrofoam®

(Answer: E. Titanium panels. Even though titanium is a lightweight metal, it's still a lot heavier than Mylar®.)

Watch the DESIGN SQUAD Aquatic Robotics episode on PBS or online at pbs.org/designsquad.

Major funding for *Design Squad* is provided by the Corporation for Public Broadcasting and the Intel Foundation. Additional funding is provided by the National Council of Examiners for Engineering and Surveying, United Engineering Foundation (ASCE, ASME, AIChE, IEEE, AIME), Noyce Foundation, Northrop Grumman Foundation, the IEEE, and the Intel Corporation.

HELPING HAND

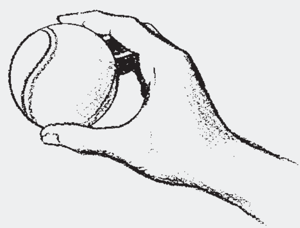
CHALLENGE 5
LEADER NOTES

The Challenge
Build a device that lets you grab different objects and drop them into a container that's at least two feet away.

In this challenge, kids (1) follow the design process to build a grabber that can reach at least two feet; (2) develop a way to open and close the grabber's jaw; and (3) figure out how to connect the "jaw" to a stick.

1 **Introduce the challenge** (5 minutes)
Begin by telling kids the challenge. Then get them thinking about what they need to do to make a squeezing motion. Ask:

- What's the difference between scooping and grabbing? (*When people scoop, they get a lot of something all at once and lift the items up as a group. When people grab, they get only one or two things at a time and handle them with more control.*)
- What kind of motion do you do to squeeze something? (*An opening and closing motion*)
- How does the design of your hand help you grip things? (*Your thumb and fingers give you two sides to put something in between. The muscles in your fingers can apply a pinching pressure.*)



- What other parts of the body can make a squeezing action? (*Jaw, arms, legs, elbows, feet, toes, tongue, lips, chin, eyelids*)
- What are some devices that people use to grasp things without actually touching them? (*Devices include: cooking tongs, chopsticks, hair clips, tweezers, a pooper scooper, pliers, binder clips, and a carpenter's vise*)
- What do all grabbing devices have in common? (*They all have two parts—or arms—that can go on each side of the item being grabbed. They also have a way to press these arms together to make a pinching motion. Some, like pliers and scissors, have a pivot connecting the two arms. The arms rotate [i.e., swivel or sweep] around the pivot.*)
- Tell kids that with each of these devices, the arms act as levers. A **lever** is a rigid bar that pivots around a fulcrum. In these devices, the **fulcrum** is the point around which the two arms swivel. Show kids a pair of pliers or scissors. Tell them that each blade is a lever arm and that the rivet holding the two blades together is the fulcrum.

2 **Brainstorm and design** (10 minutes)
Show kids the materials and ask, "How can you use these materials to build a device that lets you grab (not scoop) an object?" After discussing their ideas, have them sketch their designs on a piece of paper or in their design notebooks.

DESIGN SQUAD

SHOW KIDS THE RELATED TV EPISODE

Photo: Helen Tsai

In Helping Hand, kids figure out how to build a device to grab things. Show them the Water Dancing episode in which *Design Squad* teams compete to build swim fin prosthetics for a double-amputee dancer who performs underwater. Get it online at pbs.org/designsquad.

Photo: Natalie Hebshie

A grabber needs to have parts that can go on each side of an item and a way to pinch these parts together.

Photo: Natalie Hebshie

Engineers dream up creative, practical solutions and design and build things that change the world and make a difference.

Photo: Natalie Hebshie

Testing reveals things about a design and about the materials. Kids can use this information to improve a design.

3 **Build, test, evaluate, and redesign** (35 minutes)
Distribute the challenge sheet and have kids begin building. If any of the following issues come up, ask kids questions to get them thinking about how they might solve their problems.

- Jaws don't open or close. *Make sure kids have a way to both open and close the jaws. Sometimes they build one way but not the other. Next check that nothing is blocking the jaw's movement, that the two jaws can slide easily past each other, and that the jaws turn smoothly around the pivot.*
- Objects fall out of the jaw. *Check that the jaw closes firmly and completely enough to actually hold something. If the pressure is too gentle, brainstorm ways to strengthen it. Also see if the jaw's gripping surface can reliably hold on to things. If not, add cardboard to make it wider, sandpaper to increase the friction, or toothpicks to bite into an object.*
- The jaws bend, bow, or twist. *An opening-and-closing system using rubber bands and string can put a lot of stress on the jaws. Reinforce the jaws with something stiff, like extra cardboard or wooden skewers. Also, check if the jaws are longer than necessary. A jaw system with short arms is far less likely to bend than one with long arms.*
- The jaws don't work at the end of the stick. *Make sure the opening-and-closing system actually works. Sometimes a system looks good and works when a kid directly moves the parts but doesn't when there's no hand actually operating the parts at the end of the stick.*

4 **Discuss what happened** (10 minutes)
Have kids talk about their designs and how they solved any problems that came up. Emphasize key themes in this challenge—levers and mechanical squeezing systems—by asking questions such as:

- What are some situations where having a longer reach would be handy? (*When someone needs to get something that's out of reach*)
- Where can you find examples of levers in your grabbers? (*Many grabbers will have an arm or two that swings around a pivot. In these grabbers, each arm is a lever.*)
- What's an example of when you had to do something a few times to get the jaws to work the way you wanted? (*Answers will vary. But point out that engineers always revise their early ideas. It's part of the design-build-test process. Testing reveals things about a design and the materials. Engineers use that information to improve a design.*)

FOR EVENTS

This activity works best as a facilitated activity. We don't recommend using it at an event.

HELPING HAND

DESIGN SQUAD as built on TV
PBS
pbs.org/designsquad

YOUR CHALLENGE

Design and build a device that lets you grab different objects and drop them into a container that's at least two feet away from you.

BRAINSTORM & DESIGN

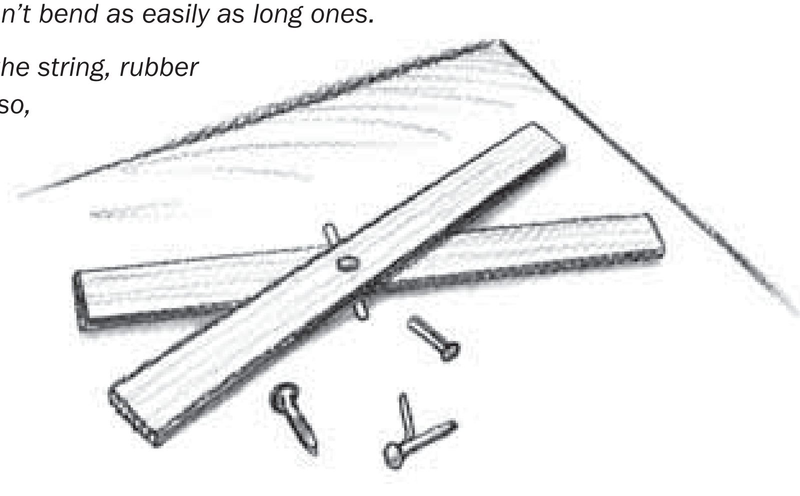
Look at your materials and think about the questions below. Then sketch your ideas on a piece of paper or in your design notebook.

1. Using these materials, what can you build to grab objects that are two feet away from you?
2. How will your grabbing device open and close so it can grip an object and let it go?
3. How will you attach your grabber to the end of the stick?
4. How will you control your grabber when it's at the end of the stick?

BUILD, TEST, EVALUATE & REDESIGN

Use the materials to build your grabber. Then test it by trying to pick up different objects. When you test, your design may not work as planned. When engineers solve a problem, their first solution is rarely their best. Instead, they try different ideas, learn from mistakes, and try again. Study the problems and then redesign. For example, if your grabber's jaws:

- have a weak grip—*Increase their force. Each arm of the jaw is a* **lever**—*a bar that pivots around a* **fulcrum***. In this case, the fulcrum is the brass fastener. Change the strength of your jaw's grip by adjusting the length of the arms and the fulcrum's position. (See illustration.)*
- keep dropping things—*Make sure that the jaws close enough to actually hold something. Also see if the jaw's gripping surface is big enough and shaped right to have a firm grip.*
- bend or twist—*Reinforce them with something stiff. Also, check if the jaw's arms are longer than necessary—short arms don't bend as easily as long ones.*
- don't work at the end of the stick—*Make sure the string, rubber bands, and moving parts aren't getting stuck. Also, move the jaws with your hands. If they don't work the way they should, readjust the parts.*



MATERIALS (per person)

- 4 brass fasteners
- corrugated cardboard
- hole punch
- objects to pick up (e.g., tennis balls, cotton balls, plastic soda bottles, and paper cups)
- 2 rubber bands
- sandpaper
- scissors
- string
- tape (duct or masking)
- 4 toothpicks
- 4 wooden skewers
- yardstick (or long paint stirrers for 5-gallon buckets, a thin wooden slat, or lath 2–3 feet long)

TAKE IT TO THE NEXT LEVEL

- Supersize me! Build a grabber that can pick up two objects at once.
- Smooth moves! Add a second motion to your grabber, such as making the stick that holds the jaws able to bend like an elbow or extend another two feet and then retract.

MAKE IT ONLINE

Blast me a marshmallow, would ya?

Build an air-powered marshmallow launcher out of plastic pipe and marshmallows. See how on Make Magazine's project page at makezine.com/designsquad.

ENGINEERING IN ACTION

There's something unique about four-year-old Michael—he has four hands! Born with six inches of his left arm missing, Michael wears a standard prosthetic (i.e., artificial) hand. It has some limitations—Michael can pick up and hold things but can't squeeze or press very hard. Michael's father wanted him to be able to do more with his prosthetic hand and have some fun in the process. With this in mind, he contacted engineers at the Open Prosthetics Project. Together, they built Michael two more hands—hands unlike any you've seen! One is a dinosaur puppet. Michael grips things by controlling its jaws. The other is a fishing rod. Michael uses it to catch fish as well as to reel in stray toys. Michael's father continues to think up and build more hands for Michael. "Once you have the training," he says, "you can conceive, design, and build whatever your imagination pictures."

Watch the DESIGN SQUAD Water Dancing episode on PBS or online at pbs.org/designsquad.

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Special thanks to the kids at the Jackson/Mann Community Center who tested the activities and gave them their stamp of approval (and made this sign and the paper tables that hold it).

Front cover photos: Anthony Tieuli, Lauren Feinberg
Back cover photos: Helen Tsai, Lauren Feinberg

WELCOME TO THE WORLD OF DESIGN SQUAD

WATCH TV

Competition plus engineering plus two teams of high school students equals fun! See it on PBS.

VISIT THE WEB SITE

Get episodes, games, cast information, show details, and much more. Visit pbs.org/designsquad.

DO CHALLENGES WITH KIDS

Bring engineering to life, engage a wide range of ages and ability levels, and use readily available materials. Download all the *Design Squad* challenges (in both English and Spanish) from pbs.org/designsquad/parentseducators.

HOST EVENTS

Take *Design Squad* to a museum, library, or mall and spark kids' interest in engineering with a lively, fun-filled event. Get the Event Guide at pbs.org/designsquad/parentseducators.

BECOME A PARTNER

Join our community of partners committed to fostering a positive image of engineering. Sign up at pbs.org/designsquad/engineers.

WATCH DESIGN SQUAD ON PBS

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