Challenge: Robots!

Educator Guide

Using Game-Play to Explore Robotics with Students in Grades 3-10

Contents

NATIONAL GEOGRAPHIC + LOCKHEED MARTIN
EITC Engineers in the Classroom

Published by The National Geographic Society
Gary E. Knell, President and CEO
John M. Fahey, Jr., Chairman
Melina Bellows, Chief Education Officer

Created by National Geographic Education and Children's Media

This educator guide was created as part of:

EITC Engineers in the Classroom

Engineers in the Classroom is a partnership of the following entities:

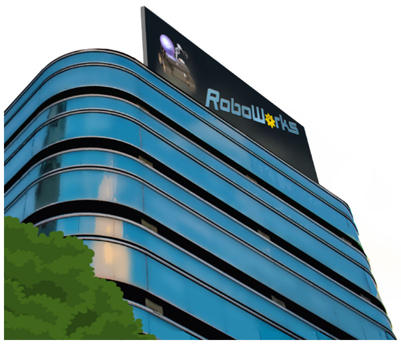
National Geographic + Lockheed Martin

Visit http://www.ClassroomEngineers.org/ to find the full collection of educational materials.

About Engineers in the Classroom

The resources on the Engineers in the Classroom website are the result of a partnership between Lockheed Martin and National Geographic. Lockheed Martin sends professional engineers into classrooms to speak to students about the importance of science, technology, engineering, and math (STEM) and STEM careers. The goal is to inspire and channel students into STEM and related careers. Visit www.ClassroomEngineers.org for more information about the program.

Introduction to the *Challenge: Robots!* Game



The purpose of this guide is to provide both formal and informal educators of students in Grades 3 to 10 with support and supplementary activities that will enrich students' experience with the web-based game *Challenge: Robots!* This game aligns with national standards in science, including the Next Generation Science Standards (NGSS) for engineering & technology, and Common Core State Standards (CCSS) for English Language Arts and Literacy (reading, writing, and speaking & listening).

Learning Objectives

Students will:

- encounter engineering concepts and apply them to a robotics challenge
- use 21st century skills of critical thinking and problem solving:
  - use critical thinking to reason effectively, using both inductive and deductive reasoning, as appropriate to the situation
  - use systems thinking to analyze how parts of a whole interact with each other to produce overall outcomes in complex systems
  - use problem solving to identify and ask significant questions that lead to better solutions

VISITING ENGINEERS

If you are visiting a classroom as part of the EITC program, be sure to provide the classroom teacher or facilitator with a copy of this guide. It contains many supplementary activities that can be used after your visit to extend the learning.

Game Overview

The goal of *Challenge: Robots!* is to expose students to exciting careers in engineering, focused specifically on the area of robotics. It is a browser-based game that challenges students to take on the role of an engineer at RoboWorks, a robotics factory. Students undergo orientation and training exercises in the form of fun, self-directed challenges. Through these engaging and fast-paced activities, students learn important concepts about the engineering process (a series of steps that engineering teams use to guide them as they solve problems), as well as the main parts of a robot, how those parts change with the problem the robot is intended to solve, and basic robotics programming. After the two-part orientation, three challenges are available, and players in the role of new RoboWorks engineers can explore them in any order. Each challenge focuses on designing a robot to solve a real-world problem—on land, sea, or in the air. These challenges are all based on real robots that are used today.

Game-Based Learning

Using interactive games to facilitate learning in educational settings has a number of recognized benefits. For most students, games are highly engaging and motivating. Games provide real-time feedback and built-in goals—such as "leveling up" or reaching a desired conclusion—that can motivate students to improve. The *Challenge: Robots!* game is a series of engaging educational challenges that encourage students to self-identify as engineers and practice the engineering process. The game is used as a springboard for inspiring a deep understanding about engineering concepts, with a specific focus on the field of robotics.

The use of portable technology like laptops and tablets in educational settings is a recent trend that is expected to grow, and a number of educational games, including *Challenge: Robots!,* can be played on both desktop computers and tablets. In fact, educational games that can be played on mobile devices like tablets benefit from the intuitive nature of these devices, which often makes it easier for students to start and play these games. This flexibility allows for game-based learning in schools, afterschool and informal settings, and at home.

Role of Facilitators

Challenge: Robots! is designed to be adaptable to both formal and informal learning spaces and can be used by classroom teachers, visiting engineers, and out-of-school educators. Facilitators may choose how they want to incorporate the game in their learning experiences, and the supplementary activities in this guide have been designed as suggestions of ways to enhance the learning about engineering careers and robotics. Feel free to pick and choose activities and use them in any order or method that works for your situation.

During game play, facilitators should walk around the room as students play and ask questions to target or expand student thinking and to help any students who may be struggling. Facilitators should also be prepared with additional activities and resources that students can explore if they complete the game-based activities before others. See the Supporting Game Play section of this guide for suggested questions to ask during game play and the For Further Exploration section for books and other activities to keep on hand for students who finish early.

In addition, although the After Game Play activity suggestions in this guide are grouped by grade band (elementary, middle, and high school), facilitators should review all of the activities to determine if an activity in a different band could be used or adapted for the abilities or needs of a specific group of students.

VISITING ENGINEERS

As a classroom visitor, you have the opportunity to inspire the next generation of engineers! Your goal is to encourage young people to consider careers in science, mathematics, engineering, and technology—STEM careers. Get students excited about engineering by sharing who you are, what you do, and why what you do makes a difference for yourself and the world. For tips and strategies to help you design your visit, check out the Engineer Guide, "Build the Future" video, and PowerPoint presentation all found under Explore More at: ClassroomEngineers.org.

VISITING ENGINEERS

Be sure to find out well before your visit about the technology available in the space in which you are visiting. Adapt your activities to accommodate any issues with the available technology, the strength of Internet connections to run several computers at once, and so on.

Background Information

Engineering

The importance of educating students about the field of engineering is more crucial today than ever before, because engineers play a part in all facets of society. Engineers design products, but they also design the machinery that makes those products. They design better ways to build and use technology. They design buildings, highways, and transit systems; snowboards, robots, and running shoes. Engineers are vital to the fields of health care, energy, technology, space exploration, financial systems, ecology, the food industry . . . the list goes on. In fact, it would be difficult to name an endeavor that doesn't require engineering skills, because engineers focus on problem solving, designing solutions, and making things work more effectively. Engineers use the theories and principles of science and mathematics to link society's needs to the commercial applications that meet those needs.

The academic disciplines of science, technology, engineering, and mathematics are so deeply intertwined that they are often discussed together, referred to simply by the acronym STEM. Engineering careers require a grounding in all four subject areas. *Challenge: Robots!*, while highlighting engineering skills and careers, integrates all four subjects, from identifying the science-based problem, to designing a technical (robotic) solution, to the mathematics involved in programming the robots to complete their tasks. It is important to teach the skills of engineering to all students, not only because engineering careers span every walk of life, but because the subject covers so many important 21st century skills, including creativity and innovation, critical thinking and problem solving, and communication and collaboration. The activities within this guide were designed with these 21st century skills in mind, with the added bonus that they give students the chance to use their own creativity to create something real.

A grounding in engineering requires students to learn systemic practices for solving problems. The *Challenge: Robots!* game keeps the six steps of the engineering process* at the forefront throughout the orientation and challenges.

Although the steps are written in simple language for the sake of brevity, students learn more about each step through game play, discussions, and supplementary activities. They practice defining the problem by learning how to ask questions. They develop skills in researching a problem before working on a solution. During the "plan" stage they create prototypes, and at the testing step, students learn the importance of iteration—in engineering, there is no such thing as failure; improvement is built into the last step of the process. And finally, students understand that the engineering process steps are cyclical. This cycle of steps/activities should be repeated again and again until everyone is satisfied with the solution.

1. Define the problem you wish to solve.
2. Learn all you can about the topic.
3. Plan how you will solve the problem.
4. Build your solution.
5. Test how well your soultion did.
6. Iterate a plan to improve it.

*Note that the engineering process is not a hard and fast list of steps. There are many variations of the model, using different verbs. However, the process remains the same and is similar to the process shown here.

Engineering Careers

Despite several national initiatives to diversify participation in STEM fields, and some growth in the numbers in the past few years, only 20 percent of engineering school students receiving bachelors degrees in 2012 were women. Even today, many girls think certain jobs, like engineering, are more suited to boys. With this guide, we not only hope to counteract this attitude, but the careers activities found in each grade band of this guide are designed to encourage more students—both boys and girls—to explore the exciting opportunities available in this field.

According to Dr. Debbie Chachra, Ph.D., a faculty member at the Olin College of Engineering, there is significant research that shows that most current engineers had the following three advantages: someone who exposed them to engineering, at least one role model, and social support. The purpose of *Challenge: Robots!*, as well as the other games in this series (see *Challenge: Asteroids!* and *Challenge: Extreme Weather!*) is to provide that exposure.

Another way to expose students to engineering role models is to have them listen to male and female engineers talk about their jobs and why they love them. Facilitators can show some of the powerful interviews with engineers found at the NatGeoEd.org website. Look for them in the "Cool Scientists" section of this web page: NatGeoEd.org/mysteries/.

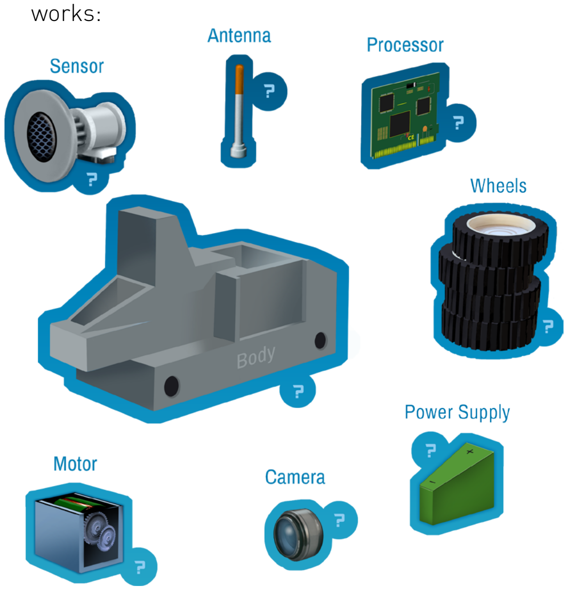
VISITING ENGINEERS

Exposure is why it's so important to take the time to tell students about what you do as an engineer AND how you got interested in engineering as a career.

Robotics

A robot is a programmable machine designed to sense, analyze data, and respond as programmed, and it may take the place of humans in dangerous environments, locations where humans cannot go, or in manufacturing processes. The field of robotics has been growing substantially since the 20th century and spans a range of fields, including both engineering and computer science.

To understand how robots function, *Challenge: Robots!* introduces students to some basic parts every robot needs, such as motors and controllers, and includes three types of parts whose variety can drastically change how the robot operates and works:



- **Sensors:** Robots can not only see, smell, and hear, but with different sensors can sense other things in the environment, often better than humans.
- **Mobility options:** Most robots move, whether they rotate in place, travel across a floor, fly, or swim. They can be fitted with wheels, propellers, wings, fins, and other options to maximize efficient movement.

VISITING ENGINEERS

If you have any career experience in robotics, be sure to tell students what you've done and what you know about the field of robotics. Whenever possible, make connections between your experiences and ones they are able to easily relate to.

- **End effectors:** Robots can utilize a variety of tools designed to perform a task, like wrenches, drills, nets, and magnets. Matching the correct tool to the job is important to a robot's success.

In *Challenge: Robots!* students are introduced to three different types of robots that are currently in use in the real world:

- **Micro-robots** are miniaturized versions with tiny, sophisticated parts. Insects are often used as robotic models, and the flying robots explored in the Robotic Bees game challenge imitate honeybees as one of a fleet of identical units controlled by a single controller. Students learn how these bees could be used to pollinate a field of crops.
- **Underwater robots** can perform tasks and record data that would be difficult for humans to perform or gather. In the Ocean Cleanup game challenge, students learn about robots that are being designed to clean up the Great Pacific Garbage Patch, a massive collection of marine debris in the North Pacific Ocean. Those robots not only require ways to swim underwater, but need a method of gathering trash that is mainly microscopic in size. And they must be deployed in linked patterns to be most effective.
- **Land-based robots** can explore spaces and perform tasks that would be difficult for humans. In the Tunnel Explorer game challenge, students need to locate and safely remove treasures buried in an Egyptian pyramid, where tunnels are either collapsed or filled with obstacles. They learn about robots that can traverse a variety of dark and hazardous terrains, but also locate and safely transport delicate objects in an obstacle-filled area.

How This Guide Is Organized

This guide is divided into three main sections to support the game *Challenge: Robots*!: before, during, and after game play. The first section provides information to help you prepare for the game, pre-game activities, and ideas to support game play. The second section includes tips for monitoring game play and prompts for supporting students as they play. The third section contains post-game discussions and activities. Those classroom activities are divided into three grade bands: elementary, middle, and high school. In addition, this section contains optional activities for wrap up and further exploration of the three real-world problems. The appendix contains a glossary of terms used in both the game and this guide.

Preparation

The following are a few things to gather or prepare before beginning the *Challenge: Robots!* experience.

Technology Requirements and Set Up

Challenge: Robots! is a browser-based game that works on both Macs and PCs and also on tablets. To get the most out of the game experience, we recommend that you have the following technology:

- On a PC: Windows 7 or 8 operating system; Chrome 39.0+, Firefox 34+, or Internet Explorer 9+ browser
- On a Mac: OSX v. 10.6+ operating system; Chrome 39.0+, Firefox 34+, or Safari 7+ browser
- On Tablets: iOS version 8 and one generation back or Android 4.1+ operating system
- Multiple computers or tablets with Internet access (one per student preferred); Internet browsers, open to the *Challenge: Robots!* game **(www.NatGeoEd.org/robots-challenge/)**
- A single computer or tablet with Internet access, attached to a projector, Internet browser open to **NatGeoEd.org/robots-challenge/**

Ideally, you will be able to have one student per computer, but you might want to test your school or organization's Internet bandwidth to ensure that it can handle multiple students playing the game on the Internet at the same time. If you don't have enough computers to go around, consider mixed-ability pairs, allowing students with special needs the support of their peers.

> **VISITING ENGINEERS**
> Scan the glossary in the appendix for engineering terms or concepts you may want to focus on, reinforce, or elaborate upon in your discussions with students. Hearing you use vocabulary terms as you describe your own experiences will help them to understand and retain that vocabulary.

Materials to Gather

Many of the activities in the After Game Play section require facilitators to gather recyclables, craft materials, and even discarded mechanical and radio-control toys. On the next page is a list of materials organized by grade band. Note that the first item in each list is a commercial kit. Other items are easily accessible or recyclable, but two of the high school activities require students to tear apart and reuse ("hack") old mechanical toys (like push cars), household gadgets (like alarm clocks and can openers), and tools (like rotary drills). Consider holding a used toy and gadget drive several weeks before using the game, asking for donations from families, or looking for inexpensive items at flea markets and yard sales. Review the activities for more details and to see how the materials will be used.

All Grades

- Unlined paper
- Coloring tools such as markers, crayons, and paints
- Recycled cardboard of all weights and dimensions, including boxes
- Scissors, box cutters (if age-appropriate)
- A variety of tapes and glues
- Old magazines and toy catalogs

Elementary School

Create Engineer Journals

- Heavy paper for creating journal covers (one sheet per student)

Design Working Robots with littleBits

- *littleBits* commercial circuitry kits for children (http://littlebits.cc/)

Simple Machines Flyswatter Game

- Two unused flyswatters
- Blocks of varying shapes
- Recycled toy wheels of different sizes
- String

Middle School

Create Engineer Journals

- Individual notebooks

Design Working Robots with Thames & Kosmos RC Machines Kits

- *Thames & Kosmos Remote Controlled Machines Kits* (http://shop.nationalgeographic.com/ngs/browse/productDetail.jsp?productId=2000078)
- Video camera or cell phone with video capabilities

Design Playground Equipment

- Old toys or construction kit parts

High School

Create Engineer Journals

- Individual notebooks

Robot Hackathon

- Basic tools (hammers, screwdrivers, saws, scissors, extra screws, nuts and bolts, and so on)
- Discarded non-mechanical toys that can be taken apart for parts

Design Working Robots with Lego Mindstorms

- *Lego MindStorms* (http://www.lego.com/en-us/mindstorms/)

Build a Better ________

Discarded radio-control toys of any type (vehicles, robots)

- Discarded mechanical tools, kitchen gadgets, and toys (for example, wind-up toys and clocks, push toys, mechanical can openers, and so on)
- Discarded non-mechanical toys that can be taken apart for parts
- Basic tools (hammers, screwdrivers, saws, scissors, extra screws, nuts and bolts, and so on)

Handouts and Bulletin Boards to Prepare Ahead of Time

- Project the image of the Engineering Process, provided at www.NatGeoEd.org/robots-challenge-educator-guide/.
- Designate space for an interactive bulletin board related to the parts of a robot. Divide the board space into at least three sections, labeling each SENSORS, MOBILITY TYPES, and END EFFECTORS. Leave the board as it is until students have completed the online game. Then assign them the task of searching magazines and the Internet for images of these different types of robot parts. Have students print or cut out these pictures and staple them to the bulletin board to show the range of possibilities that make robots so varied.
- Find and review images found online related to the three real-world challenges students can explore in the game: Colony Collapse Disorder, The Great Pacific Garbage Patch, and Egyptian Archaeology Challenges.

- Find photographs of items designed by engineers, either in hard copy or online images you can project. Note that the Engineers in the Classroom website offers a PowerPoint presentation of the work that engineers do. Find it at: http://www.classroomengineers.org/education/media/powerpoint-presentation/. Look for items that span different fields of engineering, for example:
    - aerospace engineers: space shuttles, airplanes, helicopters
    - civil engineers: highways, bridges
    - mechanical engineers: robots
    - electrical and electronics engineers: broadcast systems, lighting fixtures
    - biomechanical engineers: artificial limbs, running shoes, child safety seats
- For all grades, duplicate the 1-page ***Challenge: Robots!* Take-Home Sheet**, found on page 34. This can be sent home with students after they have played *Challenge: Robots!* in the classroom. The sheet provides information for parents and caregivers on how to find the game and support additional game-play at home.
- For Grades 2-3, consider duplicating the **Engineer Journal** cover found on page 30, one per student, on heavy paper.

At **RoboWorks,** we love making different kinds of robots. Our customers ask us to build robots for them that solve real-world problems.

VISITING ENGINEERS

To help students understand the variety of items designed by engineers, share the EITC PowerPoint presentation, found at: http://www.classroomengineers.org/education/media/powerpoint-presentation/.

- For elementary grades, print and cut apart the **Engineering Design Problems Cards**, found on page 31. Consider printing them on cardstock or heavy paper and laminating them.
- For high school, duplicate the **Robot Hackathon Design Sheet** found on page 33, one for each team of students.

Before Game Play

Before beginning the activities in this guide, take a few moments to learn what your students already know about engineers and robots and to activate that prior knowledge.

Activate Prior Knowledge

For All Grades

Create a list of statements about engineers and robots on the board or chart paper. Make sure the list is a mixture of facts, such as those listed in the Fast Facts sidebar on page 10, as well as some misleading or outright false statements. (Ask older students to come up with their own statements about the fields of engineering and robotics from their experiences or prior knowledge.)

VISITING ENGINEERS

After students have completed the written portion of this prior knowledge activity and it's been collected, consider conducting a brief "vote" in the class. Read each statement and have students line up on opposite sides of the room according to whether they vote true or false. Discuss (or have older students informally debate) each item.

Grades 3–6

- Read each statement aloud. Ask students to vote on whether it is true or not true (or if they don't know). Have students write their answers on a numbered list for you to collect.
- Save the team votes or individual lists for a later activity when you have completed all of the activities you select from this guide. For example, you might repeat the activity and then show students the changes in their answers, debriefing on why they changed.

Grades 7 and above

- Follow the same procedure as for younger students, but include more complex facts about potential careers in engineering and the steps of the engineering process, as well as more complex facts about robotics (such as whether robots are threatening American jobs).
- Download and duplicate the three-column chart from NatGeoEd.org/three-column-chart. Have students label the three columns "Fact," "Fiction," and "Unsure."
- Using the list of accurate, misleading, and false facts, have students write each statement below the category in which they think it belongs. Discuss their decisions, inviting students to debate whether a statement was classified correctly as fact or fiction.
- Collect the papers to use as a later activity when you have completed the activities you select from this guide. Consider using the same list of statements in a written test format to pass out when you have completed all selected activities. After grading the tests, return their original three-column charts to allow students to compare their answers before and after playing the game. Have each student write an essay on how and why their ideas about engineering and robotics changed.

Create Engineer Journals
(Grades 3-5)

To help structure the learning during the *Challenge: Robots!* game and your classroom activities, as well as to create a keepsake for students to remember the experience, have students create "Engineer Journals" to hold their notes, sketches, and ideas about the activities they complete in the game and in classroom activities. NOTE: Students in middle- to high-school can use a regular, spiral-bound notebook to take notes and create their drafts of activities.

Fast Facts

Engineers

- The Ferris Wheel is named after the American engineer who created it.
- Emily Roebling, known as the "first woman field engineer," supervised construction of the Brooklyn Bridge.
- The word *engineer* comes from Latin words meaning "design" or "devise."
- There are more than 2 million engineers in the United States.
- History's first known engineer was Imhotep, who designed the Step Pyramid in Egypt in 2250 BCE.

Robots

- Robots in some cases have replaced people performing repetitive jobs, like riveting parts together on assembly lines.
- Robots can replace people doing dangerous jobs, such as bomb disposal.
- Robots can play complex games, such as chess, better than human beings.
- The word "robot" was first used in a 1920 play and comes from the Slavic word *robota*, meaning "slavery."
- History's first robot was a mechanical bird, built in the fifth century BCE by a friend of Plato.

VISITING ENGINEERS
Although this activity won't work for your single classroom visit, be sure to share the idea with the facilitator!

Create Your Own Journal

1. First, show students images to illustrate that not all robots are alike. Use pictures from books or project images from the web.

2. Distribute one sheet of 8.5" x 11" heavy paper to each student and have them fold it in half for the cover of the journal. For younger students consider printing the Engineer Journal cover, found on page 30, on heavy paper. It provides a title and a ready-to-color robot outline. Older students should use their creativity to design a cover.

3. Have students add their names to the cover of their journals.

4. Distribute 4-5 sheets of unlined paper to each student. Have them fold the sheets in half and insert them into the cover. Staple the booklets together, and, beginning on the first right-hand inner page, have them number the pages of the journal. This will provide a 16- to 20-page booklet to hold engineering notes and sketches.

Ideas for Using the Journals

Look for references to this Engineer Journal in activities throughout this guide. You may also:

- Designate one page toward the back of the journal for students to record new terms and their definitions (see the Glossary in this guide for selected terms and definitions).
- Reserve the inside cover of the journal as the place to tape or staple a copy of students' RoboWorks ID Cards (earned during the Orientation level in *Challenge: Robots!*).
- Title one of the first pages in the book "Why Engineers Use Journals." Discuss the importance of note-taking to all STEM careers such as engineering. Ask students to suggest some reasons for using notebooks like this. Encourage students to consider reasons such as:
    - using the journal as a memory jogger;
    - ensuring that all steps in the engineering process are followed;
    - learning from past mistakes and recording new information from iteration;
    - documenting critical thinking and decision making, to record why one decision won out over another; and
    - creating a historical reference for future engineers to learn from your experiences.
- Have students use the journal for making notes and sketches during the PLAN step of their challenges throughout the activities.
- Reduce and reproduce handouts of your own design (or from the National Geographic website, found in the For Further Exploration section) that go with an activity or discussion, and paste or staple them directly into the booklets.
- Consider collecting the journals or notebooks periodically to review students' work or to ensure the journals aren't lost before the experience is over.

During Game Play

VISITING ENGINEERS

If you are an engineer visiting the classroom, go to the Engineer Guide at ClassroomEngineers.org for more ideas on how to start the session. You may also wish to watch the "Strategies for a Successful Classroom Visit" video, which features two seasoned Engineers in the Classroom volunteers talking about what it takes to have a successful classroom visit experience.

Introduce Engineering

- Pass around or project the engineering items that you collected ahead of time and ask students if they know what type of worker designed them. If they guess engineers, ask if they know what kind of engineers.
- Explain that the field of engineering includes a wide range of career choices. Work with students to name some of the engineering careers that go with the images.

VISITING ENGINEERS

If you haven't already viewed it, the intro video "Build the Future," found at the EITC website (ClassroomEngineers.org) would be useful to show at this time.

Introduce *Challenge: Robots!*

Explain that the purpose of the game students will play is to show one field of engineering: mechanical engineering. Students will take the information and skills they learn in the game to help them complete their own robot projects. Project the title and first screen of the game, and explain that this company, RoboWorks, is looking for new engineers to hire. RoboWorks gives all prospective employees some basic training in engineering and robotics to see if they have what it takes to design solutions for solving global problems.

Use the following to provide overviews of each of the parts of the game:

Orientation

- In this first part of the orientation, new employees are introduced to the engineering process. Direct students' attention to the projected image of the engineering process, provided at www.NatGeoEd.org/robots-challenge-educator-guide/. The steps of this process are important to every job an engineer takes on, and are repeated in a cycle over and over until a successful solution, like a robot, has been created.
- Have students copy the six steps of the process in their Engineer Journals. Then have them write the following sentence, which can be used as a mnemonic device to remember the steps: **Daring Lady Pirates Blasted Treasure Island.** Ask students to create a drawing of the sentence to illustrate its meaning.
- At the end of the orientation, students will receive RoboWorks ID cards. Make arrangements for students to print and cut them out. Consider posting all the cards on a wall of RoboWorks employees or tape/staple the cards to the inside cover of their Engineer Journals.

Build a Robot

- This second part of the orientation focuses on the parts of robots as well as giving an introduction to programming. Students will see some robotic parts they've heard of before, but likely a few new terms as well. Point out the bulletin board you prepared earlier. Explain that students should look for images of different sensors, mobility types, and end effectors to add to the bulletin board once they've played the game and know what types of parts are possible. Note that the After Game Play classroom activities include additional explorations on programming robots.

Choose a Challenge

- Players have the opportunity to select a global challenge that real engineers are working on today. They may pick any challenge, in any order. If time is important, limit players to just one challenge in their first time playing the game. They can return and complete any or all of the challenges as often as they like. Before the game begins, introduce the types of real-world engineering problems and provide background on the challenges found in *Challenge: Robots!* using the information on pages 14-15 of this guide.

Review Real-World Problems That Appear in the Game

Ask: *What are some problems in our community, state, nation, or the world?* Capture students' ideas on the board. Then have students discuss what they know about three things that people around the world are worrying about right now:

Colony Collapse Disorder
(from the Robotic Bees game challenge)

What Is It?

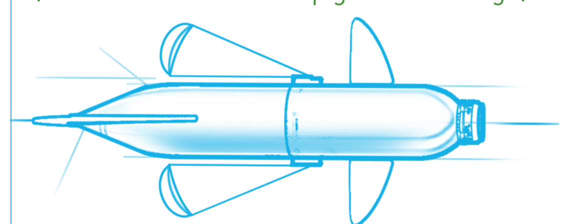
Honeybees are responsible for pollinating flowering plants. While they travel from plant to plant in search of nectar for their honey-making operations, pollen from the plants' anthers rubs off on the hairy bodies and legs of the bees. Then the bees travel to other plants, where the pollen attaches itself to the stigma of the new plant. This helps plants reproduce.

But in some places, the worker bees have begun to mysteriously disappear. Scientists don't yet know what happens to them, but some suspect that pesticides are interfering with bees' natural instincts.

Who Worries About It?

This problem doesn't only worry beekeepers and honey producers. Because the adult worker bees are not around to search for nectar, plants like flowers, fruits, and vegetables are left without a way to pollinate. This is a big problem for agriculture.

The Great Pacific Garbage Patch
(from the Ocean Cleanup game challenge)



What Is It?

The Great Pacific Garbage Patch is a massive collection of marine debris in the North Pacific Ocean that is larger than the state of Texas. It floats and spins around, moving with the currents away from any particular nation. The only time trash leaves the patch is when it sinks or is flushed out by a big storm and washes ashore hundreds of miles away.

Who Worries About It?

Everyone who cares about the environment worries about this giant problem. The ocean is a complicated ecosystem where billions of organisms live in natural balance. Plants like algae, plankton, and seaweed make up the beginning of the food chain. The plastics in the

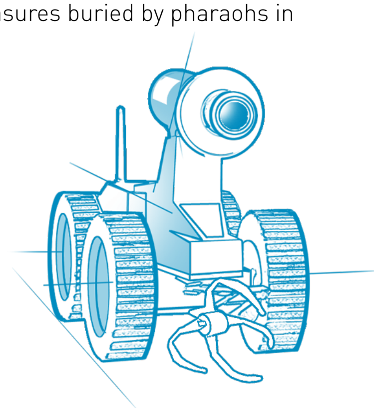
Patch are harmful to these small organisms, but also to larger animals and fish who try to eat them.

Unfortunately, no country wants to be responsible for cleaning up the Great Pacific Garbage Patch. Why? Because cleaning up the mess would bankrupt any single nation. And it has been estimated that it would take 67 ships one whole year to clean up less than one percent of the North Pacific Ocean.

Egyptian Archaeology Challenges
(from the Tunnel Explorer game challenge)

What Is It?

Archaeology sounds like a glamorous job searching for treasures buried by pharaohs in ancient times, doesn't it? But even the most exciting career has its problems, and excavating pyramids and tombs can be very dangerous for human beings. Take, for example, the exciting discovery of a causeway attached to the Great Pyramid, for which archaeologists have been searching for many years.



Who Worries About It?

Archaeologists are naturally eager to start exploring this causeway. It's supposed to be decorated in fine reliefs, and there might be other amazing artifacts inside. But the causeway has been buried under desert sands for thousands of years, and parts of it are collapsed and unstable. Ancient tunnels could also be filled with bacteria, mold, and other hazards. People working at excavation sites are constantly in danger.

Explain to students that they will play *Challenge: Robots!* to see how people are already exploring ways to fix or solve these three problems.

VISITING ENGINEERS

If you have time, you may want to watch students as they engage in the game play. Ask students what they're doing, and share how engineers work through that step of the engineering process. Be ready to answer questions students may ask you, now that they have your personal attention.

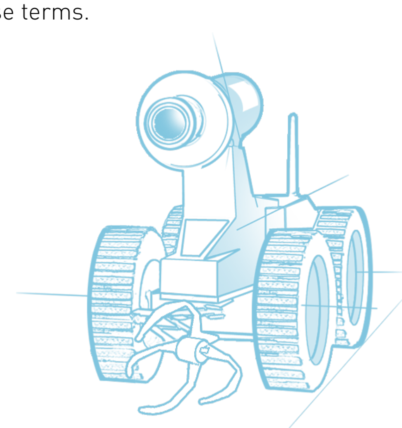
Supporting Game Play

Encourage students to keep their Engineer Journals nearby as they play *Challenge: Robots!*, adding any unfamiliar terms to their glossaries in the back to look up later, taking notes, and sketching things they find interesting.

While they play, move around the room monitoring game play, and stop occasionally to chat with students about what is happening in the game. Use the following prompts to keep the attention on learning:

- *What are you doing right now?*
- *What step of the engineering process are you working on?*
- *Tell me about the robot that you are exploring. How is it different from other robots? Why does it need to be different?*
- *If you were the engineer designing a solution for this problem, would you have tried something different? Explain.*

Be prepared to help students with terms they may not know, especially when they are selecting parts for the robots they build in the game. See the Glossary on page 26 for help defining some of these terms.



After Game Play

Debrief the Game

When all students have completed the game, or when you decide to stop game play for the day, use the following prompts to debrief the experiences. The questions are organized by game section, but can be asked in any order.

Orientation

Ask:

- *What are the steps of the engineering process?*
- *Why are those steps in that order so important to good design?*
- *What is iteration? What is its value?*
- *Why is it not only okay but a necessary part of the engineering process to fail, make mistakes, and try again?*

Build a Robot

Consider bringing in a familiar robot to use as a concrete example. For example, you may have access to a robotic toy or a robotic vacuum cleaner. Ask students to identify the parts and discuss how they compare to the MessageBot in the game.

Ask:

- *What problem or task was this robot designed for?*
- *What type of sensor does this robot need?*
- *How does this robot move? What does it use for this movement?*
- *What type of end effector(s) does this robot use to perform its task?*
- *How would this robot perform differently if any of those parts were changed to a different one?*

Use this discussion as a springboard to the bulletin board activity that was set up previously.

Choose a Challenge

Ask:

- *Which robot challenge did you select?*
- *Why did you select this particular robot challenge?* (Note: As students share their choices, draw out in the discussion the wide range of career possibilities that are found in the field of engineering. Explain that choosing a career that aligns with a personal interest or passion will make for a rewarding and fun career.)
- *What was the problem that you as the engineer had to solve?*
- *What were some of the unique aspects of that problem that you had to consider in your design?*
- *Engineers must make decisions that affect the final product. Each decision comes with what are often called design tradeoffs—like choosing between power and the final weight of the design.*
    - *What were some design tradeoffs you made during the challenge?*
    - *How did those decisions affect your robot's functionality?*

- *Were you successful in designing a robot to solve the challenge? How much iteration did it take before you succeeded?*

Write the word *programming* on the board or chart paper and work together as a class to develop a definition of the term, such as "to design a sequence of instructions for a robot's controller, programming a series of actions it will take to complete a task." Ask: *Which activities in* Challenge: Robots! *required you to program the robot to perform a task?* (Build a Robot, Tunnel Explorer)

VISITING ENGINEERS

Before you leave the classroom, take a few moments to talk about careers one more time. Share some tips about the types of school subjects, classes, or programs students should focus on if the field of engineering is something they may be interested in. Remind them that there are a lot of different types of careers in the STEM fields, too.

Before Using the Activities

The activities in this guide are designed to work as stand-alone activities and can be done in any order. There are four activity suggestions for each grade band:

- engineering robots;
- creating working robots with commercial kits;
- engineering without robots; and
- engineering careers.

VISITING ENGINEERS

Although you won't have time to oversee these activities in your one-class visit, consider revisiting the classroom later to see some of the products students create. Before you leave, be sure the facilitator has this guide and direct him or her to these suggested activities.

Many of the activities require dividing students into teams. In engineering, the ability to participate in teams is very important: it allows individual engineers to share their expertise and experiences, develop new perspectives, and rely on one another's skills and strengths. Be sure to stress the importance of teamwork whenever you have students working together. Consider creating mixed-ability teams to ensure that students with learning or language needs have the assistance of peers, but make sure everyone has the opportunity to contribute to the final products.

Engineering Activities: Elementary School

Activity 1: Engineering Robots—Programming and Coding

Remind students that in some of the activities in *Challenge: Robots!* they had to program a robot to perform specific actions (Build a Robot and Tunnel Explorer). Discuss the types of programming they had to do. Explain that the ability to program well is an important part of robotics design, and the robotics firm RoboWorks needs to hire teams of people who can program robots. NGSS: 3-5-ETS1-1; 3-5-ETS1-2; 3-5-ETS1-3; NSES: 4.E-2a; 4.E-2b; 4.E-2c; 4.E-2d; 4.E-2e; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d; 8.E-2e; CCSS.ELA-LITERACY: CCRA.SL.1

1. Choose a volunteer from the class to act as the robot.
2. Divide the remainder of the class into small teams of 3-5. Explain that in this activity they will demonstrate their ability to work together cooperatively, and that every team member must contribute to the final product.
3. Point to your robot and explain that this is a walking robot that was designed and built by RoboWorks engineers. The robot will begin its task from the spot where it is standing now, and has ONLY the following movements available (ask the robot volunteer to demonstrate each movement as you read and describe each.) List the words in bold in capital letters on the board:
   - **WALK** in a straight line, one step at a time (no diagonals or curves).
   - **WALK** forward, but not backward.
   - **TURN RIGHT** or **TURN LEFT** (90 degree turns) in one step.

- **BEND** forward.
- **PICK UP** an object directly in front of it.
- **DROP** an object directly in front of it.
- **LIFT** an object and **WAVE** it from side to side.

4. Each team's "job interview" is to program this robot to complete the task in as few steps as possible. All teams who are successful in programming the robot will pass, but the team or teams who use the fewest number of steps will be hired.
5. Choose a task from this list (or create your own) and write it on the board:
   - Pick up a_______ from the floor.
   - Collect trash from the floor and throw it away.
   - Pick up a _______ from _______ and give it to the teacher.
   - Pick up an eraser and clean the board.
6. Give teams 10-15 minutes to program a list of movements (using the command terms on the board) that the robot must perform to complete the task. Monitor the teams' work to ensure that all members are working together, cooperating, and sharing expertise. For example, a challenge card might be to build a robot that can collect trash. The team writes a series of commands in step-by-step manner: WALK WALK (i.e., forward two steps). TURN RIGHT. WALK, WALK, WALK. TURN LEFT. BEND. PICK UP. And so on.

Optional While the teams are working on their programming steps, allow the robot volunteer to create a costume with craft materials like cardboard boxes, poster board, and other materials.

7. Ask a student from each team to stand and read aloud the steps one-by-one. The robot is to follow the steps exactly (i.e., on the word "walk," take exactly one step). Warn readers that they cannot adjust their written steps if they see that their instructions aren't working.
8. If at the end the task is completed successfully, that team moves up to the finalist stage. When all teams have completed the task, count the steps to see which team used the fewest steps. Those teams are the new RoboWorks programmers.

Design Working Robots with littleBits©

LittleBits is a commercial kit for teaching about circuitry. The kit is composed of assorted parts that attach by magnets to create electronic circuits. The parts are easy to use and even very young children can create successful projects that include movement, sound, and light. In every kit there are simple instructions for creating a variety of projects, from flashlights to windmills to vehicles. NGSS: 3-5-ETS1-1; 3-5-ETS1-2; 3-5-ETS1-3; NSES: 4.E-2a; 4.E-2b; 4.E-2c; 4.E-2d; 4.E-2e; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d; 8.E-2e; CCSS.ELA-LITERACY: CCRA.SL.1

1. Have students, working independently or in teams (depending on your class size), create a littleBits ArtBot. This simple robot spins in a circle, holding a crayon or marker against a sheet of paper to create spiraling designs. (You can find instructions in the instruction booklet or online at the littleBits website: http://littlebits.cc/projects/art-bot--2.)
2. Ask teams to combine their robots, working together to create designs with different colors and spiral sizes. Ask:
   - *What is the end effector on your ArtBot?*
   - *What is your mobility option? How does it work to create a design?*
   - *Why might two ArtBots created from the same parts in the same way make slightly different-sized circles?*

Optional If time allows, challenge teams to design and build a different robot that will perform a task or solve a problem. Provide additional craft or recycled materials for teams to use in their designs.

Activity 3: Engineering Without Robots—Simple Machine Flyswatter Game

Write the names of simple machines on the board: *lever, inclined plane, wedge, pulley, wheel-and-axle,* and *screw*. Discuss the unique features of each simple machine and what it does and explain that engineers use these simple machines to solve a variety of problems. NGSS: 3-5-ETS1-1; 3-5-ETS1-2; NGSS: MS-ETS1-1; NSES: 4.E-2a; 4.E-2b; NSES: 8.E-2a; 8.E-2b; CCSS.ELA-LITERACY: CCRA.SL.1

1. Print and cut apart the Engineering Design Problems cards found on page 31. As the game host, you will read the problems listed on these cards.

2. Divide the class into two teams and have them stand on either side of the room. Explain that you are the host of the game, and their goal is to match an engineering problem you will read to a simple machine on the board and slap it with a flyswatter before their opponent.
3. Hand a flyswatter to the student at the front of each team. Randomly select a card from the stack and read aloud the problem. When you say "Go," one person from each team will run to the board and slap the simple machine that could be used to solve that problem. Team members are not allowed to call out suggestions during the game.
4. The first person to slap the correct problem wins a point for their team. Note: It's possible that two or more simple machines could be used to solve a problem on a card. If students dispute the answer printed on the card, allow them to make their case and decide if they should be given the point.
5. Players return to their teams and pass the flyswatter to the next person. Continue playing until all twelve cards have been played.

Optional If time allows, provide students with tools and materials you gathered before the game (blocks, wheels, cardboard, scissors, tape, and so on). Divide them into small teams and distribute one Engineering Design Problems card to each team. Have teams work together to build a simple machine that would solve that problem. NGSS: 3-5-ETS1-1; 3-5-ETS1-2; 3-5-ETS1-3; NGSS: MS-ETS1-1; MS-ETS1-2; MS-ETS1-3; MS-ETS1-4; NSES: 4.E-2a; 4.E-2b; 4.E-2c; 4.E-2d; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d

Activity 4: Engineering Careers—What Kind of Engineer Am I?

Explain that there are many different careers in engineering. Ask students to try to name some different careers. (Watch for misunderstandings about train engineers in younger students.) CCSS.ELA-LITERACY: CCRA.SL.1

1. Write the following five types on the board: civil engineers, environmental engineers, mechanical engineers, biomedical engineers, and electrical engineers.
2. Ask students if they can guess what engineers do in each of these fields. Ask: *What kind of problems do these engineers solve?*
3. Read the following riddles aloud, and have students guess the type of engineer that matches each one.

- *I am interested in controlling motion, energy, and force. I work to develop machines to meet the needs and wants of society. Cool things I design include snowboards and robots. What kind of engineer am I?* (mechanical)
- *I use science and engineering principles to protect and improve the environment. The quality of air, water, and soil are very important to me. I help factories reduce their pollution. What kind of engineer am I?* (environmental)
- *I specialize in roads, bridges, buildings, and water supply systems and construction. I worry about making these structures safe enough to withstand natural disasters. My favorite place to be is in the middle of a construction site. What kind of engineer am I?* (civil)
- *I combine the fields of biology, medicine, and engineering in my work. I design solutions that will improve human lives, designing amazing things like artificial hearts and even bionic arms! What kind of engineer am I?* (biomedical)
- *I specialize in power supply and generation. I can develop wiring and lighting installations in buildings, automobiles, and aircraft. If you like power, you'd like my job. What kind of engineer am I?* (electrical)

Engineering Activities: Middle School

Activity 1: Engineering Robots—Cardboard Challenge

An important aspect of the engineering process is the importance of research and planning. In this activity, teams of students respond to a real-world problem and design a cardboard prototype of a robotic solution. NGSS: MS-ETS1-1; MS-ETS1-2; MS-ETS1-3; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d; 8.E-2e; RST.6-8.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1

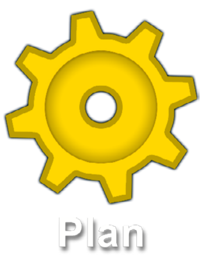
1. Direct the class's attention back to the projected image of the Engineering Process, provided at www.NatGeoEd.org/robots-challenge-educator-guide. Explain that students will focus on the *learn, plan,* and *build* steps in this activity.

2. Write the word *prototype* on the board and work together to create a class definition of the term, similar to "early version or model." Explain that engineers often create a model, or prototype, of a design when they are planning their solutions.

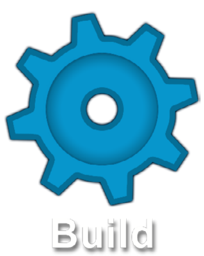
3. Write the following task on the board: Build a robot that a teacher could use to help with instruction.

4. Divide the class into teams of 3-5 students and have them work together through steps 2, 3, and 4 of the engineering process, below. Remind them to use their Engineer Journals to take notes, make sketches, and record the team's decisions.

Research the problem by first determining a school subject where a robot might be of use, and then asking teachers of that subject what types of tasks they'd like a robot to perform for them. Research the Internet to find out about robots that perform similar tasks.



Begin designing a robot on paper, identifying the parts of the robot that would be needed to complete the tasks. Will the robot need to walk, roll, or fly? What end effectors will be needed to complete tasks? What sensors are required to explore the environment?



Provide cardboard, old toys, and other recycled and craft materials for teams to use to create cardboard prototypes of their designs.

5. Have teams present their cardboard prototypes to the class. They should explain the school subject the robot is designed to assist, describe the tasks they decided to include from their research and why, and explain the parts of the robot that help the robot in performing the tasks.

Activity 2: Design Working Robots with Thames & Kosmos Remote-Control Machines Kit

This kit, found at http://shop.nationalgeographic.com/ngs/product/kids/toys-and-games/all-toys/remote-control-machines-kit, one of several kits from Thames & Kosmos, is very versatile. It comes with instructions to create ten different robotic vehicles and machines, and with three different motors, a variety of end effectors, and 182 building pieces, teams can design and build their own unique items as well.

The kit can also be combined with other Thames & Kosmos kits to increase the options and possibilities, but because this kit can only be used to design and create one robotic option at a time, some activity management will be necessary to organize its use. Consider acquiring enough kits for teams of 3-6 students to use together, or place the set in a learning center, allowing one team at a time to create while the remainder of the class works on other activities. NGSS: MS-ETS1-1; MS-ETS1-2; MS-ETS1-3; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d; 8.E-2e; RST.6-8.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1

1. Begin the activity by generating a list of tasks that could be completed by a robotic vehicle, for example:
   - sweep or push trash from the streets
   - lift heavy materials like beams to an upper floor of a building under construction
   - a vehicle that spirals in different-sized circles

2. Have teams of students work together, using the steps of the engineering process and recording in their Engineer Journals, to define the problem, learn about what is need to solve it, and then plan, build, and test their designs.

3. Remind teams about the importance of iteration, and remind them to record in their journals exactly what happened in each test and what they tried during subsequent cycles of the process.

4. After teams have a working model, have them record video of their robotic vehicle performing the task. (Note: This is especially important if the kits must be taken apart right

away for another team to share.) At least one member of the team should narrate the video, describing how the robot was designed and what decisions were made about mobility options and end effectors.

Activity 3: Engineering without Robots—Design Playground Equipment

Ask students to imagine they have been hired by the city or community to design new playground equipment for a planned city park. NGSS: MS-ETS1-1; MS-ETS1-2; MS-ETS1-3; NSES: 8.E-2a; 8.E-2b; 8.E-2c; 8.E-2d; 8.E-2e; RST.6-8.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1

1. Assemble the discarded toys, recycled materials, and craft materials you gathered before playing the game.
2. Discuss the types of playground equipment that are found in parks. Ask: *What makes them popular? What makes them safe? What might be done to make a traditional playground item like a slide or merry-go-round new and more fun (but still safe)?*
3. Divide the class into teams and have them work together to "hack" (cut apart and redesign) the toys with other materials to create and design playground equipment with a new twist. Encourage them to follow the steps of the engineering process and record their discussions and decisions in their Engineer Journals.
4. Have teams share their creations with the class. Ask:
   - *What did you design? How is it different from traditional playground equipment?*
   - *Did you use any components in your designs that were similar to the robot parts we studied? Describe them.*
   - *What simple machines, if any, did you use in your design? (e.g., lever, inclined plane, wedge, pulley, wheel-and-axle, screw) Why did you use that simple machine?*
   - *What was the most challenging part about creating your equipment?*

Optional If time allows, use poster board or projected grid paper to discuss as a class how best to arrange all the new equipment in the park. Ask: *What factors go into laying out attractions for a good flow of traffic? What might be needed to ensure maximum fun with maximum safety?*

Activity 4: Engineering Careers—Research and Report

Many people think that engineering is a single career. Help students understand the range of possibilities in the field of engineering by having students conduct Internet research on a specific career to report to the class. CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1; CCRA.W.2; CCRA.W.7

1. Create a list on the board of 10-15 engineering careers, choosing from the list at the Educating Engineers website, found at: http://educatingengineers.com/career-specialties. Students will be familiar with some careers and less familiar with others.
2. Give students time to read through the list, and then assign or allow students to self-select a specific career to research. Some careers will be covered by more than one student, and they may choose to work together on the project.
3. Briefly discuss how to conduct research through Internet search engines, and make sure students are aware of any rules your classroom or your school may have. For example, decide if user-created sites like Wikipedia should be accepted as resources, whether students can search .com sites, and so on.
4. Before beginning research, have students turn to a blank page in their Engineer Journals and copy a list of questions that you want them to use to guide their research, including:
   - *Did I know this career existed before?*
   - *What does this type of engineer do?*
   - *What are some interesting things these engineers get to work on?*
   - *Where do they work?*
   - *What kind of schooling is required to become this type of engineer?*
   - *How much money might you make in this field?*
   - *What is the most interesting thing I discovered during my research?*
   - *Does this career sound like something I would like to do? Why or why not?*

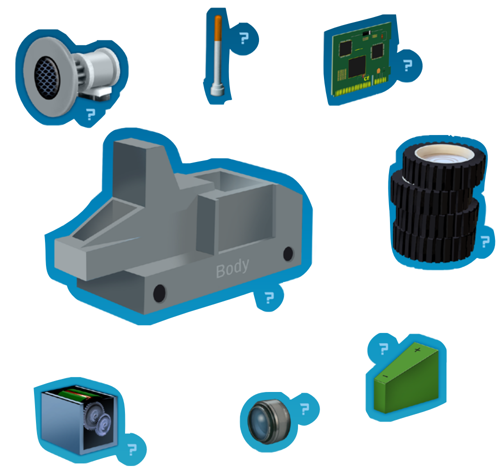
5. Have students create an interesting presentation of the career they chose, addressing each of the questions they researched. Allow them to come up with their own presentation format; for example, they may create a poster with images of these engineers at work or some of the items that they work on. Or they could create a PowerPoint or other software presentation, or role-play and speak to the class as if they are a visiting engineer. Encourage them to be creative in their presentation styles and to share their information in an exciting or engaging way.

Engineering Activities: High School

Activity 1: Engineering Robots—Robot Hackathon

The term *hacking* has a lot of meanings, but in this instance it refers to the act of modifying or customizing everyday products to improve their functionality, to repurpose them, or to create something new for fun. It's a new trend in creative learning, and for this activity the focus is on toy hacks, specifically, hacking working remote-control (RC) toys. NGSS: HS-ETS1-1; HS-ETS1-2; HS-ETS1-3; HS-ETS1-4; NSES: 12.E-2a; 12.E-2b; 12.E-2c; 12.E-2d; 12.E-2e; RST.9-10.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.R.1; CCRA.W.2; CCRA.W.7

1. Designate a RESOURCE table of recycled materials, such as discarded toys, cardboard, and paper.
2. Designate a TOOL area where you have stocked tools, such as scissors, hammers, saws, assorted screws, nuts and bolts, and wire.
3. Create teams of students (depending upon the number of remote-control toys you were able to gather before the game), and provide each team with an RC toy.
4. Ask students to work together within their teams, using the engineering process, to use the RC toy as the basis for a robot that will solve a real-world problem. They should use their Engineer Journals to record decisions made in each step of the process, take notes, and make sketches.
5. Pass out the Robot Hackathon Design Sheet from page 33 to each team.



6. Have teams share their robot designs with the rest of the class. Ask students to provide feedback to team members on how well they think the design works, and make suggestions on how it can be improved.

Activity 2: Programming Robots with Lego Mindstorms©

Lego Mindstorms EV3 is as easy as building with Legos but includes added components for creating and designing action robots with little instruction time. The kit includes two motors and three different sensors, as well as a "programmable brick" that serves as the control center and power station for robot projects. NGSS: HS-ETS1-1; HS-ETS1-2; HS-ETS1-3; HS-ETS1-4; NSES: 12.E-2a; 12.E-2b; 12.E-2c; 12.E-2d; 12.E-2e; RST.9-10.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.R.1

1. Have students, working independently or in teams (depending on your class size), first DEFINE a problem that they would like their robot to solve. Then, following the rest of the steps in the engineering process, have team members collaborate and record their decisions for each step in their Engineer Journals. Explain that they will use these notes when they share their projects with the class.
2. When all teams have completed the design of a robot, have them take turns presenting their robots to the class, demonstrating how they work and what problem they were designed to solve. Ask:
   - *What is the end effector on your robot? Why did you choose that end effector?*
   - *What mobility option did you choose? Why did that seem like the best solution?*
   - *What type of sensor did you use? Why did you choose that sensor?*

The Lego website provides free downloadable software at http://www.lego.com/en-us/mindstorms/learn-to-program to use with the programmable brick, and this requires computer time. The site includes instructions and videos to help students understand the simple block-based programming used in the kit.

Activity 3: Engineering without Robots—Build a Better ________

In this activity, students learn about reverse engineering and use that process to try improving a mechanical toy or object like a can opener or wind-up clock. NGSS: HS-ETS1-1; HS-ETS1-2; HS-ETS1-3; HS-ETS1-4; NSES: 12.E-2a; 12.E-2b; 12.E-2c; 12.E-2d; 12.E-2e; RST.9-10.3; CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.R.1

1. Designate a RESOURCE table of the collection of discarded, broken, or inexpensive mechanical tools or kitchen gadgets gathered before the game.
2. Designate a PARTS area or table where you place recycled materials, discarded non-mechanical toys and toy parts, cardboard, and so on.
3. Designate a TOOL area where you have stocked tools, such as scissors, hammers, saws, assorted screws, nuts and bolts, and wire.
4. Write the heading "Build a Better ______" on the board. Ask if anyone ever took apart a flashlight when they were younger to see how it worked. Invite volunteers to share what they learned about flashlight design and operation during their explorations. Draw a simple diagram of the internal parts of a flashlight on the board as students talk. Did they ever use the parts to create their own flashlight design? Explain that engineers do the same thing, and there is an official name for it: *reverse engineering*—"to study the parts of something to see how it was made and how it works so that you can make something that is like it."
5. Create small teams or pairs of students (depending on the number of mechanical gadgets or toys you have) and have them work together to carefully take one of the items from the RESOURCE table apart and explore how it works. Have them use their Engineer Journals to create a detailed drawing of the internal components of the gadget, labeling each part and briefly describing the part's function. Allow students to research their gadgets if necessary.
6. Ask pairs or teams to come up with a way to either improve the item or extend its functionality beyond the original purpose. Have them follow the engineering process to guide their work. For example, during the LEARN and PLAN stages, they can examine online reviews or interview friends or family members who use the mechanical gadget and ask them if they'd like to see a new feature or improvement.
7. Have students create a prototype of their improved design using the PARTS and TOOLS areas.
8. Have students present to the class how they would improve their chosen object.

Activity 4: Engineering Careers—Video Interviews

The best way to interest students in the exciting career opportunities in STEM fields is to have them speak with actual engineers. In this activity, students will research local businesses to find an engineer that is willing to visit the classroom or be videotaped. CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1; CCRA.W.2; CCRA.W.7

1. Start by sharing a couple of the video interviews found on the NatGeoEd.org website, particularly in the "Cool Scientists" section of www.NatGeoEd.org/mysteries/. Two scientists in particular on this site, Kingsley Fregene, an electrical engineer working on flying objects, and Amber Case, who focuses on how culture impacts technology, serve as good models of engineers working in fields that fit the topics of *Challenge: Robots!* After showing one or more of the videos, ask:
    - *What information about their personal interests did these scientists share? How did those interests lead them into their current work?*
    - *How do they apply what they observe in nature or society to their research and design?*
    - *How did they show their passion for their work?*
    - *You don't see an interviewer asking these scientists questions; what questions do you think were asked to get them to share such interesting facts about their lives and work?*

2. Discuss the types of businesses that exist in the local community. Generate a list of companies on the board and have students research them to see if any have an engineer or scientist from another STEM field on staff. Add any names to a master list of local STEM experts. NOTE: If unable to locate enough local engineers to go around, consider broadening the search zone to businesses in nearby counties or towns.
3. Have students conduct research on the company: what they do, what the engineer or scientist does for them, and so on.
4. Before beginning this activity, contact the local STEM experts generated in the brainstorming session by email or phone, to find people who are willing to be interviewed, either at the school or by video teleconference, for this activity. Explain that students will be required to make contact during school hours, and ensure that the engineers and scientists can take this time away from work.
5. Provide students with a list of scientists and engineers who have agreed to be interviewed, as well as their contact information and preferred school time for taking the call. Have students select their subjects from this list.
6. Work together as a class to develop an interview protocol—a list of questions that students devise to get their subjects talking. Provide the following guidance for question generation:
   - Base your questions on what you know about the interviewee from your research on the company and what they do.
   - Ask open-ended questions that will require the interviewee to explain him or herself. Don't ask yes or no questions.
   - Start with the basics: Where did he or she grow up? What does he or she do? What got him or her interested in this field of work?
   - Work up to more complex questions toward the end of the interview.
7. As a class, share the interview questions generated and work together to develop a 5-10 minute interview protocol that each student will use. Explain that the protocol is to be used as their general script, but they should be flexible enough to follow an interesting topic if one comes up during their individual interviews.
8. Before scheduling interviews with local engineers, conduct mock interviews in the classroom, with pairs of students taking turns asking each other the questions on the protocols.
9. Schedule the interviews during class time, welcoming people who are willing to come to the classroom and arranging for video conference calls with those who can only offer a few minutes of their time.

Wrap Up for All Grades

Presentation Contest

The purpose of *Challenge: Robots!* and these supplementary classroom activities is to teach students, both boys and girls, about the exciting STEM careers available today, specifically in engineering and robotics. As a wrap-up activity, host a contest in which students compete to share what they've learned in a fun and engaging way.
CCSS.ELA-LITERACY: CCRA.SL.1; CCRA.SL.5; CCRA.R.1; CCRA.W.2; CCRA.W.7

1. Write the topic of the contest on the board: "Why engineering is a cool career."
2. Explain that students can work independently or in pairs to produce a presentation that develops and illustrates their opinions on this topic.
3. Before beginning the activity, discuss the types of presentations students can create. The format should be left open-ended and limited only by students' creativity and preferences, but may include:
   - written essays
   - picture books
   - interactive posters, with circuits that provide lights or sound effects
   - videos
   - role-playing skits between two or more characters

Optional Consider finding one or more volunteers who work in the engineering field and inviting them to your presentations. They could select the top 1-3 presentations and award a certificate or other small prize, and perhaps answer students' questions about their own field of engineering.

Challenge: Robots! at Home

Duplicate and distribute the *Challenge: Robots!* Take-Home Sheet found on page 34, which shares the unique learning experiences in which your students have been engaging, and encourages families to continue playing the game and discussing important concepts about engineering and robotics on their own.

Extending the Learning

Learn More About Robobees!

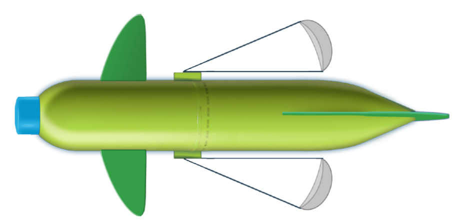
Students who completed the Robotic Bees game challenge may enjoy learning about the real-world engineers who are actually designing and building these bees. The National Geographic video Robobees is only 3 minutes long and provides a peek into this work. Find it at: http://video.nationalgeographic.com/video/explorers-project/140925-explorers-wood.

This video provides a model for engaging discussions about the importance of iteration and how failure is not the end of the engineering process, but a vital part of cyclical design. Watch and discuss the video. Then ask students to explore scientific discoveries that were preceded by failures.

Learn More About Robotics in Archaeology!

In the Tunnel Explorer game challenge, students learned about robots designed to navigate hazardous areas and collect artifacts in a safe manner. Share this video created by Indiana University's Tech Bytes, a series that highlights the intersections of academia and emerging technologies. In this episode, "Aerial Archaeology," a research faculty member in the school of informatics at IU shares a flying robotic camera used to create 3-D maps of hard-to-reach archaeological sites: https://youtu.be/dwNMETSxAaA. Ask students to learn more about this type of robot: What parts are unique to the machine? How does it work? How does it help archaeologists? What interests did this researcher have as a child that contributed to his choice of career?

Learn More About Oceanic Garbage Patches!



The Great Pacific Garbage Patch that players learned about in the Ocean Cleanup game challenge is such a massive problem it will be decades before it can be handled, if ever. But now scientists have discovered another mass of garbage in the Atlantic Ocean as well. Introduce this garbage patch using this online article from National Geographic: http://news.nationalgeographic.com/news/2010/03/100302-new-ocean-trash-garbage-patch/.

Ask student teams to find out how science students are working to catalog the types of trash found in this problem area. Ask: *What comprises most of the trash? Where does this trash come from? Where does it go?* Have students in older grades create ocean maps of either the Pacific or Atlantic garbage patches, using the MapMaker Interactive tool on the NatGeoEd.org website (www.NatGeoEd.org/mapmaker-interactive/). Direct students to add the layer Surface Ocean Currents (found in the Water category) to begin creating their maps. Have them create maps that show the ocean currents and track the debris back from its source. Ask*: Why can trash that escapes the vortices make its way to some land masses but not others?*

For Further Exploration

Books

- Stewart, Melissa and National Geographic Kids (2014). *Robots (Level 3).* National Geographic.
- Salvadori, Mario (2000). *The Art of Construction: Projects and Principles for Beginning Engineers & Architects.* Ziggurat Book: Chicago Review Press.
- National Geographic Kids (2015). *125 Cool Inventions: Supersmart Machines and Wacky Gadgets You Never Knew You Wanted!* National Geographic.

Websites

- Engineers in the Classroom: http://www.ClassroomEngineers.org/
- Robots 3D activities: NatGeoEd.org/robots/
- NGX Challenge: Robotics Technology: NatGeoEd.org/NGX/
- The Rube Goldberg Challenge: http://rubegoldberg.com/?page=The_Rube_Goldberg_Challenge
- EngineerGirl: http://www.engineergirl.org/
- Code.org: http://www.code.org

Videos

- "Underwater Robot," from National Geographic: http://education.nationalgeographic.com/education/media/underwater-robot/
- "Inspired by Nature and Robotics," from National Geographic: http://education.nationalgeographic.com/education/video/inspired-by-nature-and-robotics/

Appendix

Glossary

- **accelerator** *noun*. a pedal or other device that controls the speed of a vehicle's engine.
- **antenna** *noun*. structure through which electromagnetic signals are received.
- **body** *noun*. the main part of an object or organism.
- **controller** *noun*. a device that is used to operate a machine or vehicle.
- **design** *verb*. to plan.
- **design tradeoff** *noun*. an engineering design situation in which one must choose between two things that are opposite or cannot be had at the same time.
- **end effector** *noun*. a device or tool on a robot that interacts with the environment.
- **engineer** *verb*. to design, produce, or plan (something), especially in a clever and skillful way.
- **engineering** *noun*. the art and science of building, maintaining, moving, and demolishing structures or objects.
- **gyroscope** *noun*. device consisting of a rotating wheel mounted so that its axis can turn freely in any direction, and capable of maintaining the same absolute direction in spite of movements of the mountings and surrounding parts.
- **hacking** *verb*. changing everyday products to improve their functionality, give them a new purpose, or to create something new for fun.
- **hybrid** *noun*. the end result from combining two things.
- **iteration** *noun*. a procedure in which repeating a sequence of operations gets one closer and closer to a desired result. (verb form: iterate, to repeat)
- **mobility options** *noun*. a part of a robot that allows it to move. Options may include wheels, propellers, wings, sails, and gyroscopes.
- **motor** *noun*. a part that provides movement to various robot parts.
- **ocellus** (plural ocelli) *noun*. a tiny, simple eye that detects only light and shadow.
- **optic flow** *noun*. the motion of the visual world as an object that can see moves through it.
- **patent** *noun*. an official document that gives the holder exclusive control and possession of something.

- **power supply** *noun*. a part that delivers electricity to power the robot.
- **processor** *noun*. a part that controls all robot operations.
- **program** *noun*. set of coded instructions for the automatic performance of a task provided to a robot or computer.
- **prototype** *noun*. an early version or model of a new product or invention.
- **reverse engineer** *verb*. to take something apart and study its parts so that you can improve it or make something like it.
- **robot** *noun*. a programmable machine designed to sense, analyze data, and respond as programmed.
- **robotics** *noun*. branch of electronics that deals with the study, construction, operation, and use of robots.
- **sensor** *noun*. a part of a robot that provides feedback or information about its surroundings.
- **sonar** *noun*. method of determining the presence and location of an object using sound waves (echolocation).

Skills

21st Century Skills

- Learning and Innovation Skills
  - Creativity and Innovation
  - Critical Thinking and Problem Solving
  - Communication and Collaboration

Critical Thinking Skills

- Understanding
- Applying
- Analyzing
- Evaluating

Life and Career Skills

- Flexibility and Adaptability
- Initiative and Self-Direction

Science and Engineering Practices

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations (for science) and designing solutions (for engineering)
- Obtaining, evaluating, and communicating information

Connections to National Standards

Common Core State Standards for English Language Arts (CCSS.ELA): http://www.corestandards.org/ELA-Literacy/

CCSS.ELA-LITERACY.RST.6-8.3
Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS Anchor Standards for Reading: http://www.corestandards.org/ELA-Literacy/CCRA/R/

CCSS.ELA-LITERACY.CCRA.R.1
Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

CCSS Anchor Standards for Writing: http://www.corestandards.org/ELA-Literacy/CCRA/W/

CCSS.ELA-LITERACY.CCRA.W.2
Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

CCSS.ELA-LITERACY.CCRA.W.7
Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation.

CCSS Anchor Standards for Speaking & Listening: http://www.corestandards.org/ELA-Literacy/CCRA/SL/

CCSS.ELA-LITERACY.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-LITERACY.CCRA.SL.5
Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations.

National Science Education Standards (NSES): http://www.nap.edu/openbook.php?record_id=4962

Grades K–4

4.E-2a.	Identify a simple problem.
4.E-2b.	Propose a solution.
4.E-2c.	Implement proposed solutions.
4.E-2d.	Evaluate a product or design.
4.E-2e.	Communicate a problem, design, and solution.

Grades 5–8

8.E-2a.	Identify appropriate problems for technological design.
8.E-2b.	Design a solution or product.
8.E-2c.	Implement proposed solutions.
8.E-2d.	Evaluate completed technological designs or products.
8.E-2e.	Communicate the process of technological design.

Grades 9–12

12.E-2a.	Identify a problem or design an opportunity.
12.E-2b.	Propose designs and choose between alternative solutions.
12.E-2c.	Implement a proposed solution.
12.E-2d.	Evaluate the solution and its consequences.
12.E-2e.	Communicate a problem, process, and solution.

Next Generation Science Standards (NGSS): http://www.nextgenscience.org/next-generation-science-standards

3-5-ETS1-1.	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2.	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3.	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Credits

Research Manager

Todd Georgelas, National Geographic Standards and Practices

Writer

Janis Watson, Implementation Manager & Curriculum Specialist, The Creativity Labs @ Indiana University

Editors

Christina Riska Simmons, National Geographic Society

Elaine Larson, National Geographic Society

Educator Reviewer

Jaclyn Ricords, d'Vinci Interactive, Education Consultant

Expert Reviewer

Carl Jackson, Senior Engineering Manager, Lockheed Martin

Designers

Eileen O'Tousa, National Geographic Society

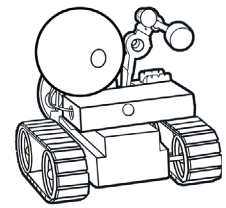
Meghan Irving, National Geographic Society

Illustrator (Cartoon on page 13)

Fermín Solís

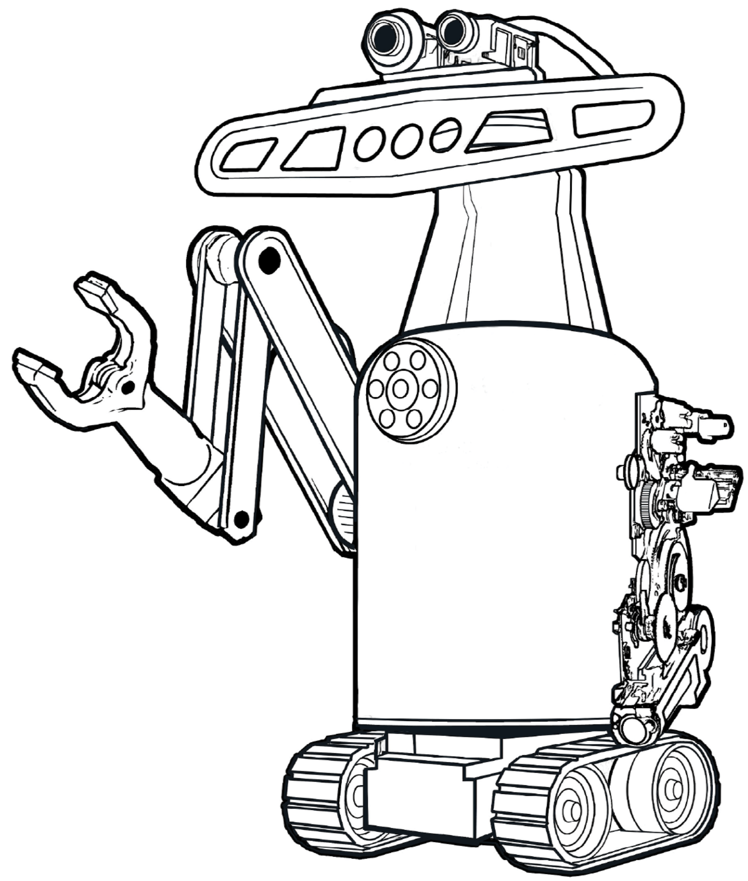
Challenge: Robots!

NatGeoEd.org/Robots-Challenge



RoboWorks

Engineer Journal



NAME:

Challenge: Robots!

NatGeoEd.org/Robots-Challenge

Engineering Design Problems Cards

Cut along the dotted line.

Engineering Problem

I want my front door to stand open, but each time I let go it slowly closes again.

(WEDGE)

Engineering Problem

I need to chop these fat logs into smaller pieces, but my axe keeps getting stuck.

(INCLINED PLANE)

Engineering Problem

I need to move a heavy box up to the second-story loft in my barn, but it is too heavy for me to carry it up the stairs.

(PULLEY)

Engineering Problem

I placed a flag on a high pole outside my house, but it was destroyed in a bad storm. I've got a new flag, but I don't want the same problem.

(PULLEY)

Engineering Problem

In ancient Egypt, slaves had to move huge blocks of stone, but they were too big for men to carry.

(WHEEL AND AXLE)

Engineering Problem

I've got a door that I keep closed with a hook. I wish somebody would invent a door knob that turns and pushes a latch into the frame.

(WHEEL AND AXLE)

NATIONAL GEOGRAPHIC

Challenge: Robots!

NatGeoEd.org/Robots-Challenge

Engineering Design Problems Cards, Continued

Cut along the dotted line.

Engineering Problem

Manhole covers fit tightly into a round hole and weigh 50 kilograms (110 pounds). The road crews need access to those sewers.

(LEVER)

Engineering Problem

Highways are built over and under other streets to avoid needing street lights at every intersection. Now we need a way to get vehicles on and off those elevated roadways.

(INCLINED PLANE)

Engineering Problem

I tried opening my soft drink bottle with a hammer, but I kept breaking it.

(LEVER)

Engineering Problem

I'm moving my rolling desk to my new house. I got it to the moving van, but it's too heavy to lift.

(INCLINED PLANE)

Engineering Problem

My stool is a bit too short for me but too tall for my friend. I need a way to make the seat adjustable . . . go up and down.

(SCREW)

Engineering Problem

Early jars were capped with metal disks held on with wax seals. In 1858, John Landis Mason (inventor of the Mason Jar) came up with a new cap that used a simple machine to hold it on.

(SCREW)

Challenge: Robots!

NatGeoEd.org/Robots-Challenge

Robot Hackathon Design Sheet

Use the following guidelines to frame your progress as your team hacks a remote-control toy or vehicle.

1

DEFINE
Think about jobs or tasks that are either too boring/repetitive or too dangerous for humans. Decide on one task that could be completed or solved by a robot.

2

LEARN
Research the job or task to define exactly what the robot needs to be able to do. Write down the steps of this task exactly.

3

PLAN
Consider your team's RC toy and decide how to modify it to solve the problem.

4

BUILD
Rework the toy so that it solves the problem, utilizing the tools and resources areas. Figure out how you can use the radio controls to guide the robot to complete the task.

5

TEST
Set up a test to determine if your robot is able to complete the task. Make sure your test imitates the real-world application of the task.

6

ITERATE, ITERATE, ITERATE!
Make changes to improve your robot's design until you have a robot that meets the approval of the entire team.

Challenge: Robots!

NatGeoEd.org
/Robots-Challenge

Challenge: Robots! Take-Home Sheet

Your child has been learning about the exciting careers in the field of engineering and specifically about how engineers build robots by playing an online game called *Challenge: Robots!*, one of a collection of games developed by National Geographic and Lockheed Martin. You can explore the game with your child at home by visiting the website at: NatGeoEd.org/robots-challenge/. The game is open-ended, and children can return to play any or all parts of it again and again. Repetition will help reinforce learning!

In *Challenge: Robots!* players take on the role of an engineer at RoboWorks, a robotics factory. They are met by the robot Sprocket, who shares information on what it means to be an engineer at the factory. The game menu offers five options, each of which includes its own fun challenge designed to build understanding about specific engineering and robotics concepts. You can help support your child's learning by asking questions about what they learned in each section of the game, or by playing along. The following outline provides a brief overview of each of the game activities.

Orientation

In this first part of the orientation, new employees are introduced to the engineering process. These six steps are cyclical, and are intended to be repeated until a final design is accepted. One of the most important steps of the engineering process, and one you can emphasize at home, is the sixth one: *iterate*, which means to repeat and improve. Engineers learn that there is no such thing as failure: each test that doesn't succeed is an opportunity for learning. As Thomas Edison is credited with saying when a reporter commented on the fact that he hadn't yet come up with a solution to a problem he was working on: "I haven't failed. I've discovered 10,000 things that don't work!"

Build a Robot

This second part of the orientation focuses on the parts of robots and how they are programmed. Children play a challenge that asks them to sort various robot parts into categories, like end effectors (tools), sensors, and so on. In the process, children learn that specific parts allow robots to *perform different tasks* in different ways. A second part of the activity asks them to choose steps that a robot will follow in sequence to perform a task. Play a simple game with your child, having them follow steps exactly as you state them (walk, walk, walk, turn left, and so on) to a particular goal.

Challenge: Robots! Take-Home Sheet, Continued

Challenge Activity: Robotic Bees

This challenge explores the real-world problem of Colony Collapse Disorder, in which worker bees in honey bee hives are disappearing, leaving the young bees and queens without resources. This issue is a problem not only for beekeepers but for agriculture, since honeybees are the main vehicle for pollination of flowers and vegetable crops. The challenge focuses on the design of micro robots, whose designs are based on insect body plans. Children learn the importance of balancing body size and weight with the power needed to travel across fields performing a task. Talk to your child about *design tradeoffs* like this one: what is more important, power or weight?

Challenge Activity: Tunnel Explorer

Archaeologists exploring ancient Egyptian tombs face hazardous conditions every day. This challenge focuses on the recent discovery of a buried causeway that connects the Great Pyramid of Egypt to the Valley Temple, something scientists have long searched for. Unfortunately, parts of the causeway have collapsed under the desert, and there is always the danger of toxic air. In this challenge, players design a robot that can travel underground, navigate terrain too difficult for humans, and bring back any delicate artifacts it discovers along the way. The challenge focuses on *programming* the robot: creating step-by-step instructions on how the robot can navigate to an artifact while avoiding hazards. Talk about the challenges involved in programming, how they are able to translate a line of coded instructions to the terrain of the path, and so on.

Challenge Activity: Ocean Cleanup

Here players learn about the real-world problem of the Great Pacific Garbage Patch, a massive collection of marine debris in the North Pacific Ocean that is larger than the state of Texas. It floats and spins around the seas, moving with the currents, and because it's in the middle of the ocean, no nation claims responsibility for it. Cleaning up this disaster is nearly impossible, because most of the trash has been broken down over time to minute pieces of plastic that never biodegrade. Scooping up any of the plastic also removes microscopic aquatic organisms that are important parts of the food chain. Players are charged in this challenge with designing a robot fleet to collect as much of this trash as possible. The focus in this challenge is selecting the best *robot parts* for the task. Ask your child what types of robot body, end effectors (tools), and movement patterns make the best robot for this job.