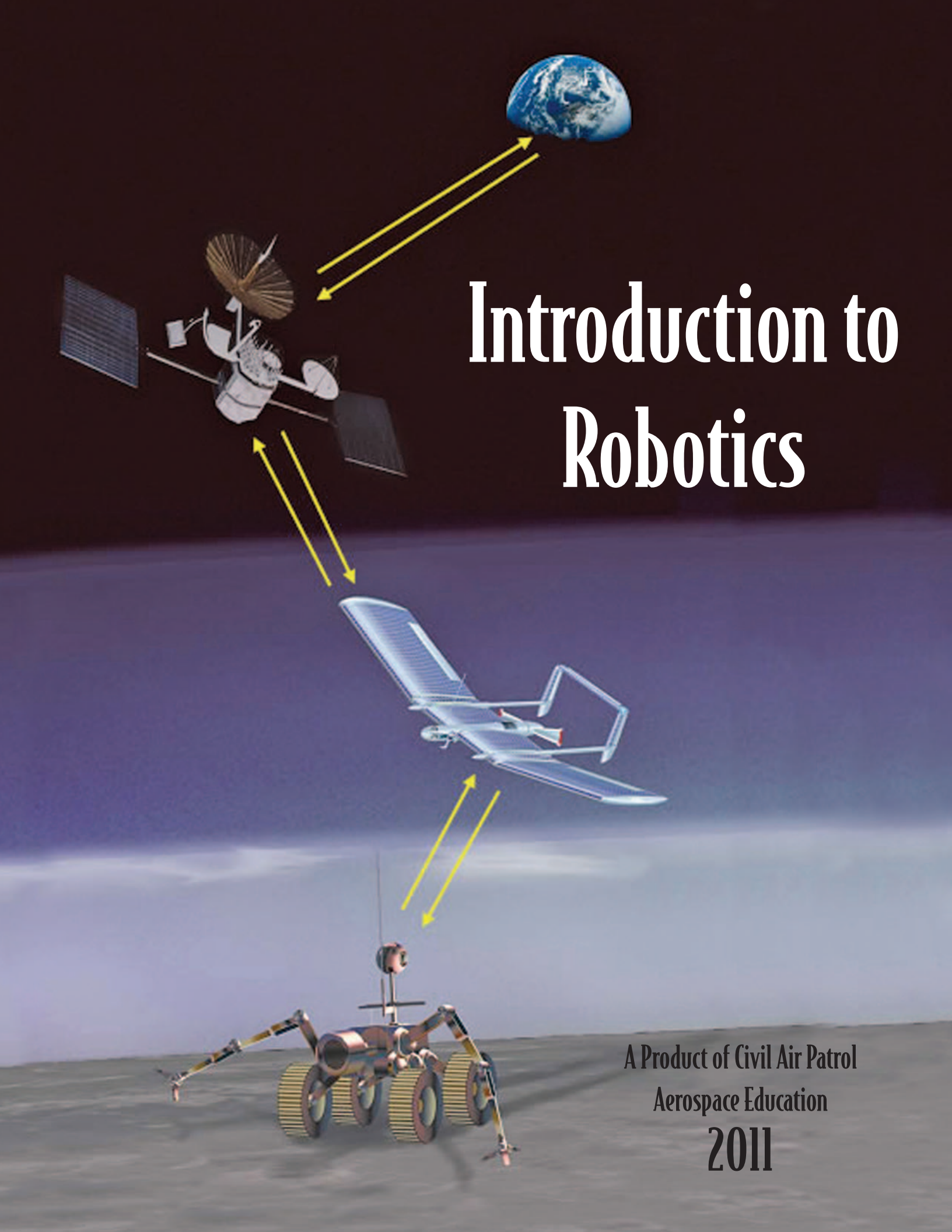




The background image is a composite showing a robotic system across different scales. At the top is the Earth. Below it is a satellite with solar panels and a dish antenna. In the middle is a blue aircraft. At the bottom is a Mars rover on a grey, cratered surface. Yellow double-headed arrows connect the Earth to the satellite, the satellite to the aircraft, and the aircraft to the rover, illustrating a hierarchical or interconnected robotic system.

Introduction to Robotics

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Credits:

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Disclaimer: Websites and information were current as of the release of this book.

The purpose of this curriculum is to provide an introduction to robotics and encourage young people to explore the technology that robotics provides. It is hoped that youth will become interested in science, technology, engineering, and mathematics (STEM) subjects that will open the door to career opportunities in the aviation and space realm.

The robotics curriculum provides beginning activities that are low-cost and high-interest. The activities progress into challenges that will require more resources and ingenuity to perform.



Safety with Robotics

Every learning environment should always follow safety rules as set down by the instructor. Some rules for safety with robotics are:

1. Use clean safety goggles if working with flying objects or projectiles. Example: parts of the robot that may come loose and fly through the air.
2. Never do any experiment without approval and direct supervision of the instructor.
3. Always be aware of robotics pieces that may be on the floor or somewhere that might cause someone to trip or fall.
4. Treat computers and other technology with care. Remember: these items involve electricity.
5. Above all, think before you do!!!!

The activities in this book that involve the use of scissors, glue, tools, or electronic parts will be addressed in the activity. Use good common sense and judgment to ensure that your experience with robotics is positive.



Safety glasses worn at robotics competition

Note: For Measurement Conversion:

To convert measurements in the activities in this book between the Metric System and the English System, visit <http://www.unit-conversion.info/length.html>.

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Why and How of Robotics?

What are the advantages of having robots in our lives? Today, some of the most boring and repetitive jobs in manufacturing are done by robots. The military and police use robots for dangerous jobs, such as manipulating explosive devices. Robots are used in inaccessible places, such as exploring our solar system or the bottom of the sea. Robots also appear in entertainment, research, medicine, and education. Mankind is only beginning to see the use and value of robotics.

Why do robotics play an important part in education? With a great emphasis being placed on science, technology, engineering, and mathematics in our education system, robotics play an important part in motivating and exciting students about these subjects. Robotics involve multiple types of design: physical design of structures and mechanisms (building a creation using construction materials, motors, and gears), as well as computational design (writing a computer program to determine how a creation should move and respond). Robots engage students in the learning process.

As students design, build, and program an autonomous robot they are exposed to STEM concepts. They learn about these concepts in a real-world application and are required to apply them over and over again. These hands-on, minds-on activities help students understand how science and technology are useful in their world and make connections to careers they may not have considered.

Many times, educators are reluctant to attempt robotics because of time, skill, and expense issues. The time issue has been addressed by showing how robotics can be integrated into the curriculum and how many national STEM standards can be covered via robotics. The skill issue takes some time to learn, and involves finding an area robotics club, a nearby high school or college that has a robotics lab, or a local engineer interested in robotics. These



resources can provide technical assistance and training. There are also online resources that have tutorials that are helpful. The last issue is expense. A robotics program can be implemented without major expense by conducting the simple introductory activities that show how robots work. Using discarded parts from electronic gadgets or pooling resources with other teachers will reduce expenses as the robotic challenges increase. Writing a grant or soliciting a community sponsor are other options which are discussed in the resource section of this book.

If you choose the LEGO® Robotics Program:

In the middle school environment, robotics is the ideal format to reinforce fundamental mathematics, the scientific process, as well as programming, problem solving, and teamwork. LEGO® is mentioned here as a possible choice for schools because of the organization of materials, the curricula created by Carnegie Mellon, and the competitions associated with the LEGO name. Of course, it is your choice as to the components you wish to use.

LEGO NXT works well in the middle school setting. The programming language associated with this material is called NXT-G. The NXT is also applicable to the high school level where the programming language may be NXT-G, ROBOTC, labVIEW, and Java. The LEGO NXT brick is a very powerful platform to use to introduce

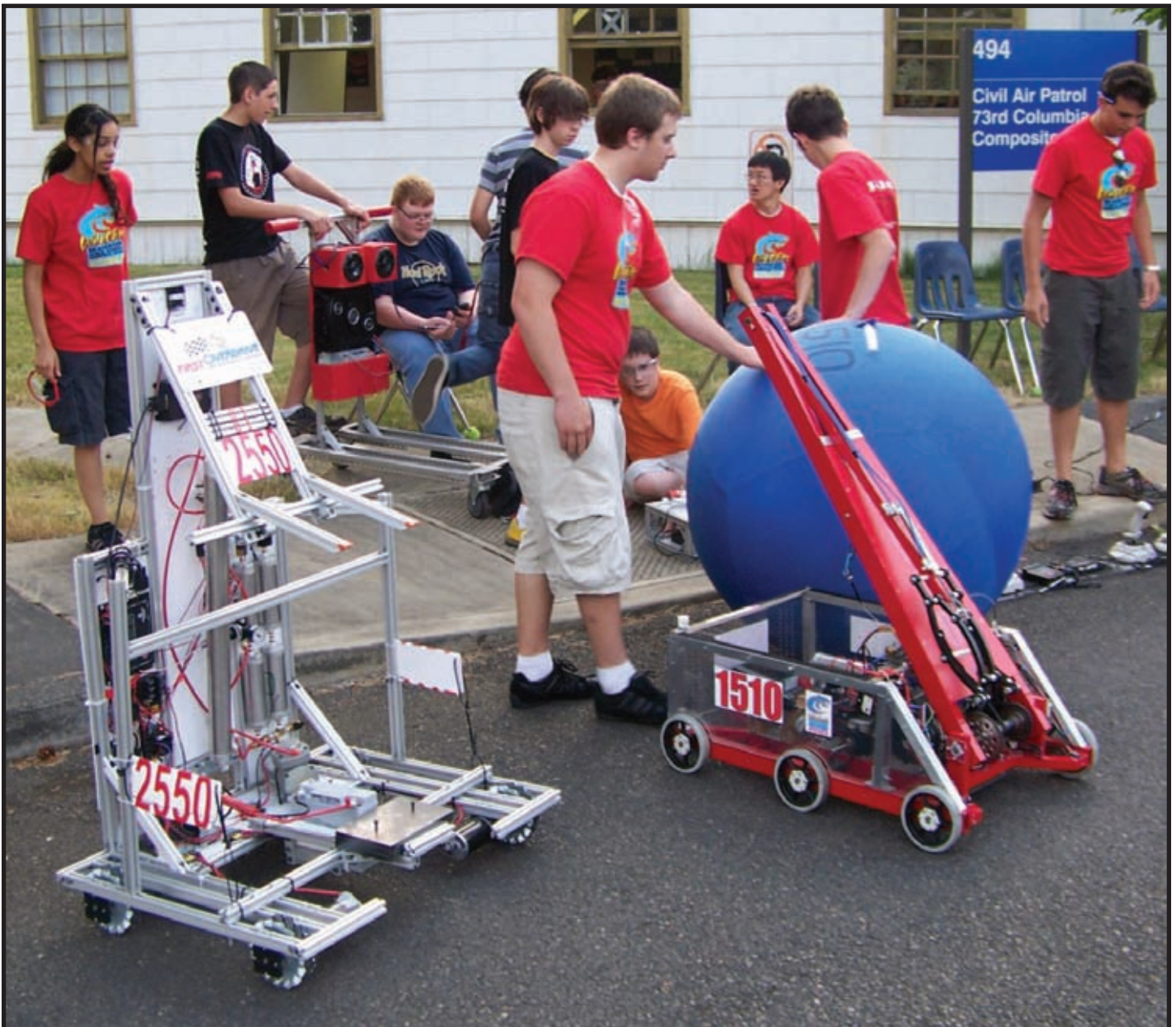
robotics.

Remember, you get what you pay for...so if you are not able to buy the LEGO®-type robotics equipment you will have to be a little more patient and innovative.

Some steps to follow to organize your students for robotics are:

- Research curriculum and resources and decide what you want to teach and how to integrate robotics in your required curriculum.
- Student teams for classroom purposes should be set up in groups of 2-4 students per robot. Some competitions, such as FIRST LEGO League, limit team size to 10 students.

- Define the role of each member of the team. For instance: (1) engineer (builder); (2) software specialist (programmer); (3) information specialist (gets the information and materials for the team to move forward or communicates the directions); (4) project manager (keeps the team on task and facilitates problem solving).
- Identify what technology and materials are required. Such items as one computer per robot, one robot per team, ample space and storage, and backup components in case of breakdown should be considered. Also, make sure you have adequate system backup by using a separate disk or memory stick for each team.
- Write a budget and get funding. Consider robots, programming software, materials, etc. when planning. As of this printing, the LEGO costs were: LEGO MIND STORMS Education NXT Base Set = \$280; and the NXT Software 2.0 = \$80 (this is for one individual set). There are packages with multiple sets also.
- Follow this curriculum's lesson format to give an introduction and background prior to procedural steps, extensions, and review.
- At the end of each lesson, share common problems and solutions, collect any written worksheets, provide test(s), if available, and move on to next lesson.
- At the end of instructional period, clean up LEGO parts and return them to sorting trays, save all programs for each group, and assign any homework questions.
- You may decide to assign projects for a 2-3 week process. Be sure to provide a rubric of what is expected and plenty of time to complete. At the end of the project time, have each group present their solutions and how they arrived at them.



Robots and Robotics

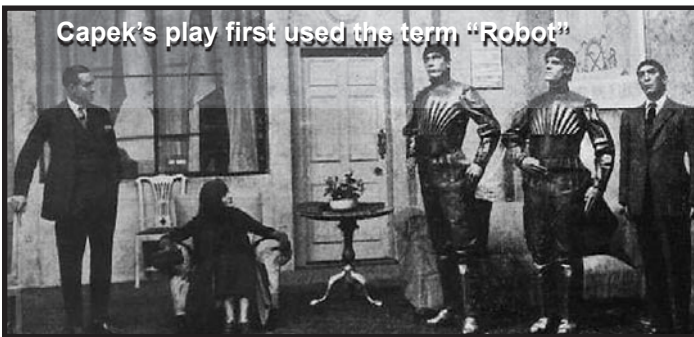
According to the Robot Institute of America (1979) a robot is:

“A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.”

The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots. There is no consensus on which machines qualify as robots, but there is general agreement among experts and the public that robots tend to do some or all of the following: move around; operate a mechanical limb; sense and manipulate their environment; and exhibit intelligent behavior, especially behavior which mimics humans or other animals.

History of Robots

- **~270BC** - An ancient Greek engineer named Ctesibus made organs and water clocks with movable figures.
- **1818** - Mary Shelley wrote “Frankenstein” which was about a frightening artificial lifeform created by Dr. Frankenstein.
- **1921** - The term “robot” was first used in a play called “R.U.R.” or “Rossum's Universal Robots” by the Czech writer Karel Capek. The plot was simple: man makes robot then robot kills man!

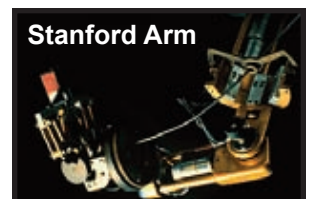


- **1941** - Science fiction writer Isaac Asimov first used the word “robotics” to describe the technology of robots and predicted the rise of a powerful robot industry.
- **1942** - Asimov wrote “Runaround,” a story about robots which contained the “Three Laws of Robotics:”
 1. A robot may not injure a human, or, through inaction, allow a human being to come to harm.
 2. A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law.
 3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

- **1948** - “Cybernetics,” an influence on artificial intelligence research, was published by Norbert Wiener.
- **1956** - George Devol and Joseph Engelberger formed the world’s first robot company in Ewing Township, New Jersey.
- **1959** - Computer-assisted manufacturing was demonstrated at the Servomechanisms Lab at Massachusetts Institute of Technology (MIT).
- **1961** - The first industrial robot was activated on the assembly line in a General Motors automobile factory in New Jersey. It was called Unimate.



- **1963** - The first artificial robotic arm to be controlled by a computer was designed by researchers at Rancho Los Amigos Hospital in Downey, California. The Rancho Arm was designed as a tool for the handicapped and its six joints gave it the flexibility of a human arm.
- **1965** - Dendral was the first expert system or program designed to execute the accumulated knowledge of subject experts. It was done at Stanford University by Edward Feigenbaum, Bruce Buchanan, Joshua Lederberg, and Carl Djerassi, along with a team of highly creative research associates and students.
- **1968** - The octopus-like Tentacle Arm was developed by Marvin Minsky.
- **1969** - The Stanford Arm was the first electrically-powered, computer-controlled robot arm developed by Victor Scheinman at Stanford University in California.
- **1970** - Shakey was introduced as the first mobile robot controlled by artificial intelligence. It was produced by Stanford Research Institute (SRI) International.
- **1974** - A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed by David Silver from MIT.



- **1979** - The Stanford Cart, rebuilt by Hans Moravec from Stanford University, crossed a chair-filled room without human assistance. The cart had a television camera mounted on a rail which took pictures from multiple angles and relayed them to a computer. The computer analyzed the distance between the cart and the obstacles.



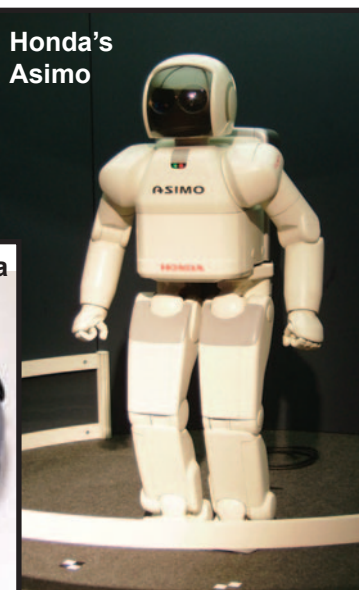
Since 1979, robots and robotics have rapidly evolved and have rapidly become an almost invisible presence in our society. We have employed robots in everything from manufacturing to military to the space program. Robotics is used at the International Space Station and is becoming more and more integrated into our daily world.



Uses of Robots

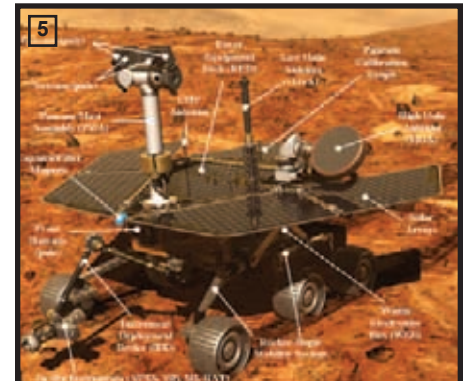
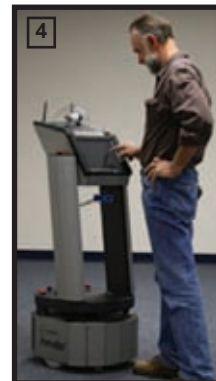
In early times, robots were used for imagination and entertainment in the form of books and plays. Today, robotic pets, lawn mowers, and vacuum cleaners are already on the market for everyday use.

Following the success of their Aibo robot dog, Sony developed a humanoid entertainment robot named QRIO. Honda's Asimo welcomes



customers to their showrooms in Japan. Toshiba built a robot that can play volleyball. Fujitsu's HOAP-2 performs Japanese Sumo wrestling stances, as well as moves from the Chinese martial art Taijiquan.

Rapid advances are being made in robotic control systems, artificial intelligence, neural networks, and in the miniaturization, sophistication, and reliability of electronic circuitry, sensors, and actuators. These are all contributing to a steady increase in the capabilities of robots. Robots currently under development may become widely used in the food, clothing, nuclear, and offshore industries, as well as in healthcare, farming, transportation, mining, and defense. Robots are also being used to further man's knowledge of and access to space.



- (1) Robotic surgical system
- (2) IED detonator - robotic device that will detonate a buried improvised explosive device
- (3) Robotic automation for industrial purposes in a foundry
- (4) Guide and security robot
- (5) Mars rover detail

The career opportunities in this field are limited only by our imagination. As green technology becomes more important to our planet, robots and robotics may play vital roles in the solutions to some of our global problems. From humanitarian efforts to provide life's necessities, to the world's population, to the exploration of planets and stars, we are looking to robots to help us achieve these goals.

Lesson 1: What is a Robot?

Activity Credit: This lesson plan was created by Teachers' Domain.

Teachers' Domain (www.teachersdomain.org) is an online library of more than 1,000 free media resources from the best in public television. The Web address for this particular lesson is http://www.teachersdomain.org/resource/eng06.sci.engin.design.lp_robot/.

Objectives:

Students will comprehend what makes a machine a robot; identify several different robots and the tasks that they do; and comprehend that engineers design robots to do specific tasks.

National Standards:

National Science Standards:

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology of science
- Science as a human endeavor

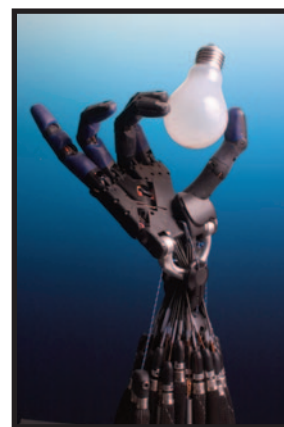
Unifying Concepts and Processes

- Form and function

National Technology Standards:

Standard 6: Students will develop an understanding of the role of society in the development and use of technology.

Standard 9: Students will develop an understanding of engineering design.



Materials:

- science/technology notebooks or paper and pencil
- drawing materials (pencils, crayons, etc.)
- internet access to use "Multimedia Resources" associated with this lesson (optional)

Note: The "Multimedia Resources" associated with this lesson can be downloaded at the Web address for this lesson from Teachers Domain in the heading above. These resources include:

- LEGO® Robots (QuickTime Video)
- Engineering for the Red Planet (QuickTime Video)
- Anatomy of a Rover (Flash Interactive)
- Kismet (QuickTime Video)
- RoboSnail (QuickTime Video)
- Robofly (QuickTime Video)
- Design Inspired by Nature (Flash Image)



Background:

Most people think of robots in humanlike terms: communicating and doing things like people would. But this specific subset of robots is actually not very common. A robot can be defined as a mechanical device that is capable of performing a variety of tasks on command or according to instructions programmed in advance. Engineers design robots to perform complex tasks more easily and with greater accuracy. Some everyday examples of robots include:

- automatic car washes
- vending machines
- automatic doors
- robotic arms used in manufacturing
- remote control cars and trucks
- automatic teller machines (ATMs)

Procedure:

Note: If possible, arrange computer access for all students to work individually or in pairs.

1. Write the word robot on the board and ask students how they would describe a robot. Have students record the class comments in their science/technology notebooks or divide the class into groups of 4 and have each group write their responses on chart paper and present to the class.

2. Have the students draw a picture of a robot in their notebooks. Tell them the image can be one of a real robot or an imaginary one (maybe a movie image). Have them make a list of the task(s) that their robot is capable of performing. These may also be shared with the class.

3. Introduce the definition of a robot: “A mechanical device that is capable of performing a variety of tasks on command or according to instructions programmed in advance.” Compare how their ideas in number 1 and their drawings in number 2 fit with this definition.

4. (This is where you may want to show the LEGO QuickTime Video and the Engineering for the Red Planet QuickTime Video from the Multimedia Resources.) Ask why engineers design robots and brainstorm some of the reasons for using robots: for example, they’re good for performing boring, repetitive tasks and can go where it is not practical or safe for humans to venture. In short, robots are developed for practical purposes, including efficiency, safety, and convenience.



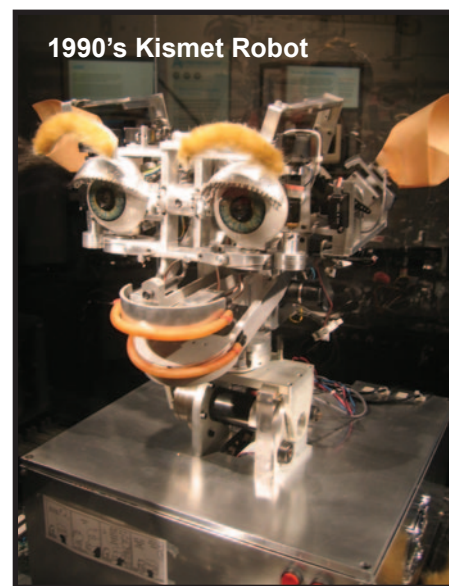
5. Have students (individually or in pairs) observe an actual robot, the Mars rover, in detail and record the different types of tasks it is capable of doing. (You can use the Anatomy of a Rover Flash Interactive for this portion of the lesson.)

6. Assign students the task of identifying and observing robots around them, noting the specific functions that they are designed to do. These robots should be ones the students see in their everyday lives, but the exercise can also be extended to include ones they have read about or seen in movies.

7. After the students share their results from number 6, ask them how their definition of robot has changed.

8. Discuss where engineers get their ideas for different kinds of robots. For example, engineers will research how other people have solved problems similar to the one that they want their design to address. Expanding on someone else’s ideas is often how advancements in technology are made. Sometimes ideas come from nature. Show the RoboSnail QuickTime Video and the Robofly QuickTime Video at this time, discussing the different approaches engineers take in designing robots to perform certain functions. You can expand your discussion to include the concept of biomimicry (an emerging discipline that studies nature’s best ideas and then imitates these designs and processes to solve human problems) and then show the Design Inspired by Nature Flash Image collection.

9. Show the Kismet QuickTime video and discuss how the original idea for this robot was to model how humans interact with one another.



10. Wrap up the lesson with a discussion about what a robot is and have students write in their science/technology notebooks how their ideas have changed and what influenced the change.

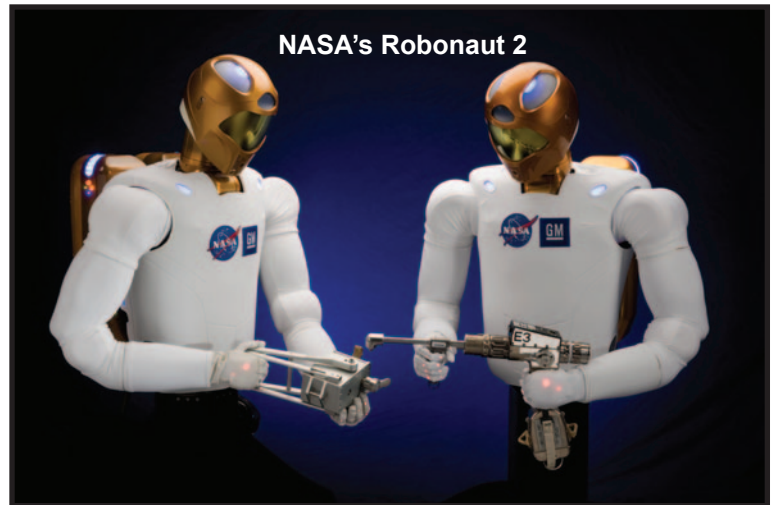
Questions for understanding and extension:

1. What is a robot? Does it have to look like a human? (A robot is a mechanical device that is capable of performing a variety of tasks on command or according to instructions programmed in advance. In order to be a robot, a device does not have to look human.)

2. Why do engineers design and build robots? (Engineers design robots to help with boring, repetitive tasks and to go where it is unsafe or impractical for humans to go. Robots are developed for practical purposes, including efficiency, safety, and convenience.)

3. Where do the ideas for different kinds of robots come from? (Ideas come from researching and expanding on someone else's ideas and, sometimes, from nature.)

4. Can you think of a situation in which a robot would be necessary or at least helpful? (Answers will vary.) What specific characteristics would designers need to include in such a robot? (Answers will vary.)

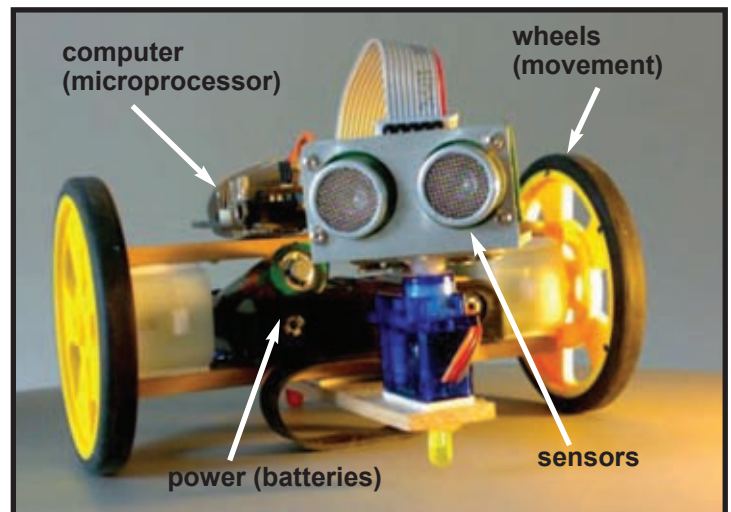


Robots Review

A robot is a machine which has some ability to interact with physical objects and to be given electronic programming to do a specific task or to do a whole range of tasks or actions. It may also have some ability to perceive and absorb data on physical objects, or on its local physical environment, or to process data or respond to various stimuli. This is in contrast to a simple mechanical device, such as a gear or a hydraulic press or any other item, which has no processing ability and which does tasks through purely mechanical processes and motion.

Robots can include these parts:

- effectors (simulating arms, hands, legs and feet)
- sensors (simulating senses that detect objects or things like heat and light and convert the objects' information into symbols that computers understand)
- computer (simulates the brain that controls the robot)
- equipment (includes tools and mechanical fixtures)
- power source (such as batteries or solar cells)



Lesson 2: Robots Are Sense-ible!

Objectives:

Students will learn the limitations of mechanical sensors used by robots.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Understandings about science and technology
- Unifying Concepts and Processes
- Evidence, models, and explanation

Materials:

- large box about the size of a paper copier box (with lid off) (You will need a box for each group of 4-5 students)
- wooden dowel (probe) about 30 cm long (1/2 inch thickness)
- piece of fabric that cannot be seen through to cover the box opening
- masking tape
- objects to “feel” (these objects should be difficult for anyone to guess by probing them - example: feather duster)



Background:

About 1.9 square meters (2.08 square yards) of skin covers the average adult. There are nearly 4 million nerves that detect touch and more than 16,000 nerves that detect temperature in a typical adult's skin. Robots, for the most part, are pretty numb in comparison. Except for small clusters of sensors specifically embedded for certain tasks, the machines don't “feel” the objects around them. Scientists around the world are working on new technology to help robots do a better job of “feeling” their environment, such as organic transistors for sensing touch and pressure sensors within the graspers of the robot. The new sense of touch for the next generation of robots will assist in such areas as crime fighting (a pressure carpet in homes that distinguishes footprints of the family members and strangers), robotic-assisted minimally invasive surgery, and robotic bomb squads that can dismantle a bomb without destroying the package. Robotics are a big part of our future space program, as well.

How difficult is it for mechanical sensors to collect data in robotic systems? The human sense of touch, as mentioned, is so well developed that it is hard to imagine what type of information a mechanical hand might be able to get. See how “sensible” you can be when you try to gather information about the size and shape of an object using nothing but a mechanical sensor.



Robotic hand sensitive to pressure. Robotic Air Powered Hand with Elastic Ligaments (RAPHaEL) was designed by undergraduate students at Virginia Tech's Robotics and Mechanisms Laboratory.

Procedure:

1. Discuss how the sense of touch allows you to determine much about your environment, such as the size and shape of objects. Also, talk about how difficult it would be to “feel” something using a mechanical probe.

2. Set up a sensory box for each group of 4-5 by using the masking tape to secure the fabric over the opening to the box so students cannot see inside. Turn the box on its long side with the fabric facing toward the person that is doing the probe.

3. Put the students in groups of 4-5. Have each group member pick a mystery object to place in the box. Make sure that the object is hidden from view until it is placed in their box. (The teacher can also be the one who chooses the objects.)

4. Each group should then turn the box around so students (other than the group member placing the object) cannot see the object. Make sure the fabric is concealing the contents of the box before you turn it around.

5. Have each member of the group take turns collecting as much information as possible about the object by carefully slipping the wooden dowel under the fabric and using the dowel to probe the object.

6. After all team members have collected their data using the probe, they should collaborate to draw a picture of what they think the object looks like. After the group is finished with their picture, have them compare it to the actual object.

7. Repeat the procedure with the other objects in the group.

8. Share each group’s results with the class.

Review:

This activity demonstrates the robotic sensor for touch. A touch sensor senses and indicates a physical contact between the object carrying the sensor and another object. The programming of the robot then tells the object carrying the sensor what is to be done. The robotic hand still has a long way to go to become as sophisticated as the human hand, but engineers and scientists are making improvements and hope to have robots doing such delicate duties as surgical procedures some day.



Canadian Space Agency's Dextre Robot

Extensions: (Questions for understanding)

1. What would happen if you changed the diameter of the dowel (smaller or larger thickness) to gather the data?
2. What would happen if you shortened or lengthened the dowel?
3. Would changing the material that the probe is made from help you collect more exact data?

Lesson 3: Can a Robot Tie Your Shoes?

Activity Credit: The Tech Museum of Innovation (<http://www.thetech.org/robotics/>)

Objectives:

Students will learn that everyday tasks that seem easy to us are difficult, if not impossible, for a mechanical robot.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Understanding about scientific inquiry

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Unifying Concepts and Processes
- Form and function

Materials:

- one pair of shoes that tie per team
- 2 tongue depressors per student in team three
- masking tape for team three
- 1 pair of heavy gloves per student in team two
- 1 set of pliers for team four
- 2 sets of pliers for team five
- enough sets of pliers per student in team six

Procedure:

1. After discussing the challenges that robots face in grasping tools and manipulating them, divide class into teams of two. (You can have as many teams as it takes to involve the whole class.)
2. One person in each team should be wearing or have available shoes that tie with laces.
3. Tell the class that they are each going to pretend to be a robot with limited hand movement and grasping ability. A “controller” on each team will give robot directions, as needed.
4. Give each team a task concerning tying shoes with some robotic handicaps.
 - Team One – A team “controller” gives robot directions while other team member “robots” tie shoes blindfolded.
 - Team Two – Team “controller” gives robot directions while other team member “robots” tie shoes with heavy gloves on.
 - Team Three – Each team member is a “robot” who tapes tongue depressors onto their thumbs and tries to tie shoes. All members problem solve what worked and what didn’t.
 - Team Four – One person on the team ties the shoes with a set of pliers in one hand.
 - Team Five – One person on the team ties the shoes with two sets of pliers — one in each hand.
 - Team Six – Each person uses one set of pliers and works together to tie the shoes.

Background:

Use of the hand for grasping and manipulation requires a high level of dexterity. The hand consists of a palm with four, folding fingers and one opposing thumb. Each finger has three bones with joints that allow bending. The thumb has two bones with two joints. Extensors straighten the fingers out. Flexors allow the fingers to bend and grasp. The thumb has two flexors that help with holding onto objects. The hand is one of the most sophisticated aspects of the human body. With it we can operate tools, articulate ideas, or perform delicate tasks, as well as gather information about our environment.

Robots are machines that do specific tasks. Robots have limitations on how much like humans they can be. The process of manipulating objects is difficult because the robot has limited movement and needs a human to program the instructions for each movement. Even though robots are evolving into sophisticated machines that are more autonomous and display more humanlike movement, there is a long way to go for these human helpers to be able to conquer some simple human tasks, like tying a shoe. Getting robots to work together to accomplish a task is a cutting-edge technology that may help conquer more delicate human tasks.

5. This can be a race or timed event to see how difficult it is to do a simple task without the use of the special features of the human hand.

6. You may choose to have a race between two people in the class trying one of the team challenges described after the initial tests are done in teams.

Review:

Robot helpers like Robonaut 2 (currently a member of the International Space Station crew) will be able to help astronauts in the everyday duties that need to be accomplished in the space station. Each of R2's arms can carry about 20 pounds (9.1 kg), and its hands have articulating fingers and thumbs. The robot, which builds on NASA's work with its first

Robonaut project, should be able to use the same tools astronauts on the space station use. This activity shows the limitations of flexibility and movement that a robot has to overcome in order to do everyday activities. The programming of these robots also has to be precise so that the mission is accomplished.

Extension:

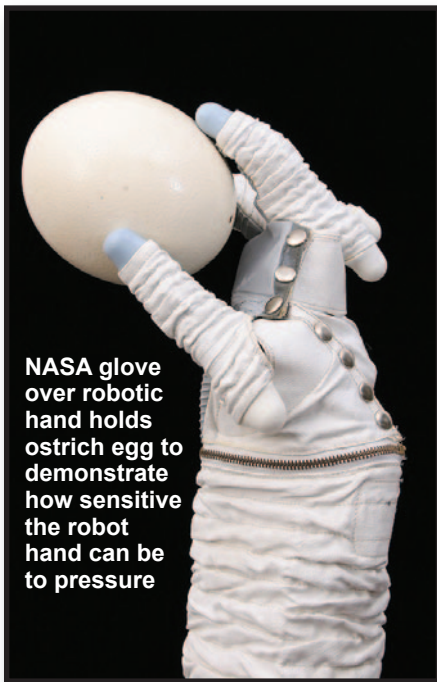
1. Have students research what the engineers and scientists in robotics are doing to improve the way robots can use their "hands." Some sources might include:

http://future.wikia.com/wiki/Hands_And_Grips

<http://www.physorg.com/news175354299.html>

any other site found by searching the web

2. Have students research what spinoffs for daily living can come from improved robotic dexterity technology. What other uses might we have for robots that can manipulate objects similar to humans?



NASA glove over robotic hand holds ostrich egg to demonstrate how sensitive the robot hand can be to pressure



Robonaut holding a ball

Robonaut (pictured on right) is a humanoid robot that was developed to function as an astronaut assistant. The dexterous manipulation technology in its hands might one day be used in applications, such as human prosthetic development. Other uses for robotic hands may be found in industry, medicine, military, and space exploration.

Lesson 4: Robot Hand (End Effector)

Activity Credit: NASA

Objectives:

Students will construct a robotic-like hand and demonstrate how it works and what makes it functionally different from a human hand.

National Standards:

National Science Standards:

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in society

Content Standard G: History and Nature of Science

- Science as a human endeavor

Unifying Concepts and Processes

- Evidence, models, and explanation
- Form and function

Materials:

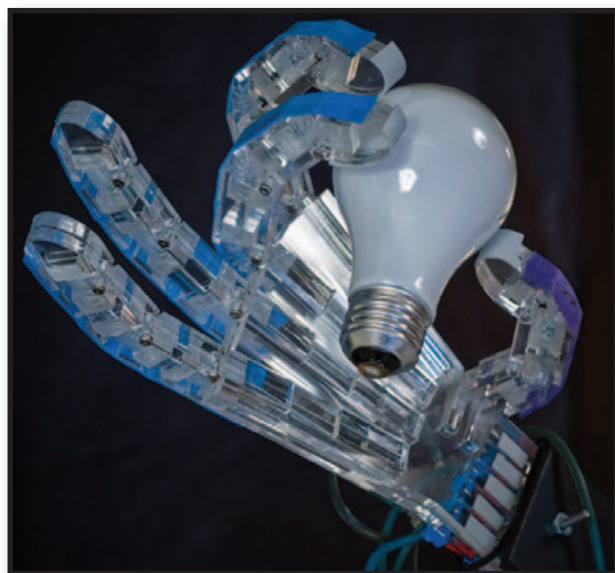
- Styrofoam food tray (or large plate) - one per student
- marker pens (permanent type)
- ballpoint pens
- duct tape
- hot glue and white liquid glue
- scissors
- cellophane tape
- straws (one per student)
- string (two large rolls)
- rubber bands (approximately 3 per student)
- paint stick (one per student)
- robot hand (end effector) handout (one per student)

Background:

Robotic arms and hands are used in the space shuttle and the space station to build, repair, investigate, and more. Robotic hands are being developed to imitate the size, shape, and degrees of freedom of the human hand. The many uses of such a robotic hand include prosthesis, industry, and space exploration, just to name a few.

Many robot hands have three fingers to reduce cost and simplify control, such as those needed by industry. Some robots do not even have fingers, but, instead, have the needed tools directly attached to them.

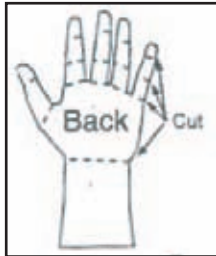
In order to study and replicate the human hand, computer models have been used.



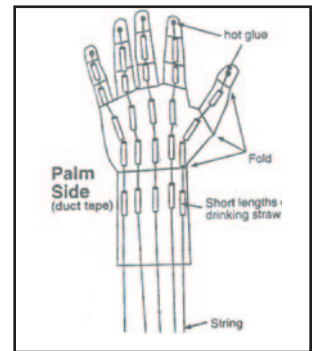
Above: Virginia Tech's RAPHaEL (Robotic Air Powered Hand with Elastic Ligaments) robotic hand; Left: Robonaut holding a ball

Procedure:

1. Discuss what an end effector is and tell students that they will be creating a rather complex end effector model.
2. Students should place one of their hands, with fingers spread, on the smooth side of a Styrofoam food tray or plate. Use a permanent marker pen to trace the hand up to the forearm.
3. Students should then cover the entire tracing of their hands with duct tape and press it smooth.
4. Next, trace hands again on the duct tape and cut out with scissors.
5. Turn the cut-out hand over and score the Styrofoam on each finger with the point of a ballpoint pen where the knuckles should be. Bend each joint gently (the Styrofoam will make a popping noise). The tape on the other side becomes the hinge on the knuckle. Also, make a wrist joint the same way.



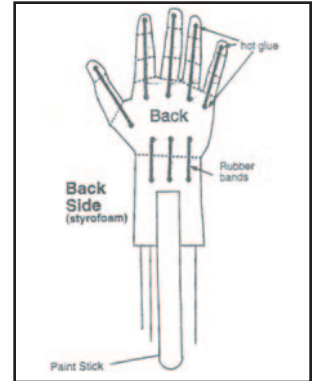
6. Use cellophane tape to tape short lengths of straw on the palm side (duct-taped side) of the hand where indicated on the diagram.



7. Knot 5 pieces of string on one end and hot glue knots to fingertips. Run the other end of the strings through the straws, as shown.

8. Glue or tape a paint stick to the forearm.

9. Tape pieces of rubber bands across each knuckle joint on the Styrofoam side to serve as muscles and tendons. The rubber bands must be stretched enough so that all the fingers on the hand will open automatically.



10. Work the hand by pulling the strings, one at a time to control each finger, or all at once to open and close entire hand.

Review:

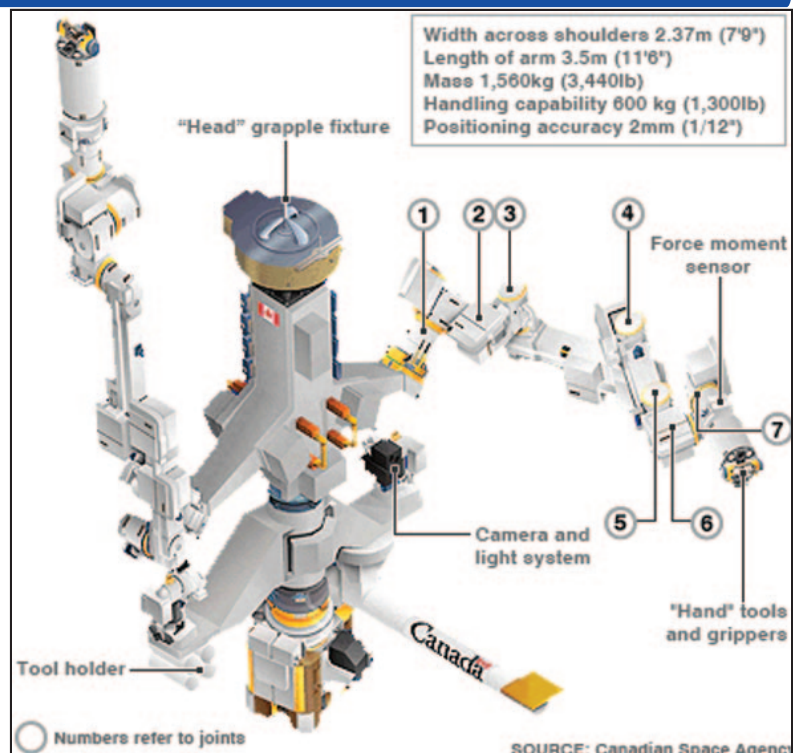
This activity demonstrates how an end effector is constructed to resemble a human hand. The robot uses the end-effector to accomplish a task. The end-effector may be holding a tool, or the

end-effector itself may be a tool. Scientists are trying to find ways to make the robot hand more like that of a human hand so that the robot can handle detailed and complex tasks.

Extension:

1. Have students research the end effectors used by NASA and tell what duties each is designed to perform. (An end-effector can be a sensor, a gripping device, a paint gun, a drill, a sampling device, an arc welding device, etc.)

2. Have students think of a job that an end effector could do and design an end effector for the job.



Student Directions (End Effector Hand-out)

Name _____ Date _____

After constructing your robot hand, answer the following questions:

1. What is an end effector? _____

2. Compare your model with the simple model of the hand in the picture:



3. How do you think robotic hands will be useful in the future?

(Use the back side of the paper if you need more space.)

Robot Hand (End Effector)

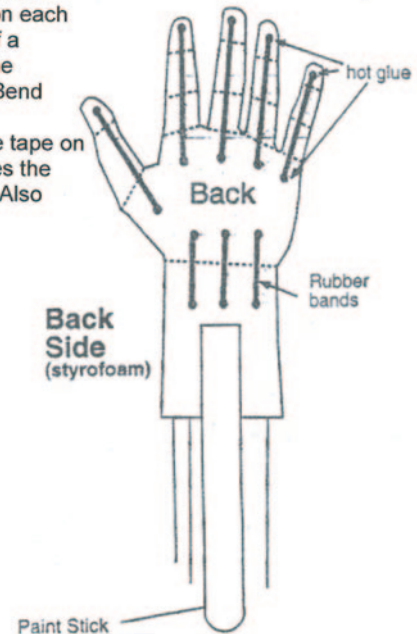
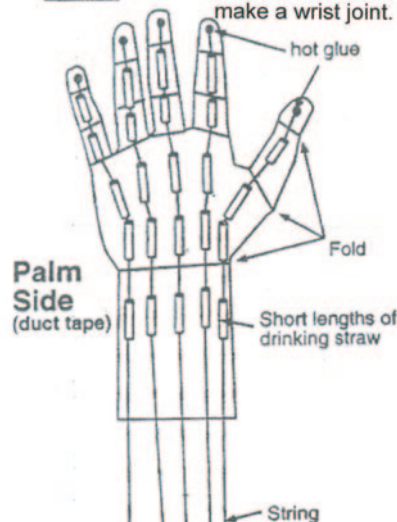
Instructions

1. Place your hand with fingers spread on the smooth side of a Styrofoam food tray. Use a marker pen to trace your hand.
2. Cover the tracing of your hand with duct tape and press it smooth.
3. Trace your hand again on the duct tape and cut it out with scissors.

5. Glue short lengths of straw on palm side of hand where indicated on a diagram.
6. Knot 5 pieces of string on one end and glue knots to fingertips. Run the other end of the strings through the straws as shown.
7. Glue a paint stick to the forearm.
8. Glue pieces of rubber bands across each knuckle joint on the Styrofoam side to serve as muscles and tendons. The rubber bands must be stretched enough so that all the fingers on the hand will open automatically.
9. Work the hand by pulling on the strings.



4. Turn the hand over and score the Styrofoam on each finger with the point of a ballpoint pen where the knuckles should be. Bend each joint gently, the Styrofoam "pops." The tape on the other side becomes the hinge on the knuckle. Also make a wrist joint.



Lesson 5: Robotic Arm and End Effector.....

Activity Credit: NASA

Objectives:

Students will develop a robotic arm and an end effector to interact with the environment.

National Standards:

National Science Standards:

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in society

Content Standard G: History and Nature of Science

- Science as a human endeavor

Unifying Concepts and Processes

- Evidence, models, and explanation
- Form and function

Background:

An end effector is the device at the end of a robotic arm, designed to interact with the environment. The robot's use determines the type of end effector needed. Robotic end effectors can be used in many applications. NASA has used end effectors on the robotic arms on the Space Shuttle and the International Space Station. The Space Shuttle's Remote Manipulator System (RMS) has been moved in varied ways to accomplish a particular mission. The RMS has seven degrees of freedom (DOF). In robot terms, this means that the arm can bend and rotate in seven different directions to accomplish its tasks. Like a human arm, it has a shoulder joint that can move in two directions (2 DOF); an elbow joint (1 DOF); a wrist joint that can roll, pitch, and yaw (3 DOF); and a gripping device (1 DOF). The gripping device is called an end effector. That means it is located at the end of the arm and it has an effect (such as grasping) on objects within its reach.

Other space utilization may include tools used on rovers for purposes of scooping up samples, imaging the contents of the scoop, and performing science experiments.

NASA has also introduced a Robonaut that uses an end effector at the end of the arm that more closely simulates the human hand. Robonaut 2 is the latest addition to this effort. This robot can lift 20 lbs. with each arm and has nimble hands, fingers, and opposable thumbs using dexterous, human-like features to accomplish many jobs.

Materials:

- Battery-operated toy cars (one car for each group of four)
- Masking tape
- Assortment of materials to build a robotic arm, such as long strips of cardboard, binder clips, brads, clothespins, craft sticks, plastic straws, fishing line, hangers, paper clips, rubber bands, tape, and twine. (Other items can be added if the instructor chooses.)
- Assorted small materials for robotic arm to pick up, such as table tennis balls, marshmallows (these are science manipulatives, **not** food items), cotton balls or any other light weight, and three-dimensional objects



Procedure:

1. Purchase enough battery-operated toy cars for each group of four to have one.

2. Introduce the lesson and give some background information on the robotic arm and end effector. Invite discussion and research. *Remind the students that the robotic arm should be manually operated and attached to the battery-operated toy car.

3. Have students brainstorm how they could build a robotic arm in their groups. *Have them bring the materials they will need to build their arms to class in preparation for the actual building day.

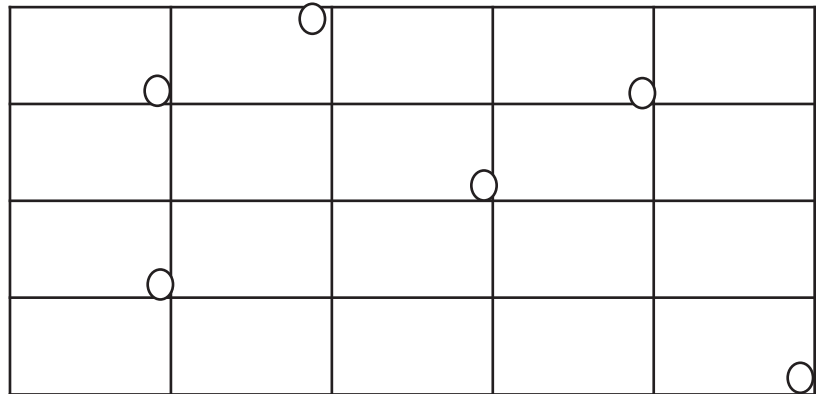
4. Have the student build and attach their robotic arm to the battery-operated car in their group. Provide time for the students to test and modify their robotic arm, as needed.

5. Using masking tape, construct a gridline box on the floor based on the pattern (to the right) with the circles representing a small object the robotic arm must pick up.

6. Place a small object at each circle in the grid that the robotic vehicles must pick up.

7. Allow each team the opportunity to operate their robotic vehicle on the grid, picking up one object each turn. Each team's robotic vehicle must travel only on the gridlines. If the vehicle strays off a gridline, there is a 5-second penalty. Determine how many tries and how much time will be allowed for each object retrieval attempt.

8. Have student teams use the Team Worksheet on pages 20 and 21 to draw their robotic vehicle, record gridline runs and related times, and answer team discussion questions.



Review:

This activity involves not only the robot hand with end effector, but also allows the students to use engineering to problem solve. One of the important objectives in the development of robots is to enable robots to interact with their environment. Interaction

is often accomplished with some sort of arm and gripping device or end effector. The robot hand may be used to pick up and move an object or used as a tool to complete a task. Robotic end effectors, such as the ones on the Mars Rovers, can be useful in gathering data.

Extension:

1. Order a copy of the NASA video “Let’s Talk Robotics” from NASA Core at: <http://corecatalog.nasa.gov/item.cfm?num=011.0-04D> and allow students to view it and discuss.

2. Have students discuss the pros and cons of each group’s design and come up with a plan for a class robotic arm incorporating all of the ideas from the discussion.

3. Instructions on “How to Build a Cardboard Robotic Arm” can be found at: <http://knol.google.com/k/how-to-build-a-cardboard-robotic-arm#>.



NASA Robonaut Teamwork

Mobile Robotic Arm and Gridline Box Collection

Team Worksheet

Team Name: _____ Date: _____

Team Members: _____

Directions: You are a member of a team of students, all working together to design and build a robot arm out of materials provided from home or the classroom. The robotic arm should be manually controlled and attached to a battery-operated toy car. You are responsible for testing and modifying your design to drive along a course and collect items such as paper cups, table tennis balls, marshmallows, etc. Your goal is to design a working robotic arm that can stay on the moving platform (the toy car) and travel along the gridlines of the course, picking up items as it goes along the course. You will be timed on how long it takes your mobile robotic arm to accomplish the mission. Five-second penalties will be given each time your toy car strays off a gridline. You may have a practice run and modify your design before the actual run. Trial and error are part of the design process. There is no “right” answer to the problem - your team’s creativity will likely generate an arm unique from the others designed in your class. Make sure the items you choose for the construction of your robotic arm are approved by your teacher.

Drawing of Your Team’s Design:

Chart of All Teams' Timed Gridline Runs

Object #	Time Team	Time Team	Time Team	Time Team	Time Team
1					
2					
3					
4					
5					
6					
Totals					



Questions about your design process:

1. What materials did you choose to construct your robotic arm? _____

2. How did working as a team help in the design process? _____

3. What did you learn from the designs developed by other teams? _____

4. Name three industries that make use of robotic arms. _____

Lesson 6: “Out of Sight” – Remote Vehicle

Activity Credit: NASA

Objectives:

Students will operate a robotic vehicle while it is not directly in view of the driver of operations team. This activity will allow students to learn about the challenges faced while trying to operate a planetary rover and how teamwork and problem solving help accomplish a common goal.

National Standards:

National Science Standards:

Content Standard E: Science and Technology

- Abilities of technological design

Content Standard G: History and Nature of Science

- Science as a human endeavor

National Mathematics Standards:

6. Problem Solving

- Solve problems that arise in mathematics and in other contexts

4. Measurement

- Apply appropriate techniques, tools, and formulas to determine measurements

National Technology Standards:

5. Technology Research Tools

6. Technology Problem-Solving and Decision-Making Tools

Materials:

- Remote control car for each 4 to 6 member teams (you may consider borrowing these from students)
- Measuring devices (meter stick or tape measure) - 2 per team
- Rocks or other marking devices to set up “waypoints” in which to drive car
- Background information on planetary rover teleoperation
- Student calibration and mission planning sheets. 1 copy per team (pages 25, 26, 27)
- Stopwatches
- Compasses
- Protractors
- Pencils
- Masking tape for marking starting lines
- Optional: Calculators and video camera and monitor



Background:

These rover teams are much like the real FIDO (Field Integrated Design and Operations) rover field tests that took place out in the Mojave Desert in the spring of 1999. The FIDO Rover was calibrated and tested in much the same manner, with the “drivers” operating out of a small mobile trailer, away from actually watching the rover drive during the field testing. High School students from LAPIS (the LAPIS acronym encompasses the first initials of the four sites that participated in the pilot program: Los Angeles, CA, Phoenix, AZ, Ithaca, NY, and St. Louis, MO) drove the rover via the internet. While these tests were taking place, there were scientists, engineers, and students in the field to measure the actual results of



FIDO during field testing in the Mojave Desert

the commands for the rover to move. In doing so, the rover software and responses to the commands could be tested while still here on Earth to see if they were, indeed, accurate. That way, when the commands are given to the Athena Rovers on Mars (FIDO is the Earth test rover for the Athena Mars Exploration Rovers - Spirit and Opportunity), the scientists and engineers can have a better idea of what movement they might expect.



FIDO with Sojourner Rover and MER (Mars Exploration Rover)

Procedure:

1. Divide the class into teams of 4 to 6 students (smaller groups are better if you have enough robotic vehicles).

2. Randomly select two designated drivers (test driver and calibration driver) for each team. The drivers need to be isolated away from the vehicle course so they do not know the set up.

3. During the time away from the course, the calibration driver (with the help of the test driver) will calibrate the remote vehicle as to:

- Distance traveled in 5 seconds (3 distance trials)
- Time needed to turn in 45° increments, a full 360°
- Optional - Whatever other type of calibration test to get information you think might be important

4. The rest of the team (course calibrators) will work on setting up a symmetrical course that the vehicle will drive through (the same course design for each team - multiple courses could be set up all at once to speed up the team testing) using the rocks or other items to serve as way points (or targets) that each vehicle will try to navigate to.

5. Have the course calibrating team members measure the distance to each object and record the distance on the course sheet (make sure all the teams are following the same path so that the times and accuracy can be compared).

6. Have the course calibrating team measure the angle of turn needed to point the remote vehicle toward the next waypoint. (Note: The turns should be made in 45° intervals for easier measurement.)

7. Once the drivers and course calibrating team

members have finished their tasks and recorded all necessary data, all the team members can merge their data sets to create a mission plan scenario. Neither driver should still be allowed to actually see the course that the remote vehicle will be driving; this is to be a “blind” test. The measured distance to each waypoint can be calculated with the speed and time necessary to achieve each waypoint destination. This should give the driving time necessary for the remote vehicle to travel to each waypoint destination. Time and coordinates should be given for each waypoint direction (i.e. 12 seconds straight; stop; left 45°; 17 seconds straight; stop; right 90°, etc.).

8. Once the data is calculated, the test driver will have the course calibration team members place the remote vehicle at the designated course starting line. The test driver (who is not in direct eye-contact with the vehicle) will drive the team vehicle according to the mission plan calculations taken from the calibration speed tests and course measurements. A team member can read out the commands and another member can time the remote vehicle’s travel.

9. The calibration team members watching the test will measure the resulting movement of the remote vehicle and record the actual distance traveled by the remote vehicle next to the premeasured data.

10. After the actual driving results are compared with the precalculated results, determine the adjustments needed to drive the remote vehicle more accurately and repeat the test to see if the changes helped.

Review:

This activity simulates the preparation that has to be done in order for the rovers to receive and carry out the missions that the Earth teams have planned for them. When the Earth team “drivers” perfect the commands with a simulation on Earth and hone the exact sequence of movements for the rover, they upload those commands and send to the real rover. Then, as the sun is coming up on Mars, the rover wakes up, receives a communications uplink from Earth, processes the commands, and goes to work while the rover drivers go to sleep. All possible problems have to be planned for before the actual instructions are given.

Evaluation

The students can work in teams or individually. Assessment can be based on completion of student worksheets and team participation using a rubric.

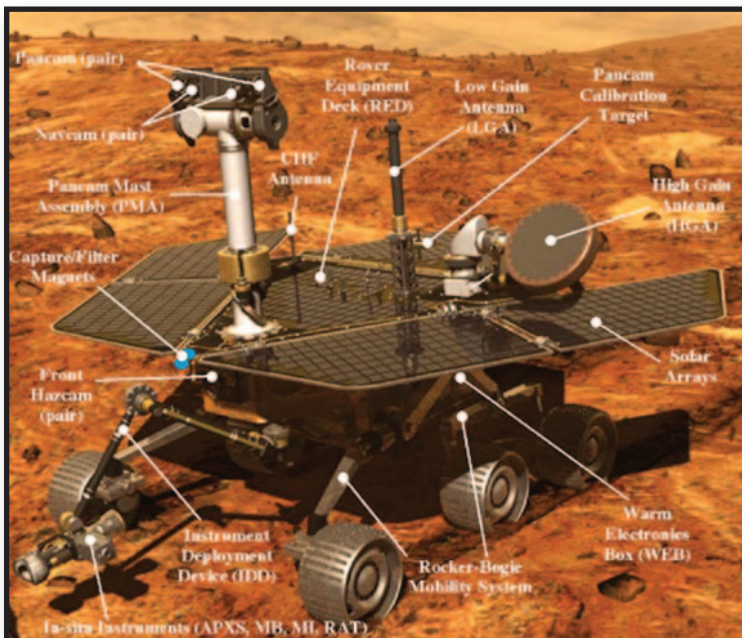
“Out of Sight” Student Questions

Directions: Answer the questions using the results from your remote vehicle test.

1. Did your actual test results differ from the calculated distance results? If so, how and why?
2. What were the differences in operating the remote vehicle this way (not being able to see the course that the vehicle would have to drive on) versus just driving the remote vehicle the regular way?
3. What changes could you have made that would have given you better results?
4. What do you think would be the hardest challenge about driving a remote vehicle on another planet?



Part of the Mars Exploration Rover team



Parts of Mars Exploration Rover used for gathering data and operating on Mars



Next Mars Exploration Rover, Curiosity, is viewed by team of engineers and technicians

“Out of Sight” Student Worksheet

Team Name: _____

Test Driver and Calibration Driver: _____

Course Calibration Team Members: _____

Calibration Tests:

Using a stopwatch and measuring tool, record the time or distance of the remote vehicle during the following tests. Make sure that all measurements are taken the same way each time and from the same starting place to insure they are accurate. Mark the starting place with a piece of masking tape.

Calibration Test	Distance or Time
How far did the remote vehicle travel in 5 seconds?	Distance trial #1 =
How far did the remote vehicle travel in 5 seconds?	Distance trial #2 =
How far did the remote vehicle travel in 5 seconds?	Distance trial #3 =
Add the three distances together and divide by 3 (the number of distance trials) to get the average distance the remote vehicle traveled in 5 seconds =	Average distance for trials =
Divide the average distance (answer in box above) by 5 seconds to get the distance per second =	
Time needed to turn 45° = Time needed to turn 90° =	
Time needed to turn 135° = Time needed to turn 180° =	
Time needed to turn 225° = Time needed to turn 270° =	
Time needed to turn 315° = Time needed to turn 360° =	
Time needed to come to a full stop =	
Other remote vehicle test data: What else do you want to know? Invent your own test. My test is:	



"Out of Sight" Mission Planning Sheet

Team Name: _____

Test Driver and Calibration Driver: _____

Course Calibration Team Members: _____

Directions:

Using your data from the remote vehicle calibration tests and the measurements made by the calibration team, design a mission plan that will get your remote vehicle to each of the targets (waypoints) on the driving course. Use the average speed (length/second) and the measured course distances to plan how long your rover will run in each direction to reach each waypoint. Also figure out how many degrees the rover must turn (how many seconds it takes to turn the right distance from the calibration tests) to go to the next waypoint. List your moves on this sheet.

Remote Vehicle Mission Plan

1. Distance to waypoint #1 = _____
Remote vehicle time to waypoint #1 = _____
2. Turn _____ degrees for next waypoint
Remote vehicle time to turn _____ degrees = _____
3. Distance to waypoint #2 = _____
Remote vehicle time to waypoint #2 = _____
4. Turn _____ degrees for next waypoint
Remote vehicle time to turn _____ degrees = _____
5. Distance to waypoint #3 = _____
Remote vehicle time to waypoint #3 = _____
6. Turn _____ degrees for next waypoint
Remote vehicle time to turn _____ degrees = _____
7. Distance to waypoint #4 = _____
Remote vehicle time to waypoint #4 = _____
8. Turn _____ degrees for next waypoint
Remote vehicle time to turn _____ degrees = _____
9. Distance to waypoint #5 = _____
Remote vehicle time to waypoint #5 = _____
10. Turn _____ degrees for next waypoint
Remote vehicle time to turn _____ degrees = _____
11. Distance to waypoint #6 = _____
Remote vehicle time to waypoint #6 = _____



Students using LEGO NXT robot for challenge.

“Out of Sight” Student Course Calibration and Actual Results of Remote Vehicle Tests

Team Name: _____

Test Driver and Calibration Driver: _____

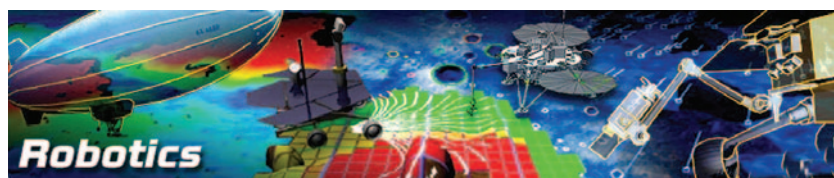
Course Calibration Team Members: _____

Directions:

Fill in the chart with the data your team collected:

1. Record the waypoint measurements taken along the course before the remote vehicle driving test.
2. Record the actual data collected as the remote vehicle runs the course. Were there any differences between the two measurements? If so, record the difference in the “Difference in Results” box.

Actual Measurements to Waypoints	Actual Distance Traveled by Remote Vehicle	Difference in Results
Waypoint #1 measurement		
Waypoint #2 measurement		
Waypoint #3 measurement		
Waypoint #4 measurement		
Waypoint #5 measurement		
Waypoint #6 measurement		



Lesson 7: Leland and the Robotic Arm

Activity Credit: Discovery Now

Written and produced by NIA (National Institute of Aerospace), supported by a generous grant from the American Institute of Aeronautics and Astronautics (AIAA) and Lockheed Martin
Website is www.discoverynow.us

Objectives:

Students will: examine how and why Leland Melvin switched from a career in professional football to a career as an astronaut; discover how difficult it is to guide a robot through a series of simple tasks; use Internet resources to deepen their understanding of the benefits of using robots in space exploration; and create a digital collage comparing model “robotic arms” to actual robotic arms.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural and human induced hazards
- Science and technology in local, national and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

National Educational Technology Standards:

- Creativity and Innovation
- Communication and Collaboration
- Research and Information Fluency
- Critical Thinking, Problem-Solving & Decision Making
- Digital Citizenship
- Technology Operations and Concepts

National Mathematics Standards:

- Algebra
- Measurement
- Problem Solving
- Communication
- Connections
- Representation

Orbiter docking system and RMS from STS 122



Materials:

(For each team of students)

- Digital camera
- Blindfold
- Masking tape
- Tongue depressors or popsicle sticks
- Basket with handle (for holding items)
- Marble
- Tennis ball
- Pencil
- Pair of shoes with shoelaces

Also needed:

- Computer with Internet access for each team of students



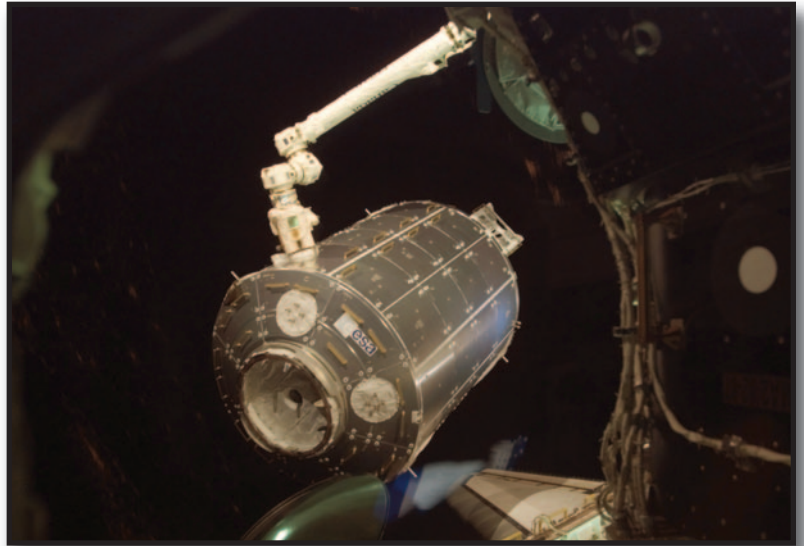
Leland examines reflection in water droplet

Background:

Sometimes, robots are better suited than humans for space exploration. They can travel to worlds too far away or too dangerous for human explorers and extend the work schedule of a crewed space mission. Unlike humans, robots can endure uncomfortable or dangerous physical conditions, perform tasks tirelessly, and not become bored or distracted. Robots can also operate in airless conditions, making them very useful for certain types of work.

The Space Shuttle Remote Manipulator System (RMS) robot arm is one example of a working relationship between humans and robots. First used successfully aboard the STS-7, the RMS is the most common type of robotic arm used in space. The 15-meter-long arm recreates the movements of the human arm, and includes a 360-degree movement at the wrist, something humans are unable to do. It has seven degrees of freedom (DOF), which means that the arm can bend and rotate in seven different directions to accomplish its tasks. The arm also has joints at the shoulder, elbow, and wrist and has a gripping component called an end effector.

The RMS has been used for remote assembly operations and for grappling as a positioning and anchoring device for astronauts working in space. It has also been used to grab the Hubble Space



RMS moving Columbus lab to ISS

Telescope and bring it into the Shuttle's payload bay. The RMS helped spacewalking astronauts repair the telescope and replace some of its components. Controlled by an astronaut inside the orbiter, the RMS served as an extension of the operator's arm. (On Leland Melvin's first shuttle mission, the crew of STS-122 used the RMS to move the Columbus lab from the payload bay of Space Shuttle Atlantis and attach it to the International Space Station.)

Procedure: (Part I)

1. Use the Discovery Now radio clip, Leland Melvin, to discuss with your students their understanding of how Leland's career change resulted in teaming with robots in space. Click on the Leland Melvin radio clip at <http://www.discoverynow.us/index.html>.

2. The following questions will help guide your discussion:

- How did Leland Melvin begin his career as an astronaut?
- What was Leland Melvin's "backup plan" after he was injured?
- How do you think Leland Melvin's football career prepared him for his mission aboard STS-122?
- What was the significance of Leland Melvin's mission aboard STS-122, Space Shuttle Atlantis?

To read more about STS-122, go to http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts122/main.



Leland Melvin (far left) and his STS 122 team

Procedure: (Part 2)

1. Divide the students into teams of three.
2. Create a course for the robot to maneuver by setting up six chairs or desks in alternating (zig-zag) positions and placing the objects (marble, tennis ball, and pencil) on or near the chairs or desks.
3. Place a shoe, with untied laces, on the last chair.
4. Assign one student to the robot's role, another student to the role of the controller, and the third student to the role of recorder using the digital camera. Remind the student to remain silent while in the robot role.
5. Loosely tape the tongue depressors to the robot's fingers with the masking tape. Remind students to make sure that the robot's fingers are not taped too tightly.
6. Blindfold the robot once the tongue depressors are secured.
7. Hand the robot the basket.
8. Following verbal instructions from the controller, the robot will move along a prescribed course, stopping on cue to pick up the marble, tennis ball, and pencil and placing each item in the basket.
9. Direct the robot to a chair and instruct the robot to:
 - a. place the basket on the floor
 - b. pick up the shoe
 - c. sit in the chair
10. Instruct the robot to tie the shoelaces.

Questions to help lead discussion after Part 2:

1. When you were the robot, how difficult was it to complete your tasks?
2. Which task was the most difficult to accomplish?
3. As the robot, did you find that being unable to speak made the tasks more difficult?
4. What sensory devices could you add to the robot to make controlling it more precise? (Research sensory devices for robots to find out your options.)

Extension:

1. Using the digital camera, have student teams create a digital collage to illustrate the differences between their "robotic" hands and the robotic arms used in space.
2. Please remind students to use only images that they have permission to include. Review copyright and copywrongs by watching the Nortel LearnIT video tutorial at:
http://nortellearnit.org/technology/Digital_Ethics/.
3. Encourage students to put a descriptive title screen, credits, and references at the end of the project.



Spheres



Robonaut



Rover Spirit

Review:

This activity shows the difficulty of programming a robot to perform a task with no experiential background or ability to communicate with the person giving instructions. Being able to problem solve and communicate and share as a team to accomplish a mission are skills that robots are not able to perform yet. Robots are designed to perform certain missions and are not adaptable.

Evaluate:

Use a rubric to evaluate the project including the digital collage. A rubric for the digital collage can be found at:

<http://www.nortellearnit.org/resources/Handouts/>.
Find out what the robots above do for NASA...

Resources:

1. Leland Melvin is Taking His Vision Into Space -
http://www.nasa.gov/mission_pages/shuttle/behindthescenes/profile_lelandmelvin.html
2. Leland Melvin: Astronaut By Chemistry -
http://www.nasa.gov/astronauts/l_melvin_profile.html
3. Leland Melvin: NASA Biography -
<http://www.jsc.nasa.gov/Bios/htmlbios/melvin.html>
4. NASA Astronaut Leland Melvin's Football Story -
http://www.space.com/missionlaunches/nfl_series_day4_of_5.html
5. Nasa and Robots - Types of Robots
<http://prime.jsc.nasa.gov/ROV/types.html>
6. The Remote Manipulator System -
<http://www.prime.jsc.nasa.gov/ROV/rms.html>

Lesson 8: Strong-Arm Tactics

Activity Credit: Copyright © 2004 TeachEngineering—
Resources for K-12. TeachEngineering.org. Used with permission.

Objectives:

Students should:

- Describe similarities and differences between human arms and robotic arms.
- Describe challenges engineers have when designing robotic arms.
- Define degrees of freedom.
- Understand how a robotic arm depends on its number of degrees of freedom.
- Describe cause-effect relationships between control commands and outcomes within a system.
- Use oral and listening skills to communicate directions.

National Standards:

National Science Standards:

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Unifying Concepts and Processes
- Evidence, models and explanation
 - Form and function

Materials:

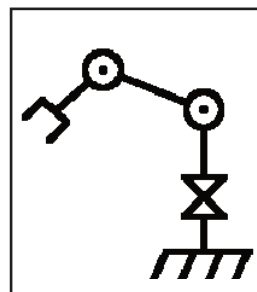
For each team:

- Robotic Arm (kits can be purchased for about \$90 at hobby stores or online at such sites as www.mindwareonline.com - put robotic arm in the search box; www.makershed.com/ProductDetails.asp?Product=CodeMKEL13; NXT Mindstorms version to use LEGOS and put together found at: www.nxtprograms.com/robot_arm/index.html; and another example found in the Procedure part of this activity)
- 1 rock that can fit into the robot arm's gripper
- Stopwatch or timer
- Cloth blindfold
- Worksheet found on page 34

Background:

The degrees of freedom, or DOF, is a very important term to understand. Each degree of freedom is a joint on the arm; a place where it can bend or rotate or translate. You can typically identify the number of degrees of freedom by the number of actuators on the robot arm. A simple robot arm diagram (on right) shows 3 degrees of freedom.

The original engineering design requirements for the Spirit and Opportunity rovers included a single robotic arm with an extensive range of motion and ability to hold four inspection instruments. The final robotic arms have five degrees of freedom and are capable of moving in just about any direction. This movement is enabled by three joints, a shoulder, elbow, and wrist, which the engineers modeled after a human arm. To provide the five degrees of freedom, mechanical engineers used many geared motors at the shoulder, elbow, and wrist.



Three degrees of freedom diagram



Mars rover Spirit's robotic arm with 5 degrees of freedom

Introduction:

Have you ever seen someone dance like a robot or machine? What is their secret to this mechanical motion mastery? It's simple, really; while dancing, they limit their body's number of degrees of freedom at any given time and move in jerky motions. The term degrees of freedom describes a certain direction of motion - and its opposite - in a joint or connection. This can best be illustrated by joints in your body. Your elbow and knee joints, which are like a door hinge, can only swing open and closed and, thus, only have one degree of freedom. Some joints have multiple degrees of freedom. Your wrist and neck can move up and down and side to side, and, can rotate clockwise and counterclockwise, thus having three degrees of freedom. Your body as a

whole has well over 100 degrees of freedom! The trick to dancing "the robot" is to move while utilizing only a few degrees of freedom.

If you think dancing like a robot is difficult, then just imagine being the engineers who designed the robotic arm for the Mars rovers. Their challenge was to design a versatile and agile arm using only five degrees of freedom. In comparison, your arm alone has over 28 degrees of freedom! Engineers from several disciplines, including mechanical, electrical, and computer science, had to come together to design the arm.

Career Connection -

Jessica Calhoun



At Johnson Space Center, Jessica Calhoun has been a Payload Deployment and Retrieval System (PDRS) flight controller and mission designer for STS-130 and STS-133. Jessica has been responsible for planning and coordinating the robotics activities for these shuttle flights, as well as writing the procedures that will be used by the crew to complete robotic maneuvers in space. As a flight controller she has monitored the robotic arm and payload motion and its proximities to the orbiter, ISS, and space station robotic arm (called the Space Station Remote Manipulator System).

When asked what prepared her for a job in robotics with NASA, she replied, "As a child, I attended Space Camp at the U.S. Space & Rocket Center in Huntsville, Alabama, and another space-themed camp program in Baton Rouge, Louisiana, at the Louisiana Art & Science Museum, which helped to instill an interest in spaceflight and exploration. In college, I pursued a Bachelor of Science degree from Georgia Tech in aerospace engineering (and graduated) in 2008. I am now in graduate school at the University of Houston, pursuing a master's degree in systems engineering. I also gained valuable work experience working at ExxonMobil, Syngenta, Lockheed Martin, and the U.S. Space & Rocket Center before starting my career here at NASA."

Jessica Calhoun was asked to tell what advice she would give to students who were interested in a career in robotics and her answer was, "Get involved! Find a local robotic team or attend a space camp one summer. There are so many different programs to do and toys you can buy that will teach you how to apply robotics. Keep informed of new technologies and learn more about them! Start thinking of different ways robotics can be used in our world and start designing. Build a prototype and see where it takes you!"

Procedure:

1. Purchase robotic arm(s) and if in a kit format, make sure all assembly is complete before the activity. This might also be a learning experience to help students understand how the robotic arm works. (CAP has found an example of a robotic arm for classroom use - T-Bot II. Two possible sources: Pitsco - a set of 10, which will supply a group of 20 if they are in pairs, - costs around \$370 - these are kits and can be ordered at <http://shop.pitsco.com/store/detail.aspx?ID=5410&retest=1&bhcp=1> or if you want one kit for \$39.95, go to <http://shop.pitsco.com/store/detail.aspx?ID=5409>. Another source is LEGO Education for the set of 10 at <http://www.legoeducation.us/store/detail.aspx?ID=1668&bhcp=1>. These are just a couple of examples from searching the internet for T-Bot II or you could search “robotic arms for classroom use.”)

2. Gather all other supplies.
3. Neatly draw and label a large picture of the controller to use as a visual aid for the activity. This can be done electronically, on a transparency for overhead use, on a whiteboard or chalkboard, or on poster board.

4. Discuss the robotic arm and discover any previous knowledge the students possess on robotic arms.

5. Set up the arm in an easily accessible and visible area to the students. Draw or mark two circles on opposite sides of the arm. These circles will be the initial and final destinations of the rock.

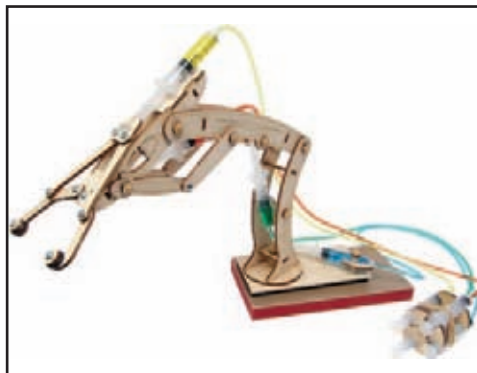
6. In front of the class, show the students how the mechanical arm works by demonstrating its degrees of freedom with the controller. Also, pick up the rock with the arm, and move it to the other marked circle.

7. Separate the class into teams of two or three (you may decide who will do the different tasks or simply give a card with the numbers 1, 2, and 3 or Controller, Eyes, and Timer to each member of the team).

8. Explain to the students that they will have to



Parts for building the T-Bot II hydraulic robotic arm



T-Bot II assembled

repeat the same operation, but in teams of two (or three) with particular guidelines.

- The student with the controller will be blindfolded and named the “Controller.”
- The other student must act as the “Eyes” and tell the Controller what to do.
- If there is a third student on the team, that person can be the official timer.
- The team with the fastest time will be the winner.

9. Have students review the controls on the robotic arm, which should be drawn and labeled neatly on the board. The Eyes need to come up with a systematic and effective way to communicate to the Controller to efficiently move the rock. The Timer can offer suggestions as to how this might be accomplished. Allow the class 10-15 minutes to develop their moving strategy.

10. Student teams should repeat the process several times to perfect

their strategy.

11. At the beginning of each team trial, position the arm straight up in the air in the same position to make each trial fair between teams.

12. Time how long it takes each team to move the rock and announce the winner. What was the secret to their success?

Did they develop a strategy and communicate effectively? Discuss as a class.

NOTE: Remind students to be very careful with the robotic arm, as they are expensive and can be damaged.

Extension:

1. Have students write an explanation of degrees of freedom. (Robotics degrees of freedom explained by Robotics Research Group at the University of Texas in Austin - http://www.robotics.utexas.edu/rrg/learn_more/low_ed/dof/)

2. Have students draw a diagram of the 6 degrees of freedom. (Interactive explanation of 6 degrees of freedom of a robotic arm found at - <http://www.thetech.org/exhibits/online/robots/6deg/>.)

Evaluation:

A rubric may be used to evaluate the performance of each team. To create a rubric, you may want to use an electronic format such as

<http://www.rubrics4teachers.com/> (you can generate a blank rubric and fill in your assessment criteria).

Complete student questions on page 34.

Review:

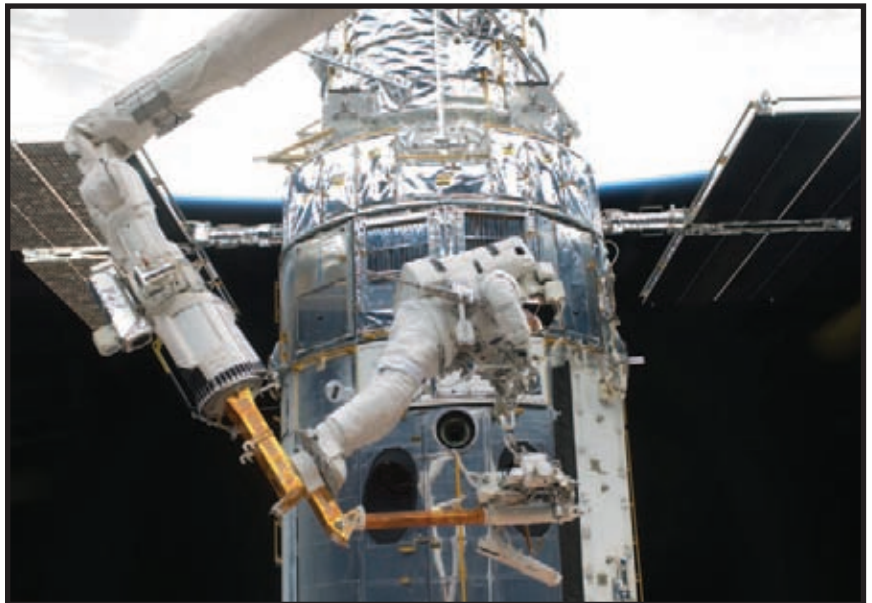
This activity gives you a perspective of the difficulty of controlling a robot arm from both a machine's and a programmer's point of view. The machine must complete a task with only the information provided by the programmer. If any information is missing or misunderstood, the mission is not completed correctly. On the other hand, if the programmer does not understand the systems within the robot and how they operate as a whole, then the programmer cannot send the correct set of instructions to the robot.

Student Questions for Strong-Arm Tactics Activity

Team members: _____

Date: _____

1. Does a robotic arm have more or less degrees of freedom than a human arm?
2. How many degrees of freedom does a door hinge have? What part of the arm is the door hinge analogous to?
3. From the role of playing the Eyes and Controller, which one is from a machine's point of view and which is from a programmer point of view?
4. What three engineering professions will come together to create a robotic arm?
5. What role will each play?



Answers to student questions:

1. A robotic arm has less degrees of freedom than a human arm. Typical robotic arms have 5 degrees of freedom, whereas the human arm has over 26 degrees of freedom.
2. A door hinge has 1 degree of freedom since it is analogous with our elbow.
3. The Eyes is from a programmer's point of view. They must take the information from the sensors, their eyes, and think of an effective method to communicate and control how the robotic arm moves. Conversely, the Controller is from the machine's point of view. They cannot see what is going on and can only take directions from the programmer.
4. The three engineering professions that come together to create a robotic arm are: electrical, mechanical, and computer science.
5. The electrical engineer will select the electrical components, like motors and circuitry of the arm; the mechanical engineer will design the shape and structure of the arm, select the number of degrees of freedom, and decide what material to build the arm from; and the computer science engineer will create a code to use the electronics to control the mechanics of the arm.



NASA engineer checks mechanics on Phoenix Lander robotic arm



**From early grades
to college to
career - robots
and engineering
excite and
challenge the
mind....**

Lesson 9: Robotic Arm

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Objectives:

Students will develop a comprehension of how simple machines can work together to power the parts of the robotic arm.

National Standards:

National Science Standards:

Content Standard B: Physical Science

- Motion and forces

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Unifying Concepts and Processes

- Evidence, models and explanation
- Form and function

Materials:

- T-Bot II robot (see sources in procedure #2)
- five 1" squared foam cubes (for extension activity)

Background:

Lever

A lever is a rigid bar that rotates around a fixed point called a fulcrum. The bar may be either straight or curved. The mechanical advantage of a lever is the ratio of the length of the arc on the effort side to the length of the arc on the resistance side. Fortunately there is an easier approximation for the mechanical advantage of a lever: the length of the effort arm divided by the length of the resistance arm. The arm is measured from the fulcrum to the point of effort or resistance, as the case may be.

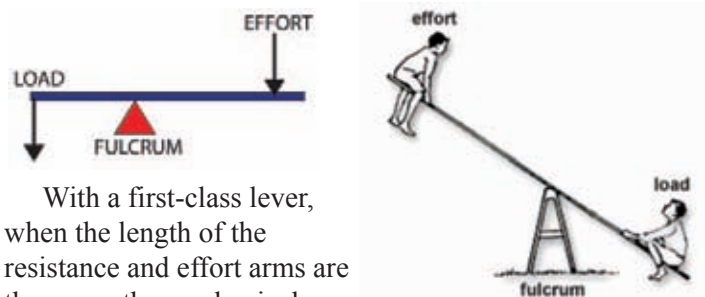
There are three different classes of levers. The class of a lever is determined by the location of the applied and resistance forces relative to the fulcrum.



First-Class Lever

In a first-class lever the fulcrum is located at some point between the effort and resistance forces. Common examples of first-class levers include crowbars, scissors, pliers, tin snips, and playground seesaws.

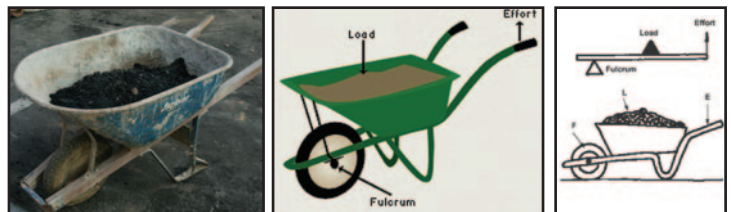
A first-class lever always changes the direction of force (i.e. a downward effort force on the lever results in an upward movement of the resistance force) and may or may not change the force itself. A first-class lever is illustrated below:



With a first-class lever, when the length of the resistance and effort arms are the same, the mechanical advantage is 1. In such a situation there is no increase in effort, nor do you have to move a greater distance. The advantage is that the effort side gets pushed downward, thus benefiting from gravity, while the resistance moves upward. When the fulcrum is closer to the resistance force (resistance arm less than effort arm), the effort force is increased, but there is a corresponding decrease in both the distance the resistance force moves and the speed with which it moves. Conversely, when the fulcrum is closer to the effort force (resistance arm > effort arm), the resistance force is decreased and there is a corresponding increase in both the distance the resistance moves and the speed with which it moves.

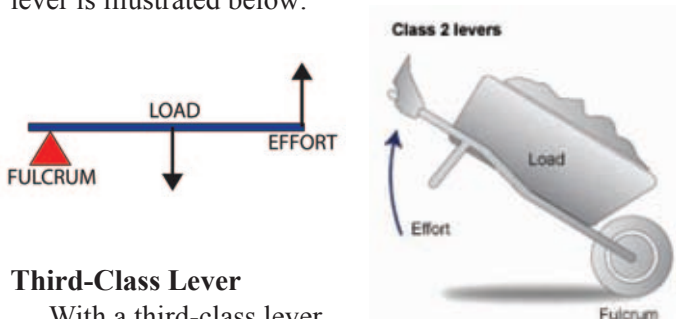
Second-Class Lever

With a second-class lever, the resistance is located between the fulcrum and the effort force. Common



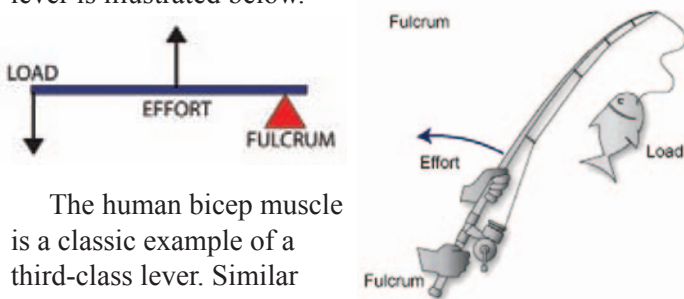
examples of second-class levers include nut crackers, wheel barrows, and certain types of bottle openers.

In a second-class lever, the effort and the resistance move in the same direction. When the fulcrum is located closer to the resistance than to the effort, an increase in force results. The mechanical advantage is still the ratio of the effort arm to the resistance arm. A second-class lever is illustrated below:

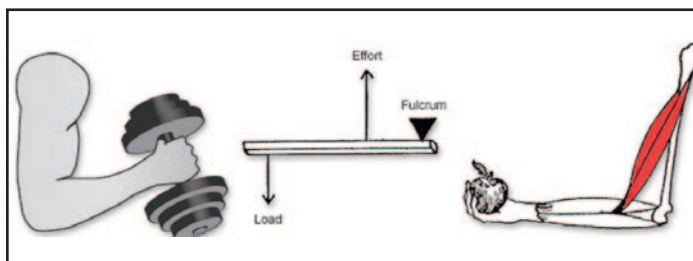


Third-Class Lever

With a third-class lever, the effort force is applied between the fulcrum and the resistance force. Examples of third-class levers include tweezers, ice tongs, baseball bats, and hockey sticks. In a third-class lever, the effort and resistance both move in the same direction. Third-class levers always decrease the output force, but gain in terms of the distance and speed with which the resistance moves. A third-class lever is illustrated below.



The human bicep muscle is a classic example of a third-class lever. Similar analogies can be drawn from almost all joints in the human body.



Mechanical Advantage:

In physics and engineering, mechanical advantage (MA) is the factor by which a machine multiplies the force put into it. The mechanical advantage can be calculated for the following simple machines by using the following formulas:

- **Lever:** $MA = \text{length of effort arm} \div \text{length of resistance arm}$
- **Wheel and axle:** A wheel is essentially a lever with one arm the distance between the axle and the outer point of the wheel, and the other the radius of the

axle. Typically, this is a fairly large difference, leading to a proportionately large mechanical advantage. This allows even simple wheels with wooden axles running in wooden blocks to still turn freely because their friction is overwhelmed by the rotational force of the wheel multiplied by the mechanical advantage.

- **Pulley:** Pulleys change the direction of a tension force on a flexible material, e.g. a rope or cable. In addition, pulleys can be "added together" to create mechanical advantage by having the flexible material looped over several pulleys in turn. More loops and pulleys increase the mechanical advantage.

Procedure:

1. Discuss the lever information found in the Background section of this activity. (Explanation of how the T-Bot II uses levers: The T-Bot II uses a third-class lever in each of its four axes of motion. A third-class lever is a lever where the force is applied anywhere between the fulcrum and the load. Levers and axes working together give the T-Bot II more movement than a single lever could.)

2. Introduce the T-Bot II robot. Make sure these kits are put together prior to this lesson. (CAP has found an example of a robotic arm for classroom use — T-Bot II. Two possible sources: Pitsco — a set of 10, which will supply a group of 20 if they are in pairs, costs around \$370 — these are kits and can be ordered at <http://shop.pitsco.com/store/detail.aspx?ID=5410&reset=1&bhcp=1> or if you want one kit for \$39.95, go to <http://shop.pitsco.com/store/detail.aspx?ID=5409>. Another source is LEGO Education for the set of 10 at <http://www.legoeducation.us/store/detail.aspx?ID=1668&bhcp=1>. These are just a couple of examples from searching the internet for T-Bot II or you could search "robotic arms for classroom use.")

3. The T-Bot II uses a third-class lever. Explain the different types of levers and have students discuss why the T-Bot II doesn't qualify as a first or second-class lever. Discuss the uses, advantages, and disadvantages of each lever type.

4. Have students (in teams of three) demonstrate and explain to each other how the third-class lever works. They should then research and discuss the possible advantages and disadvantages of this type of robotic arm. Using a PowerPoint or other presentation software, have each team present their explanations.

Review:

This activity explained how levers work in the movement of a robot arm. A robot arm works in a very similar fashion to a human arm, as a third-class lever.

Evaluation:

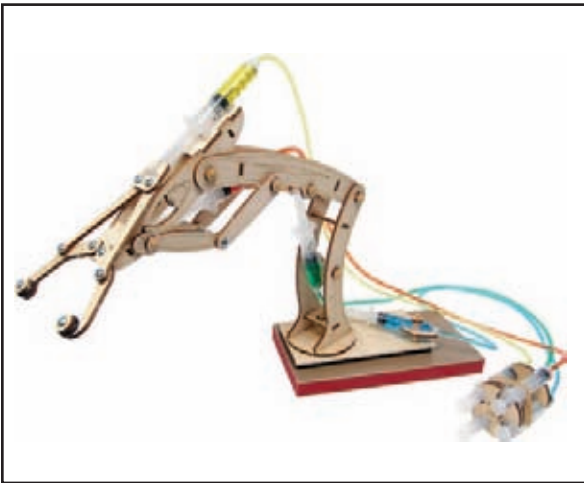
Teams can be evaluated using a rubric for each presentation. To get templates for rubrics that can be used, go to <http://www.rubrics4teachers.com/>.

Extension:

1. In a competition similar to the one in lesson 8, called “Strong-Arm Tactics,” have the teams use the T-Bot II to move four or five foam cubes (cubes should be one inch square) from one location to another (locations specified by teacher and consistent for each team). Whichever team completes the task with the fastest time is the winning team.

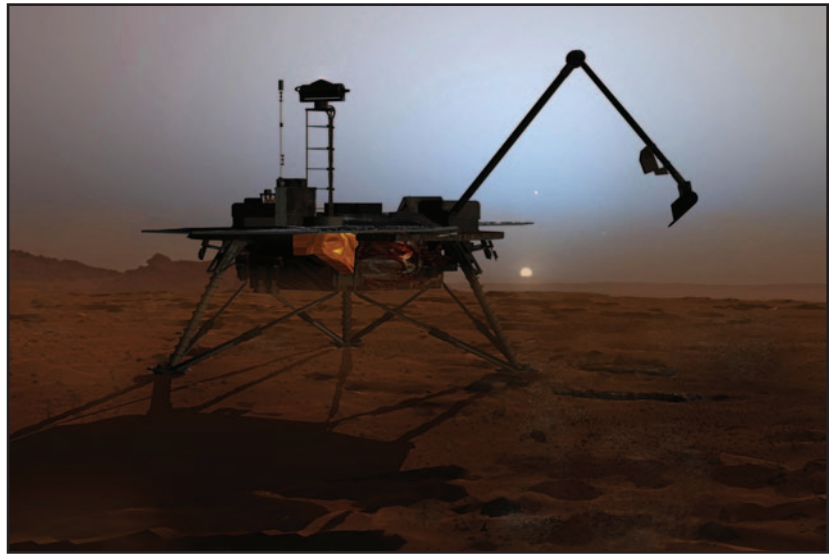
2. The T-Bot II Teacher’s Guide has activities that can be accomplished with the T-Bot II. One example of the activities in this guide is called “Domo Arigato Mr. Roboto” and can be found at <https://shop.pitsco.com/activities/item.aspx?act=26>
5. If treated carefully, this robot can be used to extend or enrich many math and science lessons.

How Robotic Arm Project Compares to NASA



T-Bot II:

See how syringes, tubes, and water work together to power the parts of this robotic arm. Each control moves one of the T-Bot II’s axes. All four controls can be used one at a time or all at once by a team of students - they try basic maneuvers or move objects as a team-building exercise! It can be used for a range of ages and educational concepts - from showing elementary students how to work together to teaching middle school students Newton’s Laws to helping high school students explore fluid mechanics.



Mars Phoenix Lander Robotic Arm:

The robotic arm is critical to the operations of the Phoenix lander and is designed to dig trenches, scoop up soil and water ice samples, and deliver these samples to instruments for detailed chemical and geological analysis. Designed similar to a back hoe, the arm can operate with four degrees of freedom: (1) up and down; (2) side to side; (3) back and forth; and (4) rotate around.

Lesson 10: End Effector

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Objectives:

Students will comprehend how the end effector is designed and assembled, as well as gain comprehension of the technological design by assembling a model.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Understandings about scientific inquiry
- Content Standard E: Science and Technology
 - Abilities of technological design
- Unifying Concepts and Processes
 - Evidence, models, and explanation

National Technology Standards:

- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 11: Students will develop abilities to apply the design process.

Materials:

For each team:

- Styrofoam coffee cups (2 for each team) Note: plastic cups may be used for durability
- 12-cm (4.72 in.) pieces of string (3 each)
- Cellophane tape
- Plastic picnic knives (serrated)
- Straw (1 each) or other items that the “effector” may be able to pick up

Background:

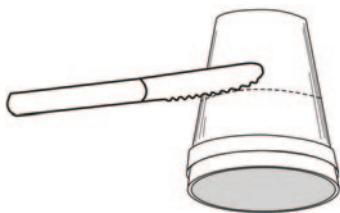
The part of the robotic arm that grabs objects is called an “end effector.” This wire-snare device is designed to fit over special grapple fixtures (knobbed pins) on the Shuttle, ISS and ISS modules.

The end effector is like a mechanical hand with a cylinder 33.2 centimeters (13.07 in.) in diameter by 25.8 centimeters (10.16 in.) deep. It contains three cables (like a snare) that close around a grapple pin onto the module. Then the cables become rigid with enough force to prevent the captured object from slipping loose.

Procedure:

1. Have students work in pairs or small groups.

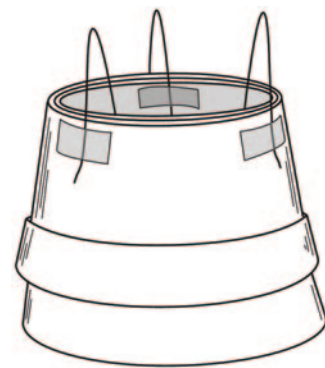
2. Nest the two cups together and cut through both cups where indicated in the diagram by the dashed line. Smooth the cut edges by scraping them with the picnic knife edge.



3. Cut three 12-centimeter (4.72 inch) lengths of strings.

4. Tape the end of the first string to the side of the inner cup just below the cut edge. Tape the other end of the string to the outside of the cup, but do not press this piece of tape tightly yet.

5. Repeat step 4 twice more, but place the strings about a third of the way (120 degrees) around the cup from the first string.



Tape the string loop from the outside of one cup to the inside of the other (as shown).

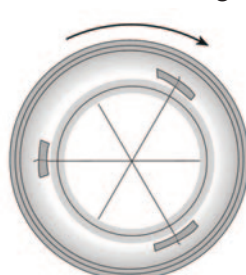
6. While holding the rim of the inner cup, rotate the outer cup until the three strings cross each other. The strings will have some slack. Pull the end of the strings on the outside until they are straight and intersect exactly in the middle of the opening. Press the tape on the outside to hold the strings.



Open position



Rotate outer cup



Continue rotating to close snares

7. Use the end effector to pick up the straw by doing the following: Have someone hold the straw upright. Open the end effector so that the strings are not crossing each other. Slip the end effector over the straw so that the straw extends down the center and not through any of the loops. Rotate the outer cup until the strings grasp the straw. Pick up the straw.



Astronaut holding on to an end effector attached to the robotic arm

Review:

The end effector used on the Space Shuttle's Remote Manipulator System (RMS) is a snare device that closes around special posts, called grapple fixtures. The grapple fixtures are attached to the objects the RMS is trying to grasp. Similarly, the end effector in this activity closes around the object it is trying to pick up and move.

Evaluation:

Have students complete the student worksheet on page 41 to check for understanding and extend the activity.

Extension:

1. Search robot sites on the Internet and review different end effector designs. How does the design of an end effector enable it to pick up and manipulate various objects?
2. Design a system that might use the end effector differently in the future of space flight.

ISS End Effector Worksheet

Name: _____

Date: _____

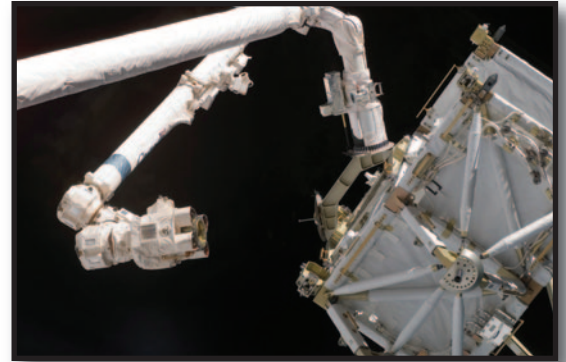
Read the following background information about the Mobile Servicing System and the “end effector” before beginning the activity:

The most complex robotic system on the ISS is the MSS (Mobile Servicing System). It consists of the Space Station Remote Manipulator System (SSRMS), the Mobile Remote Servicer Base System (MBS), the Special Purpose Dexterous Manipulator (SPDM), and the Mobile Transporter (MT). The MSS is controlled by an astronaut working at one of two Robotics Work Stations inside the ISS.

The primary functions of the MSS robotic system on the ISS are to:

- assist in the assembly of the main elements of the station (e.g. aligning newly delivered modules to the structure)
- handle large payloads
- replace orbital replacement units (plug-in equipment designed to be periodically replaced with newer units)
- support astronauts during extravehicular activities
- assist in station maintenance
- provide transportation around the station

The main component of the MSS is the 17-meter (18.59 yd.) long SSRMS robot arm. It is similar to the Shuttle RMS but will ride from one end of the station to the other on the mobile transporter, which will glide along the giant truss beam. After arriving at a worksite, the arm will grasp payloads, modules, or other structures with its wire snare end effector. If a work location is too distant for the arm to reach while still attached to the transporter, the arm can connect to an intermediate grapple fixture. Electrical power will be rerouted through that fixture. The SSRMS will then release its other end and “inchworm” itself through successive fixtures until it reaches the desired site. The SSRMS is also able to pick up and connect to the SPDM. This unit consists of a pair of 3.5-meter (3.83 yd.), 7-joint arms connected to a single joint base. The SPDM can pick up small tools for repair or servicing activities or effect delicate manipulations of smaller objects than the SSRMS can handle.

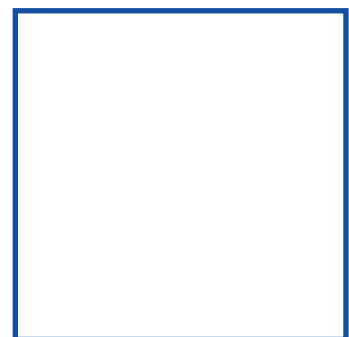
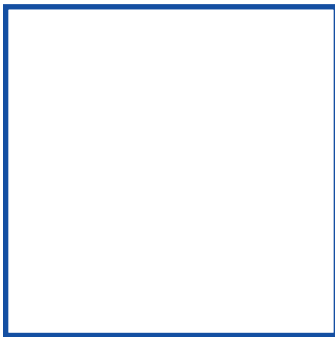


Answer the following questions after you have completed the lesson activities:

1. What is an end effector and how is your model like the ISS end effector on the Space Station Remote Manipulator System (SSRMS) robot arm?

2. Since the straw that your end effector is supposed to pick up is too slippery to be held securely, how might you modify the straw so that it can be held without changing the straw? (Hint: Design a standard grapple fixture that can be added to the straw so that it can be picked up.) Describe your solution below.

3. Compare your grapple fixture to two other grapple fixtures designed by your classmates. Draw them in the squares below:



4. Which one works the best? Use complete sentences to explain why. Use the back of this sheet for additional space.

5. How can you improve your design? Use complete sentences. Use the back of this sheet for additional space.

Lesson II: Brush Bots

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Adapted from the Evil Mad Scientist Web site:
<http://www.evilmadscientist.com/article.php/bristlebot>

Objectives:

Students will build a simple robot and learn how friction can be used to maneuver robots autonomously while exploring technological design and Newton's Laws of Motion.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- Content Standard B: Physical Science
 - Motions and forces
- Content Standard E: Science and Technology
 - Abilities of technological design
- Unifying Concepts and Processes
 - Evidence, models, and explanation

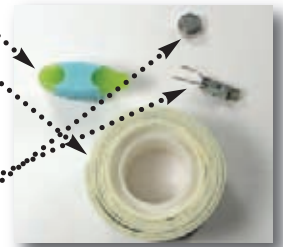
National Technology Standards:

- 9. Engineering design

Materials:

For each Brush Bot made:

- Angled-bristle toothbrush
- Double-sided foam tape
- Copper wire (1-1.5 inches)
(2.54 - 3.81 cm)
- Solder
- Soldering iron
- Unbalanced/vibrating small motor (i.e., a pager motor)
- 1.5 volt coin battery
- Wire cutters
- Electric tape (optional)

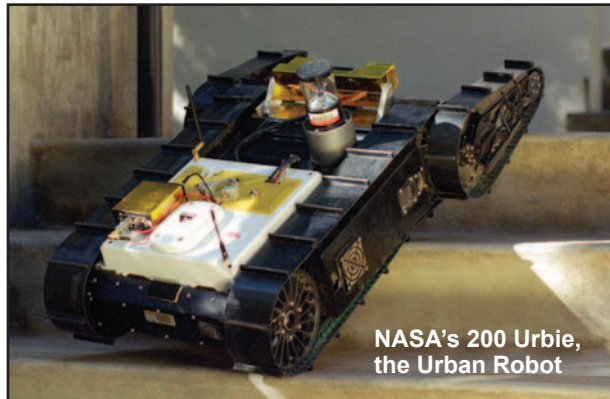


Background:

The NASA project that this activity ties in with is Urbie, the Urban Robot. In 2001, NASA was testing Urbie to be used in city terrain. This robot uses friction created by the treads to maneuver. The initial purpose is mobile military reconnaissance in the city environment, but many of its features will also make it useful to police, emergency, and rescue personnel. Such robots could investigate urban environments contaminated with radiation, biological warfare, or chemical spills. They could also be used for search and rescue in earthquake-struck buildings and other disaster zones.

A group of robot researchers at the Center for Robot-Assisted Search and Rescue

(CRASAR), at the University of South Florida, use the only rescue robots recognized by the United Nations and have helped in earthquake disasters like the 2010 Haiti in disaster. CRASAR's robots faced their first major test in the days following the collapse of the World Trade Center towers, extending the senses of the rescue workers into areas that personnel and dogs couldn't go. These researchers are moving forward with robotic rescue so that in the future it will be standard.



Science concepts for discussion before doing the activity:

Friction

Friction is defined as a force that resists the relative motion between two objects in contact. It appears when two things rub against each other. Without friction, Brush Bots wouldn't be able to move.

In the Brush Bot, the unbalanced weight causes the entire motor to vibrate which makes the toothbrush shake very quickly in one direction and then the other. Most toothbrush bristles are angled to slide smoothly in one direction, but not so easily in another. The Brush Bot is thrown forward by the swinging weight and the bristles slide a short distance across the surface. When the weight swings back, the bristles catch and resist movement. This friction allows the Brush Bot to move across smooth, flat surfaces.

Center of Gravity

The center of gravity is the exact spot on an object where there is the same amount of weight on one side of the spot as there is on the opposite side. The ease of which an object can be balanced depends greatly on the location of its center of gravity. If the Brush Bot becomes too unbalanced, it will fall over.

Newton's Laws of Motion

Newton's 1st Law: An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This law is often called the "law of inertia." The vibrating motor provides an unbalanced force that causes the Brush Bot to move erratically.

Newton's 2nd Law: Acceleration is produced when a force acts on a mass. The greater the mass of the object being accelerated, the greater the amount of force needed to accelerate the object. If you built a larger, heavier Brush Bot, you may need to use a larger, more powerful motor to move the Brush Bot because of the increase in mass.

Newton's 3rd Law: For every action, there is an equal and opposite reaction. This law describes how the friction we create works.

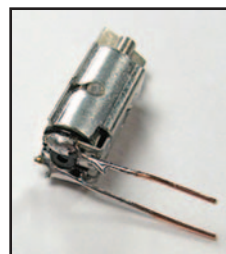
Procedure:

SAFETY: Adult supervision is required when working with wire cutters and soldering iron. Adult may instruct students how to us or make this part of the activity ahead of time. Safety goggles are required! (These can be made individually or with two students working together on one.)

1. Cut the head off of a toothbrush using wire cutters.



2. Solder a 1 to 1.5 inch (2.54 to 3.81 cm) copper wire to each of the leads on the motor.



3. Apply a strip of double-sided foam tape to the top of the toothbrush.



4. Attach the motor to the foam tape. Place the battery on top of the wire and push down to secure to foam tape.



5. Bend one wire down so it touches the foam tape. Place the battery on top of the wire and push down to secure to foam tape.



6. Bend the other wire so that it touches the top of the battery to connect the circuit. Your Brush Bot should now be operating. To turn the robot off, move one wire so that it no longer touches the battery. (Electrical tape may be used to hold the battery and wires together, if necessary.)

7. When you connect the battery for your Brush Bot to operate, does it stay upright and move in a straight line? If not, how can you modify it to make this happen. (Remember the science concepts of friction, center of gravity, and Newton's Laws of Motion that were discussed earlier.)

Review:

The Brush Bot in this activity is a tiny directional vibrobot. The configuration of the Brush Bot allowed it to move in a certain way and the scientific method was used to figure out how the Brush Bot would accomplish the task described (such as moving in a straight line).

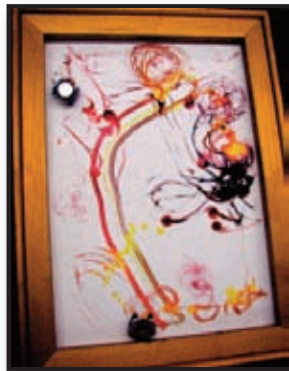
Extension:

1. Divide the class into teams for some Brush Bot competition. Each team should modify the original Brush Bot to make sure their Brush Bot can travel down a path and reach a finish line in the fastest time possible. The teams should complete the worksheet on page 45 with the modifications and the results of each modification so that a record will show their experiments. The teams then compete against each other to see who can win the “Brush Bot Race.”

Teacher Hints: *When the completed Brush Bot is set down, you may notice that it tends to steer left or right. Battery and motor placement, one stray bristle on the toothbrush that can interfere with the motion, and motor rotation direction all influence the behavior - so try flipping the battery upside down if there is trouble getting the Brush Bot to go straight.*

Brush Bot Art Connection:

Release Brush Bot(s) on a piece of art paper surrounded by a frame (so the brush bot will stay on the paper). Drop ink, paint, or liquid water colors onto the blank paper, providing the Bot(s) with a medium. The Bot(s) will go through the paint and mix colors, leaving beautiful, random patterns behind.



Additional Information:

1. One possible supplier of Brush Bot kits is Kalani Robotics at www.Kalanirobotics.com or you can order the entire NASA robotics kit from NASA CORE at <http://education.nasa.gov/edprograms/core/home/index.html>.

2. Simple circuits can also be explored by younger students. The Brush Bot is powered by a watch battery and vibrates using a cell phone vibrating motor. A simple circuit completes the system with the wires connecting the watch battery and the cell phone motor.



3. Set up a used or broken electronic parts recycle box in your classroom to collect parts for future robotic projects. Old motors from cell phones, pagers, etc. and parts from old computers can come in handy for robot building.

Brush Bot Modifications and Races

Your name: _____

Your Team's name: _____

Your team is to modify your Brush Bot's configuration so that it can travel at least 5 feet (1.5 meters) in a straight line in the shortest amount of time possible.

Modifications might include:

- Bristles: angled differently
- Number of Bots: attaching together more than one Bot might stabilize
- Motor: placement along back of brush
- Battery: placement along back of brush and the direction of placement (right side up or upside down) in the case of the flat coin battery

Modification to:	Modification	Results
Bristles		
Number of Bots		
Motor		
Battery		

Brush Bot Team Trial Times

The challenge is to see how much time it takes your team's Brush Bot. to travel 5 feet (1.5 meters) in a straight line. Your team is trying for the fastest time possible.

Trial #	Time	Comments
1		
2		
3		
4		

Lesson 12: Fridge Rover

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Objectives:

Students will develop comprehension of the engineering design process and how it applies to developing robots for extreme environments.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design

Unifying Concepts and Processes

- Evidence, models and explanation
- Form and function

National Technology Standards:

9. Engineering design

11. Apply the design process

Materials:

- Internet access
- Pen/Pencil
- Paper
- Fridge Rover (Can be purchased by searching “fridge rover” on the internet. Several sources include Hobby Lobby. Cost is \$3.00 - \$5.00 each.)
- Optional: Presentation software, such as PowerPoint
- Optional: Capability to view video clips by entire class

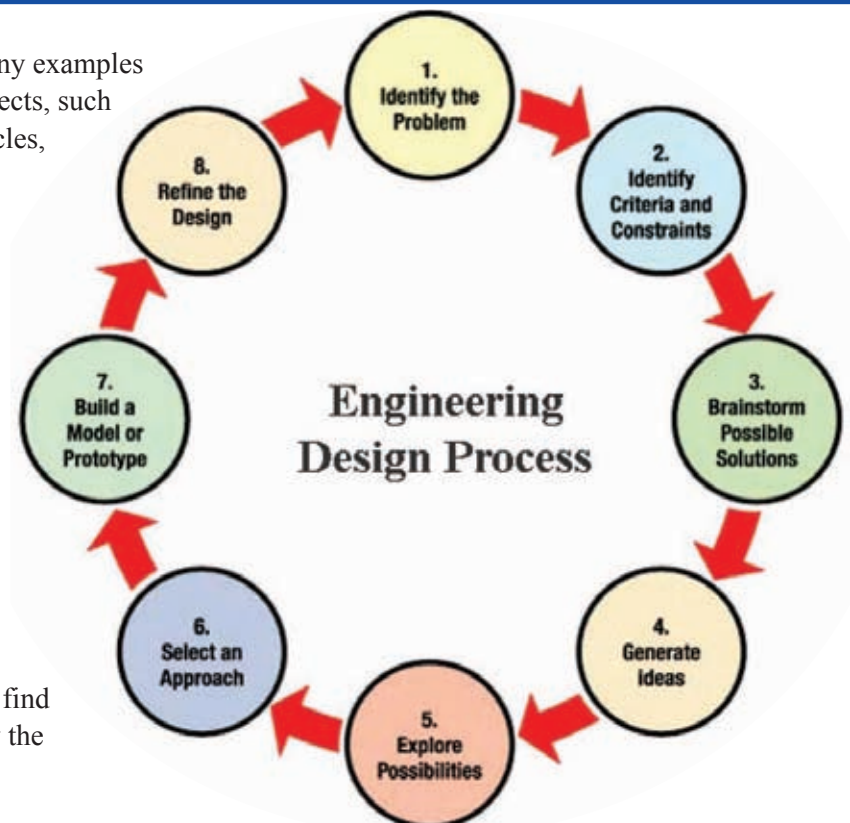
Background:

Engineering Design

When you look around, you will see many examples of engineering design at work. Physical objects, such as automobiles, skyscrapers, and even bicycles, came into being through the creative application of engineering design.

Design is the creative act that allows an engineer to turn abstract ideas into physical products or systems that meet human needs to solve problems. The design process is a step-by-step methodology that occurs over a period of time. This process requires problem solving and teamwork.

The design process contains basic steps in order to be implemented correctly. The problem must be defined so that the design team can research, get results from tests, assemble the expertise that is needed, find alternatives to achieve the goal, and modify the design.



Correlation of Fridge Rover with NASA Project:

The Fridge Rover on the near right is designed to explore a specific environment autonomously. This little wind-up magnetic rover can explore file cabinets and classroom marker boards due to its inventive design. Educators can immerse students in a scientific inquiry discussion about how they would design a robot to explore extreme environments. The file cabinet or marker board could represent an extreme environment and the fridge rover could represent one design of a robot developed to explore it.

The robotic rover on the far right is called a FIDO (Field Integrated Design and Operations) rover. FIDO was the research prototype for Mars surface missions later performed by the Mars Exploration Rovers. The FIDO rover carried out 4 field trials during the lead-up to the Mars Exploration Rovers mission, including tests in Silver Lake, California (1999); Black Rock Summit, Nevada (2000); Soda Mountains, California (2001); and Grey Mountain, Arizona (2002).



Procedure:

1. Introduce the Engineering Design Process to students and explain how engineers use this process to develop problem solving technology. (Show the video called “What is the Design Process?” found on Teacher’s Domain Website at: <http://www.teachersdomain.org/resource/phy03.sci.engin.design.desprocess/>.)

2. Discuss the skills necessary to be a robotics engineer. (Show the video called “Erik, the Robotics Engineer” found on Teacher’s Domain Website at: http://www.teachersdomain.org/search/?q=Erik%2C+the+Robotics+Engineer&fq_grade=PK&fq_grade=PS.)

3. Discuss some NASA missions that include exploring extreme environments on Earth and in space. Sample missions and projects are:

- Spirit/Opportunity rovers (<http://marsrover.nasa.gov/home/>)
- Cassini (http://www.nasa.gov/mission_pages/cassini/spacecraft/index.html)
- Lunar Reconnaissance Orbiter (http://www.nasa.gov/mission_pages/LRO/spacecraft/index.html)
- The NEEMO (NASA Extreme Environment Mission Operations) project (http://www.nasa.gov/mission_pages/NEEMO/)
- IRG (Intelligent Robotics Group), which explores extreme environments, remote locations, and uncharted worlds. (<http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/>)
- RAMS (Robotic Antarctic Meteorite Search) in 2000- (<http://www.frc.ri.cmu.edu/projects/meteorobot2000/>)

4. Discuss what makes the mission environments extreme and why NASA had to use technology rather than humans to explore them.

5. Students should work in teams to choose and research a NASA mission. They should explain how NASA used the engineering design process to develop robotics for the NASA mission they have chosen.

6. Student teams should give a short presentation to the class about their findings. The presentation can be paper and pencil with verbal explanation; other media using posterboard or diorama; or use of a computer software presentation program.

7. Student teams should design a robot on paper that is capable of exploring the “environment” of a metal filing cabinet or marker board. They should present their results to the class.

8. Students (as a class) should brainstorm (using the engineering design process) and help each group modify their design to better explore the environment of the metal filing cabinet or marker board.

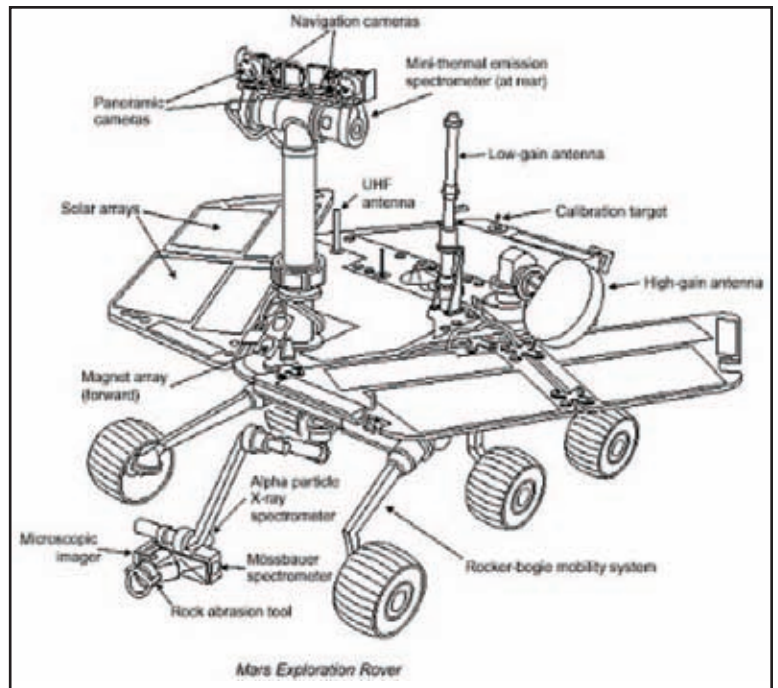
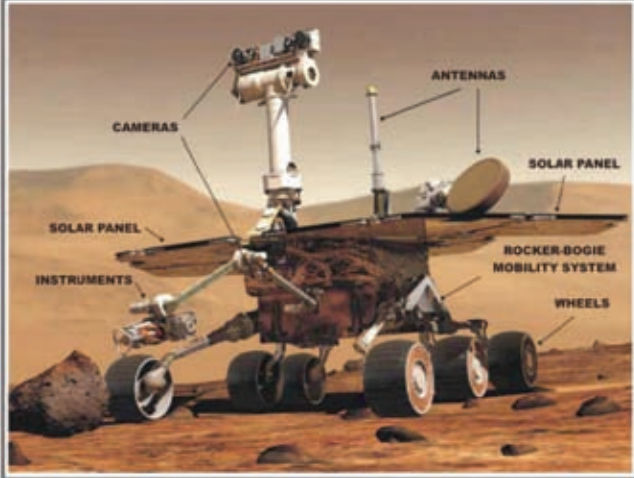
9. Use the fridge rover to demonstrate what a robot that is capable of exploring this environment might look like. Demonstrate how the fridge rover works. Relate the fridge rover to the student designs and compare and contrast the characteristics.



Review:

This activity helps students understand the design process by designing a robot that could explore an extreme environment. The career of Robotics Engineer is also discussed.

MARS EXPLORATION ROVER



Evaluation:

1. Use rubric to evaluate the student presentations. Two rubrics may be used - one for the research portion and the other for the design process portion. (See samples on this page.)

Sample Rubrics for Group Presentations

1. Research Rubric

Criteria	Beginning 1	Developing 2	Accomplished 3	Score
Introduction	Does not give information to know what the report is about	Gives a little information	Presents a concise lead-in to the report	
Research	Does not explain any of the design process for the mission	Explains a few points about the design process	Completely covers the design process	
Conclusion	No conclusion is reached and the audience is left hanging	Very little completion to the items in the research	Presents a logical conclusion based on the research	
Interest Level	Not interesting	A little interesting	Very interesting	
Method of Presentation	Poor presentation method	Some thought went into development of presentation	Good presentation method	
Group Participation	Only one member of the group did the entire presentation	A few members of the group participated	All members of the group participated	



2. Design Rubric

Criteria	Beginning 1	Developing 2	Accomplished 3	Score
Identify the problem	Does not identify the problem	Identifies part of the problem	Completely identifies the problem	
Identify criteria and constraints	Identifies no criteria and constraints	Identifies a few criteria and constraints	Completely identifies criteria and constraints	
Brainstorm possible solutions	Does not work with the entire group for input	A few members of the group work for a solution	All group members participate in a solution	
Generate ideas	No ideas are generated	One idea is generated	Several ideas are generated	
Explore possibilities	Limited possibilities	A few possibilities	Several possibilities	
Select an approach	Random approach	Somewhat of a consensus on approach	Group consensus on approach	
Model or prototype on paper	No model on paper	Some model ideas on paper	Complete model on paper	
Take class suggestions and refine the design	No changes made from class suggestions	Some changes made from class suggestions	Class suggestions considered and incorporated	

Extension:

A three-day lesson that introduces the topic of robotics engineering as a career choice can be found at <http://www.futuresinengineering.com/robotics.pdf>.

The streaming video discussed in the lesson that shows what a robotics engineer does can be found at: <http://www.thinktv.org/education/engineeringyourfuture/engineeringyourfuture.html>.

After students have researched robotics engineering, ask them to write a one-page letter to a fictional robotics company telling why they would like to work in robotics engineering.

Lesson 13: Sensory Robots

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center and HowStuffWorks, Inc.

Objectives:

Students will comprehend the five human senses and explain how sensors in robots are correlated to human senses and how they help them to do the specific job for which they were designed.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Transfer of energy

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Materials:

- Pen/Pencil
- Paper
- Internet
- Sensory Robot 1 (Original HexBug®)
- Sensory Robot 2 (Crab HexBug®)



Note: HexBug and Crab HexBug (plus other sensory models) can be found online at www.hexbug.com. The HexBugs can also be purchased at local electronics stores such as Radio Shack and retail stores such as Target. (Cost per item: \$10 - \$15)

Background:

External sensors are to robots as the five senses are to humans: touch; taste; sight; smell; and hearing. Robots may need devices that work like each of these senses: cameras for eyes; microphones for ears; etc. These sensors send information in the form of electronic signals back to the robot's controller circuit.

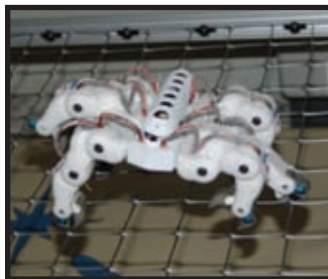
Robots are typically powered by electrical motors, hydraulic cylinders, pneumatic cylinders, or some combination of the three. Each power source has its advantages, and no single type is appropriate for all robotic applications. Robots (and automation in general) should be considered whenever a job involves heavy lifting, contaminated environments, highly repetitive work, or continuously high levels of concentration. Robots generally outperform human labor with higher precision and repeatability while their performance does not deteriorate with fatigue, whereas humans are more mobile, can learn, and can make decisions based on incomplete information.

The NASA robots that have a connection to the Hexbug robots (used in this activity) are Spiderbot and the Mars Rovers. Spiderbot uses a set of antennas as feelers to detect obstacles and terrain as it moves about on six spindly legs and HexBug® (original) senses objects in its path and avoids them. The HexBug® can travel forward until it hits an obstacle or hears a loud noise. It will

then backup in a half circle and then move forward in a different direction. The Mars rovers sleep at night to preserve enough energy to work all day. They sense when it is light or dark. Similarly, the crab HexBot® remains still in the dark and scurries around when it senses light. It can also respond to a hand clap, loud noise, or a table slap. Here is an explanation of how the HexBug works and a little background:

NOTE: This portion of the background is provided compliments of HowStuffWorks Express (a division of HowStuffWorks, Inc., an award-winning media and e-learning company). The staff of HowStuffWorks Express includes writers, editors, graphic artists, Web designers, and nationally-certified teachers in science, math and language arts who have years of classroom teaching experience. For Website info from this lesson, go to

<http://express.howstuffworks.com/hex-bug-autopsy.htm>.



Spiderbot (top) and Mars Rover, Spirit (right)



Using the HexBug® and/or other simple robot sensory models, demonstrate how the sensors work.

Here is an explanation of how the HexBug® works and a little background:

The HexBug® is a tiny battery-powered insect-like toy robot that has an ingenious design and can be used for demonstration purposes in this activity and also extension and experimentation (see Extension section of this activity). The HexBug® moves around any smooth, flat surface on its six articulated legs. There are five different versions named Alpha, Bravo, Charlie, Delta, and Echo. Each version has its own shape and color, but all

HexBugs® are approximately 2 1/4 inches (5.72 cm) wide, 3 inches (7.62 cm) long, and just over 1 inch (2.54 cm) tall. The legs attach to the body with an intricate triple-action pin and connecting lever. The feet are tiny rubber pads that grip and pull the HexBug® as it pivots its way around obstacles. The “brains” of the HexBug® center around a computer chip. The bug’s antennae are touch-sensitive, so any time the HexBug® encounters an obstacle, it pivots and changes direction to go around it. The other sensor that the HexBug® has is the sound sensor. A hand clap or other loud noise causes the device to change direction.

Part I:

Use the following activity to help students develop an understanding of the five human senses.

1. As a class, have students review the five senses (sight, hearing, smell, taste, and touch). Have a brief preliminary discussion about how each sense works.
2. Divide students into five groups, with four to five students in each group. Assign each group one of the five senses. Explain that each group will research how the assigned sense works and create a labeled picture that illustrates this process.
3. Listed below are some examples of possible research questions for each sense. Each group should select at least one of the questions they wish to explore about their sense.

SIGHT

- Why do some people need glasses? How do glasses improve vision?
- What causes nearsightedness? How is it different from farsightedness?
- Why are some people colorblind?
- How do optical illusions work? How do they “fool” your brain?
- How do red-and-blue “3D glasses” work?

HEARING

- How do sounds reach the brain?
- Why do some sounds have a low pitch, while others have a high pitch?
- Why are animals, such as dogs, able to hear sounds that humans cannot?
- When someone is “hard of hearing,” what are some possible causes?

SMELL

- Why do certain smells instantly evoke specific memories or feelings?
- How are the senses of smell and taste related?
- If you hold your nose while eating, how are tastes affected and why?

TASTE

- How do taste buds work? How does the tongue recognize different tastes, such as the bitterness of a lemon or the sweetness of sugar?
- Which taste cannot be detected by the tip of your tongue: bitter; sour; salty; or sweet? Why?

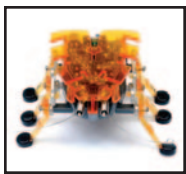
TOUCH

- How does your hand tell the difference between hot and cold surfaces?
 - How do blind people use Braille to read?
4. Each group gives a class presentation using its diagram, other visual aids, and any additional supporting materials. Each presentation should begin by explaining how the particular sense works. Then, using a demonstration of some sort, the group will provide answer(s) to the research question(s) selected for exploration.

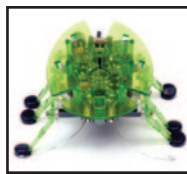
Robotic Sensors:

Now that students have a good understanding of the five human senses, relate the senses to robots and exploration of extreme environments. Ask the students the following questions:

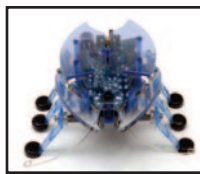
1. Do robots have senses like humans? Answer: Yes, we call them sensors and they depend on the design and objective of the robot.
2. What are some of the sensors that robots could have for exploring extreme environments? Answer: All five of the human senses.
3. Why do robots have sensors? Answer: To navigate and retrieve data autonomously (independently).



HexBug® Alpha



HexBug® Beta



HexBug® Charlie



HexBug® Delta



HexBug® Echo

Now for the HowStuffWorks Autopsy of the HexBug®:

HexBugs® are tiny robots that react to sound and touch. To do this, they use sensors that act like ears and whiskers. The bug's brain is a printed circuit board (PCB) or computer chip which carries instructions from the sensors and electricity from the batteries to an electric motor.

1. The bug's ear is a microphone. The microphone translates the pressure from sound waves into electrical impulses. The circuitry on the PCB detects the impulses and sends a signal to the motor, telling it to change direction so the bug can back up.

2. A HexBug's® antennae are similar to a cat's whiskers. Cats use their whiskers to help them decide whether they can fit through narrow spaces. If the whiskers touch the edges, the space is too narrow. Springs allow the robot to do the same thing.

3. At the base of each antenna, a small spring winds around a plastic insulator. This insulator keeps the spring

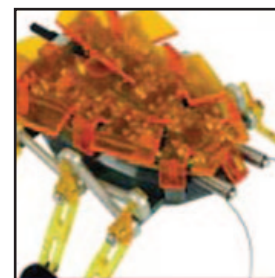
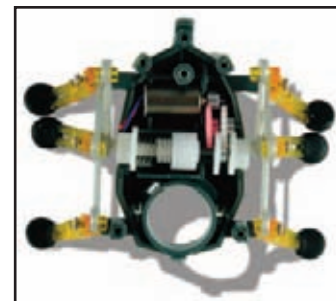
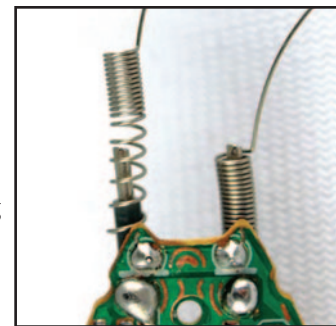


away from a metal electrode inside. But when the antenna touches an object, the spring bends and touches the electrode, completing a circuit. The bug's circuitry tells the motor to change direction, and the bug backs up.

4. The robot's motor is tiny, and it turns a very small gear. This gear connects to other gears, which carry the motor's movement to the bug's middle legs. The middle legs connect to the front and back legs with small plastic bars. The middle legs push and pull the bars, which causes the front and back legs to move.

5. None of this happens unless the HexBug's® switch is in the "on" position. The switch slides back and forth, carrying a small piece of metal with it. When the piece of metal is in the right place, it touches two electrodes. This completes the circuit between the batteries and the rest of the bug.

Note: When the HexBugs® back up, a simple clutch keeps the left legs from moving. Both middle legs attach to shafts. The right shaft fits through a spiral, and the left connects to a housing. When the motor turns, the spiral's pointed end fits into a notch in the housing. The housing turns, moving the left legs. When the motor reverses, the point slips past the notch, so the left legs stay still.



Procedure (Part 2):

1. Using the HexBug or other similar sensory robots (more can be found on the HexBug Website), demonstrate how the sensors work.

2. Ask the students what sensors the robot has and how they compare to human senses.

3. Discuss the different robots that NASA uses such as the Mars Rovers and Spiderbot and how the sensors on these robots allow them to accomplish their tasks.

4. Divide the students into the same five groups as in Part 1 of the procedure. Assign groups a NASA robot to

research from the NASA Robotics website at: <http://www.nasa.gov/audience/foreducators/robotics/home/index.html> (click on the Image Gallery to see different robots).

5. Each group will provide a presentation, with an illustration, explaining the sensors that exist in the robot and what function that particular sensor is designed to do. Students should relate the sensor on the robot to one of the human senses.

Review:

Sensory robots have devices that allow them to “sense” the world around them. These sensors can assess the environment and perform certain activities because they can “see” or “feel” the objects around them. Robots are continuing to become more sophisticated as technology and engineers develop new sensing devices.

Extension:

1. Have each group of students do the “autopsy” of the HexBug® and explain how it works. Compare their technical writing about how the HexBug® works to the explanation given by HowStuffWorks. Make students aware of vocabulary used in their descriptions and the processes involved in explaining how something works.

2. Have groups try modifying their HexBugs®. By adding in a new battery, modifying the gear ratio, or other changes, the speed that the HexBug® moves can be changed. Again, have the students write down what they did to change the HexBug® and how the change affected the HexBug®. For other YouTube videos with suggestions on how to modify a HexBug®, go to <http://www.hexbug.com/news/category/modifications/>.

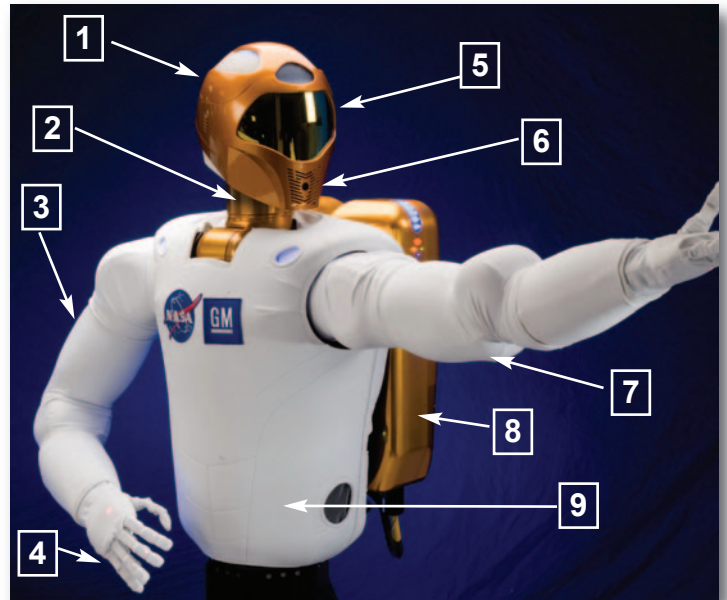
3. Student groups might also devise a specific job that the HexBug® might do and tell what sensors the HexBug® needs to do the job.

Robot Sensors in the News:

— NASA’s “Earbot” is an artificial inner ear for helping the “walker” robots that will keep them from toppling. “Walker” robots, such as the Scorpion Robot, can use “Earbot” to help them move across dangerous and rocky terrain, that may be otherwise inaccessible to man or machine.

— Robonaut 2 - The Next Generation of Complex Robots

Robonaut 2 was the first human-like robot to go into space aboard STS-133, the last mission of the shuttle orbiter, Discovery, in February 2011. Robonaut 2 has over 350 sensors to help it perform duties to assist astronauts and do routine activities aboard the International Space Station.



What Robonauts Are Made Of

1. A robot meant to work with humans and use human tools begins to look human-like by default. However, R2’s head houses not its brain, but its vision equipment.

2. R2 has 3 degrees of freedom in its neck, allowing it to yaw left or right, pitch up or down, and roll left or right.

3. Each arm is approximately 2 feet, 8 inches (.71 m) long, giving the R2 a total wingspan of 8 feet (2.44 m).

4. Robonaut 2’s hands have 12 degrees of freedom - 4 degrees of freedom in the thumb, 3 degrees of freedom each in the index and middle fingers, and 1 degree each in the ring and pinky fingers. Each finger has a grasping force of 5 pounds.

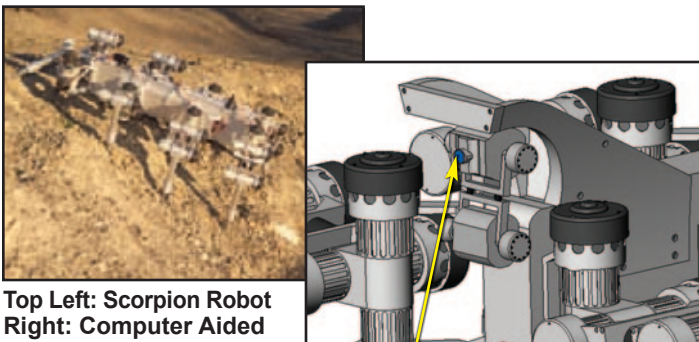
5. Behind R2’s visor are four visible light cameras - two to provide stereo vision for the robot and its operators, and two auxiliary cameras.

6. A fifth infrared camera is housed in the mouth area for depth perception.

7. Each arm boasts 7 degrees of freedom and the strength to hold 20 pounds in any pose in Earth’s gravity.

8. Here on Earth and at the space station, R2’s backpack holds its power conversion system, allowing it basically to be plugged in. On another planetary surface - or on the moon or an asteroid - the backpack would hold the robot’s batteries.

9. R2 thinks with its stomach - literally. With its head full of cameras, the only place with enough room for a brain is the robot’s torso.



Top Left: Scorpion Robot
Right: Computer Aided Design (CAD) drawing of Scorpion robot - Earbot located in front and indicated in blue

Lesson 14: Walking Solar Robot

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Objectives:

Students will construct and experiment with solar cells and learn how solar power is important to robotics and near-Earth space exploration and about energy and conservation of energy.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- Content Standard B: Physical Science
 - Transfer of energy
- Content Standard E: Science and Technology
 - Abilities of technological design
 - Understanding about science and technology
- Unifying Concepts and Processes
 - Evidence, models, and explanation
 - Form and function

National Technology Standards:

- 9. Engineering design
- 11. Apply the design process

Materials:

- Walking Solar Robot (one kit for each group of 3-4 students or one demonstration kit for teacher) - (one type of walking solar robot is the Walking King Crab Robot found at <http://www.owirobots.com/cart/index.php> - cost is around \$9.00)
- Tennis Ball (for teacher demonstration and discussion)

For each group of 3-4 students

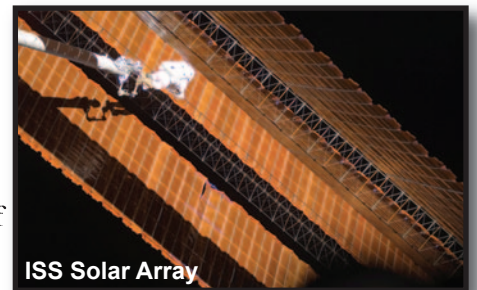
- solar cell (sold by such science supply companies as Pitsco)
- small electric motor - try to find motors that have low rpm (revolutions per minute) because the faster spinning motors make it difficult to count revolutions per minute (These types of motors can be purchased from many physical science supply companies.)
- 10-inch pie round or stiff cardboard disk
- plastic wheel that will fit over the axle of the motor (can be found at most hobby shops)
- glue (white or hot)
- permanent black marking pen
- stopwatch
- black construction paper
- red, green, and blue transparency film
- electrical wire to connect the solar cell and motor or terminal clip leads

Background:

Energy is the ability to do work. Energy can come from many sources including eating food, the sun, someone else pushing you, and many other sources. Energy is important to us and how we explain things that happen in our world, as well as in our exploration of space.

There are different forms of energy such as:

- kinetic energy - the energy contained in a moving object
- potential energy - energy stored in an object or energy of position
- thermal or heat energy - energy created when the kinetic and potential energy of an object in motion are combined
- chemical energy - a form of potential energy possessed by things such as food, fuels and batteries
- nuclear energy - any energy associated with atomic reactions
- mechanical energy - sum of energy in a mechanical system, where a group of objects interact



- electrical energy - the presence and flow of an electric charge
- electromagnetic or radiant energy - the energy that comes from electromagnetic radiation
- solar energy - an alternative energy source that involves harnessing the radiant light energy emitted by the sun and converting it into electrical current

Solar energy comes from our sun. Solar cells, or photovoltaic cells, are often silicon-based pieces of material that absorb the sun's light and convert it into electricity. If you hook enough solar cells together in a solar panel you can generate enough power to run a robot. Solar cells are also used as a power source to recharge batteries.

One example of solar panels or arrays being used to power a system is the International Space Station.

The ISS never leaves Earth orbit, which reduces the power it needs. The solar cells for the ISS are mounted on eight large, wing-like structures called solar arrays, each measuring 34 m long and 11 m wide. The arrays together contain a total of 262,400 solar cells and cover an area that is more than half the area of an American football field! A computer-controlled gimbal rotates to keep the arrays tilted toward the Sun. (A gimbal is a pivoted support that allows the rotation of an object about a single axis.)

But the Sun is not always in view because the ISS spends almost half its time in the shadow of Earth. During the shadow phase, the space station relies on stored banks of nickel-hydrogen rechargeable batteries to provide a continuous power source. The results of properly managing the switch between solar-generated power and stored battery power results in 110 kilowatts of power available for all uses. Instead of running on AC (alternating current) power, such as that delivered to homes on Earth, the ISS runs on DC (direct current).

Many space applications are using solar power to operate their missions. Examples include rovers, such as the Mars rovers, Spirit and Opportunity. These rovers use the solar power to be able to collect and transmit data from the surface of Mars. Another example of solar power being used in space is the ISS solar arrays mentioned in this article.

In the future, robots, such as Robonaut 2 (traveling on the ISS), will need solar power to help astronauts with space walks and other duties on the space station. Solar power does have its limitations, however. Once a probe leaves the inner planets for deep space, solar power is not an option. The Sun is too far away to provide the needed power for the probe to operate. In this case, another power source must be used. Probes, like Voyager I (on a 25-year journey through the solar system and out into interstellar space), use an early radioisotope thermoelectric generator (RTG), which converts the heat generated from the natural decay of its radioactive fuel into electricity. The RTG will supply Voyager with electricity until at least 2020.



Mars rover, Spirit, from above with solar panels covered with dust from Mars

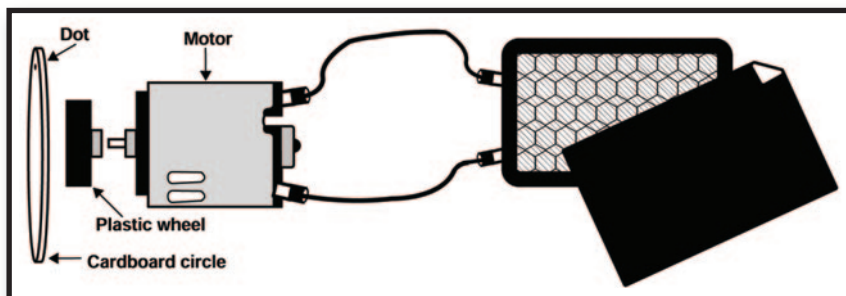
Procedure:

Part I: Begin background discussion and demonstration (teacher directed):

1. Discuss energy and the information in the “Background” section at the beginning of this lesson. Also, ask students to make a list of ways that solar power could be used to replace conventional power uses today. Such sites as <http://solarpower.com/> can be used to research this topic.
2. Throw a tennis ball against a wall and catch it when it bounces back to you.
3. Have students describe the energy changes involved from before the ball is thrown to after the ball bounces from the wall.
4. Have students specify which object (ball, teacher, teacher’s arm, wall) possesses the energy they describe. (Answer: Food energy (chemical potential energy) of the teacher is converted to kinetic energy (KE) of the teacher’s arm and KE of the ball. Some of the KE of the ball is converted to Gravitational Potential Energy (GPE) as the ball is moving upwards, and GPE is converted to KE as the ball is moving downwards. The KE of the ball is converted to elastic potential energy of the ball when it squishes against the wall, and the elastic potential energy is converted back to KE when the ball bounces off the wall.)

Part 2: Experiment: Testing the effectiveness of solar cells due to light intensity and color:

1. Explain that this investigation will allow the students to explore one of the variables that might affect how much energy a solar cell can produce. The variable being tested is intensity of light using different colored filters.
2. Students should be in groups of 3-4 and materials from the materials list, as well as a recording sheet, should be available to each group.
3. Students should do the following to complete the project.
 - Attach the plastic wheel to the shaft of the motor.
 - Make a small dot on the edge of the cardboard disk.
 - Glue the cardboard disk to the wheel so that the disk will rotate when the motor is turning.
 - Attach the solar cell to the motor. Some solar cells can be connected to the motor by clip leads while others



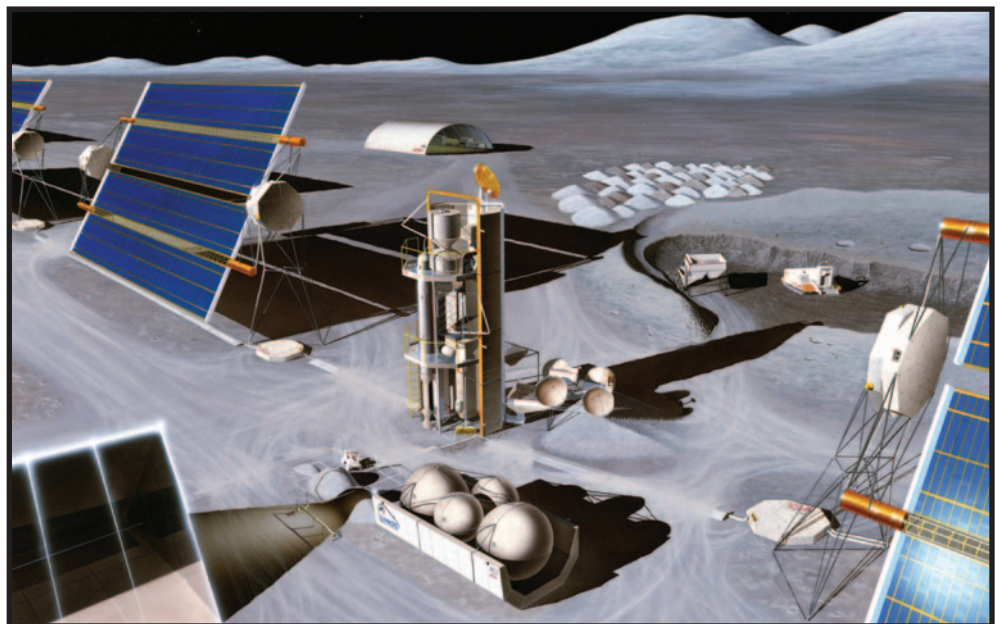
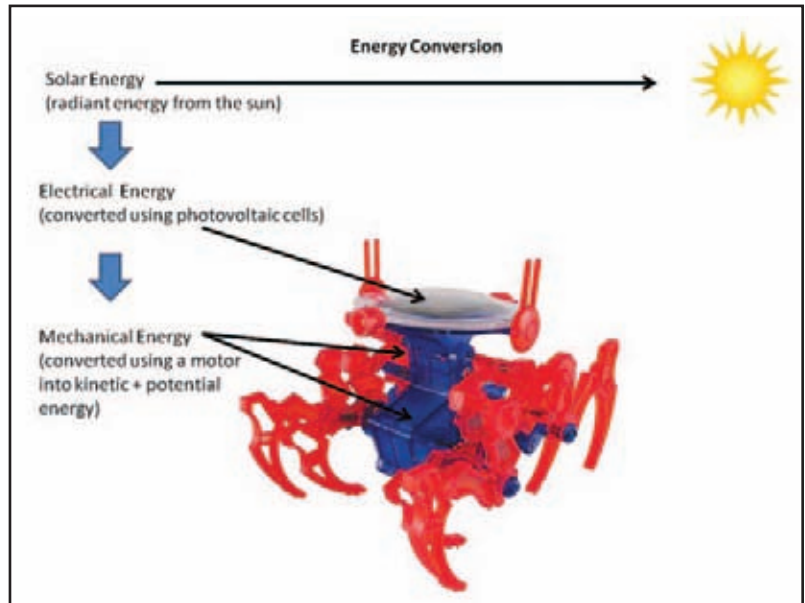
Wires attached to solar panel have to be soldered onto the motor terminals or are attached to terminals by alligator clips.

may have to be soldered to the terminals. For the second type, the teacher should attach the solar cells to the motors prior to class since some soldering may be involved and this step is a little time consuming. To connect the solar cell to the motor, connect the exposed end of the motor's positive (red) lead around the exposed positive (red) lead of the solar cell. Secure the connection with a drop of solder. Connect the exposed negative (black) lead ends of the solar cell and the motor together, and secure them with a drop of solder. Let all solder dry and harden thoroughly over the course of at least an hour before moving on.

- Place the solar cell and motor in bright sunlight. The motor should cause the cardboard disk to spin. If no spinning occurs, check the connections.
- Watch the dot on the cardboard disk. Start the stopwatch as the dot gets to the top. Count the number of times the cardboard disk spins in 15 seconds. Multiply this number by four to get the number of revolutions per minute. Record this information on the student activity sheet as the calibration of disk rpm.
- Use the piece of black construction paper and cover half of the solar cell. Repeat the procedure for counting of the number of revolutions per minute from the step above. Record on student activity sheet.
- Remove the black construction paper. Cover the solar cell with one piece of the red transparency film. Repeat the procedure for counting the number of revolutions per minute and record.
- Change the transparency film to the other two colors of transparency film and count the number of revolutions per minute for each and record.
- Answer all questions associated with the activity on the student activity sheet.

Part 3: Solar Robot Discussion:

1. Have each group build the solar robot according to the directions on the kit.
2. Use either a high-powered flashlight or the sun the power source to make the robot move.
3. Have students experiment with different types of light sources to see which is most effective in the speed and movement of their solar robot.
4. Have students do research comparing the King Crab movements in nature with that of the Solar Robotic Walking King Crab from their kit.



Future planetary power station using solar arrays

Review:

Solar energy has been used by the space program for many years to power space stations and satellites, as well as robots on other planets. Solar energy is a valuable alternative energy source and is used to power solar cells, panels, and arrays for use on earth and in space.

Conclusion (tying it all together for students):

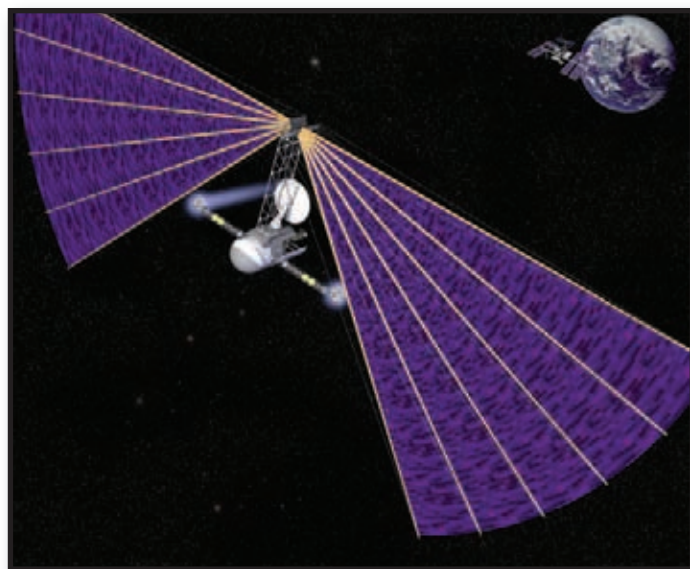
You have learned that energy is the ability to do work and this work can be done by various types of energy such as kinetic and potential. You also learned that an alternative source of energy is the sun that provides us with solar energy.

Next, you experimented with solar cells and saw how different intensities of light affected the solar cell. This helped you understand how the amount of light that a robot receives may affect the operation of that robot. (The transparent film in the activity decreased the intensity of light. The red film blocked green and blue light very well. Most green films block blue light well, but do not block red light completely. Blue films usually allow some green and red light to pass. This will help explain varying performance of the motor when using different color transparencies.)

In the final activity you saw how the solar walking crab (or similar) robot worked using the power of the sun. You can compare that movement and use of solar energy with some of the NASA projects such as the Mars Exploration Rovers, Spirit, and Opportunity. The Mars rovers have been on Mars working and collecting data long past their expected performance. The solar arrays that keep them operational have withstood many obstacles. Events (dust removal by wind) have occurred more often than NASA expected, keeping the solar arrays relatively free of dust and extending the life of the mission.

You have learned that the usefulness of solar power can also be translated for humans on Earth. Since this resource is limitless, all we need to use this energy source is the technology and

understanding about harnessing the power of the sun to make our energy future brighter. You are the scientists of tomorrow who will be developing the energy sources of tomorrow...which we are studying today.



Concept of a vehicle journeying from Earth to Mars propelled by thrusters powered by electricity from photovoltaic cells on its large fan-shaped sails

Evaluation:

Use the student sheet and discussion as a means to evaluate this lesson.

Extensions:

1. Have students develop a storyboard (a group of pictures in sequence that tell a story) for a presentation involving one of the Mars rovers, Spirit or Opportunity. Have them research their rover online. Call the story "A Day in the Life of _____" (Spirit or Opportunity). Share stories with class. (Make sure they include how solar energy is involved in the life of the rover.)

Resources:

1. Unit developed by the Florida Solar Energy Center, a research institute of the University of Central Florida. The purpose of this unit is to create an awareness of the power of solar energy, the importance of it in our lives, and its impact on the future of energy development. This is the link to the curriculum for grades 6-8 -

<http://www.fsec.ucf.edu/en/education/k-12/curricula/sm3/index.htm>.

2. A few of the suppliers of solar and other robot kits -
<http://www.scientificsonline.com/robotics.html>
<http://www.robotshop.com/world/alternative-energy-beam-robot-kits.html>
<http://www.robotbooks.com/robot-kits.htm>

Student Activity Sheet

Group members - _____

Part I: Teacher Demonstration

1. Make a list of ways solar power can be used to replace conventional power sources in our everyday lives.
2. Explain the energy changes that happened when the tennis ball was thrown against the wall and caught.

Part II: Testing the effect of intensity of light on a solar cell panel.

Complete the chart for results of your inquiry:

<u>Calibration of disk rpm</u>	<u>Rpm of disk half-covered with black construction paper</u>	<u>Red transparency rpm</u>	<u>Green transparency rpm</u>	<u>Blue transparency rpm</u>

Answer the questions below about your results:

1. What happened when you covered part of the solar cell with black paper? Why?
2. What is the relationship between the amount of solar cell that is covered and the speed at which the disk turned? Explain.
3. How is the speed of the disk related to the energy provided by the solar cell?
4. How did the colored transparencies affect the solar cells ability to function?

Part III: Walking Solar Robot

1. How did the robot react using different light sources?

Light Source	Results
1.	
2.	

Lesson 15: “Ship the Chip”

Activity Credit: Developed by the Institute of Electrical and Electronics Engineers (IEEE) as part of TryEngineering at www.tryengineering.org

Objectives:

Students will learn the importance of providing the correct packaging material to protect their “chipanaut” during transport. Students will be able to apply this activity to the STS-133 mission and the preparation of Robonaut 2 for transport.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor

Materials:

For each team of 2-3 students:

- Student sheet (next page)
- Project materials: one potato chip, paper, cardboard, glue, tape, string, cotton balls, plastic wrap, toothpicks, popsicle sticks, foil, other materials you have on hand, items students may suggest to bring in for everyone’s use, and a preaddressed mailing label to your school
- Graph paper and pencils

Note: Be sure each team has the same materials available to them.

Background:

STS-133, Space Shuttle Discovery, launched to the International Space Station (ISS) on February 24, 2011. This was the last flight of the Space Shuttle Discovery. The crew members included a former CAP cadet and current CAP senior member, Col Eric Boe. Col Boe was the mission pilot for STS-133. The mission of STS-133 was to take the Permanent Multipurpose Module (PMM), the Express Logistics Carrier 4, and critical spare components to the International Space Station. This mission also transported a VIR (Very Important Robot) named Robonaut 2 (or R2), to the ISS. Robonaut 2 (R2) was the first human-like robot to go into space. This robot will remain aboard the ISS permanently. R2 was transported to the ISS in a carefully-constructed box inside the PMM. Many modifications had to be engineered for this sensitive piece of equipment to travel to the ISS. Such considerations as launch vibrations, lack of repair parts for R2, noise requirement level for the ISS, and harmful electromagnetic waves were addressed by the engineers and other scientists prior to launch. The scientists came up with a way to protect R2 and its

delicate systems, while also allowing for time, space, and weight requirements for the mission. NASA and its engineering partners tackled this problem with ingenuity and the ability to overcome seemingly insurmountable odds and time tables to come up with a protective box that would reduce the launch-induced vibrations, but also allow R2 to be removed from the box with minimal effort. Mission accomplished!



Robonaut 2 with crew of STS-133 (Col Boe is the middle astronaut on the left)

Procedure:

1. To find more background material to begin discussing the manufacturing engineering and packaging process, go to this complete lesson at: <http://www.tryengineering.org/lessons/shipthechip.pdf>.

2. Divide students into groups of 2-3 students, providing a set of materials per group.

3. Explain that the students must work as teams of “engineers” who have been given the challenge of designing the smallest, lightest package of all the engineering teams in the classroom that will protect a single potato chip (representing the “chiponaut”) as it travels through the mail from a remote location to your school. The arriving chip must be edible, although students shouldn’t eat them after their journey through the postal system. (This rule simply prevents students from applying any substance to the chip to make it stronger.)

4. Students will need to research their local postal regulations to determine if there are minimum sizes, weights, or other considerations they’ll need to consider

in their design.

5. Students will first meet, plan, and draw their planned package.

6. Next, students will construct their packages and provide them to the teacher for mailing.

7. Once all mailed packages have arrived back at the school, students will weigh, measure, and evaluate the contents of the packages.

8. Students will complete the evaluation sheet and present their reflections to the class.



Top: Robonaut 2 shaking hands with astronaut

Left: Robonaut 2 “tweeting”

Review:

This activity involves teamwork and engineering. Engineers often work with marketing, sales, and perhaps a creative department when recommending packaging requirement for a product. Good packaging must protect the product, eliminate any damage while moving, shipping, or storing the products, and also make the product attractive if it is to be displayed in a consumer environment such as a grocery store, hardware store, or department store. For this reason, packaging is a critical part of a product's design and engineering process, and engineers must take many factors into consideration including appearance, function, and costs.

Extension:

Require teams of students to engineer a system for safely shipping the chip in a six-sided box with specific dimensions or envelope with specific weight and cost requirements for mailing. By establishing the required shipping container or other specifications the challenge will be engineering the product to fit the expectations.

Student Worksheet and Evaluation for “Ship the Chip”

Engineering Team Names: _____

Date: _____

Engineering Teamwork and Planning:

You are a team of manufacturing engineers given the challenge of designing the smallest, lightest package of all the engineering teams in your classroom that will protect a single potato chip - your “chipanaut” (provided by your teacher) shipped through the mail from a remote location back to your school.



• Planning and Design Phase

Each team should be provided with a set of materials. Review these as a group and draw your packaging design on a sheet of graph paper. Think about package strength, size, and weight as you design your package. You might want to consider how well your package will survive if it finds itself at the bottom of a stack of heavy boxes during mailing! There are also several rules you must follow, which your teacher will review with you so your package is not disqualified.

• Construction Phase

Build your package, and then complete the questions below (on the back side of this paper):

1. How similar was your design to the actual package you built?
2. If you found you needed to make changes during the construction phase, describe why you made the revisions.

• Shipping Phase

Your teacher will devise a mailing system for all the packages created in your classroom. Be sure your package has a unique code on the outside to identify to which team it belongs. Packages may be marked fragile. No overnight shipping!

Evaluation Phase:

Once all packages have arrived in the mailbox back at your school, you will work in teams to evaluate the packages. You will not evaluate your own package.

Scoring:

The following three measurements must be made for each incoming package (the mass and volume measurements must be rounded to three significant digits):

1. Mass/weight of the package in kilograms/pounds. (Use a scale to determine mass/weight.)
2. Volume of the package in cubic centimeters/inches. (To find the volume of a rectangular box, multiply the length x width x height of the box after measuring each in centimeters/inches.)

3. Intactness score of the “chipanaut” on the following scale:

- 100 points: like new; perfect
- 50 points: slightly damaged; cracked, but still in one piece
- 10 points: broken in 2-5 pieces
- 5 points: broken in 6-20 pieces
- 1 point: broken into more than 20 pieces; crumbled

Determine the overall score for each package to determine the top scoring “engineering team.” Use the following equation:

$$\text{Overall Score} = \frac{\text{Intactness score (c)}}{[\text{mass in kg/lbs. (a)} \times \text{volume in cc/in}^3 \text{ (b)}]}$$

Example:

mass/weight (a) = 0.145 kg / .32 lbs

volume (b) = 240 cc / 94.49 in³

intactness score = 100

$100 / 0.145 \text{ Kg } (.32 \text{ lbs}) \times 240 \text{ cc } (94.49 \text{ in}^3) = 2.87 (3.31)$

Make a chart to keep track of the packages for each engineering team in your class and see who has the best overall score.

Reflection:

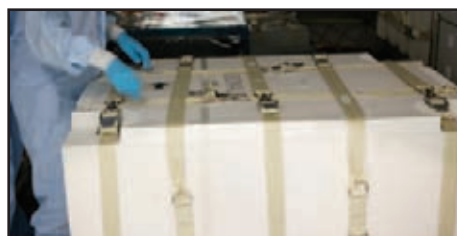
1. What aspect of the design of the package that had the best overall score do you think led to its success?
2. If you had a chance to do this project again, what would your team have done differently?

Presentation:

As a group, make a presentation to the class about what you learned during this activity and how this activity illustrates how important packaging design and engineering are to the process of shipping delicate materials, such as R2, or your “chipanaut.”



Engineers placing R2 in his protective box



R2 secured in his box for the STS-133 mission

Lesson 16: Robotic Gripper

Activity Credit: NASA's Teaching From Space Office at Johnson Space Center

Objectives:

Students will explore degrees of freedom on the robotic gripper; learn about NASA projects that involve robotic arms; and simulate remote operation of robotics in order to deepen student understanding of programming and communications in space exploration.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Abilities necessary to do scientific inquiry
 - Understanding about scientific inquiry
- Content Standard B: Physical Science
 - Forces and motion
- Content Standard E: Science and Technology
 - Abilities of technological design
 - Understanding about science and technology
- Unifying Concepts and Processes
 - Form and function

National Technology Standards:

- Standard 9: Students will develop an understanding of engineering design.
- Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

Background:

Robotic arms are models of human arms with fewer joints. They work in all types of environments, from factories to space, doing dangerous, dirty, and boring jobs. They need small computers to calculate how to move. The movements can be minimal or elaborate using several degrees of freedom.

Engineers call the numbers of joints in a robotic arm the degrees of freedom. The job that the robotic arm is designed to do determines how many degrees of freedom are needed. Each degree of freedom requires its own motor and each degree of freedom makes the calculations for the arm's movement more complicated. Basically, one degree of freedom allows the arm to reach in a circle, two allow the arm to reach in a cylinder, and three allow the arm to reach in a sphere.

The robot's effector, the end of the arm, need not be shaped like a human hand. It may be a pinch grip, a paint brush, or a welding tool - or any tool, such as the ones on robotic arms used by astronauts in space.

Some robotic arms are engineered for space duties, such as the Canadarm on the Space Shuttle and the Mars rovers on the planet Mars. The Canadarm has several joints or degrees of freedom: a shoulder joint with two degrees of movement (pitch/yaw); an elbow joint with one degree of movement (pitch); and a wrist joint with three degrees of movement (pitch/yaw/roll). The Mars Phoenix rover has a robotic arm that is a 4-degree-of-freedom manipulator with a back-hoe design that provides motion about shoulder yaw, shoulder elevation and elbow and wrist pitch.



Materials (per group of 3-4 students):

- Robotic gripper (can be purchased in most science or toy stores)
- Various items that can be picked up and moved by the robotic gripper
- Blindfolds, 1 per pair of students
- Various objects such as paper cup, a ruler, a book, chalk, a block
- Student sheet



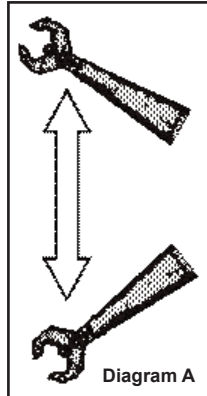
Robotic grippers

Procedure:

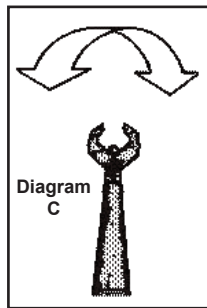
Part I: Robotic Gripper Activity

1. Students should be in groups of 3-4.
2. Place different items out for students to pick up and manipulate using the robotic gripper.
3. Explain and have students practice each maneuver, as listed in Diagrams A, B, and C, with the objects (make sure each student in the group gets an opportunity to practice with the robotic gripper):

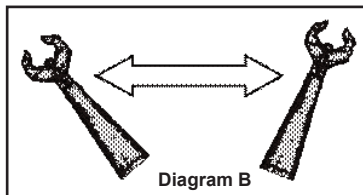
- Pitch Maneuvers - Pitch is an up and down tilting motion similar to opening a box lid. Practice pitch maneuvers by raising and lowering an object.
- Yaw Maneuvers - Yaw is a left or right turning motion. Practice yaw maneuvers by moving an object from left to right.
- Roll Maneuvers - Roll is a rotational motion. Practice roll maneuvers by rotating an object.



Up and Down Motion Pitch



Rotating Motion Roll



Left and Right Motion Yaw

Note: The maneuvers/motions described in Part 1 of this activity are called degrees of freedom and use only a wrist motion. Additional degrees of freedom include: heaving (moving up and down), swaying (moving left and right) and surging (moving forward and backward). These degrees of freedom are not possible when students only use their wrist to move the robotic gripper. However, when the elbow and/or shoulder joints are also used, these degrees of freedom exist.



Test operators in a clean room at NASA's Jet Propulsion Laboratory, Pasadena, Calif., monitor some of the first motions by the robotic arm on the Mars rover Curiosity after installation in August 2010. This photo, taken Aug. 31, 2010, shows the arm in a partially extended position. The arm has a reach of about 2.3 meters (7.5 feet) from the front of the rover body. Curiosity is scheduled to land on Mars in August 2012.

Part 2: Simulating Remote Operation of Robotics

1. Give students some background on the NASA Phoenix Project. The project information can be found at: <http://phoenix.lpl.arizona.edu>.

Note: Of all instruments onboard the Mars Phoenix rover, the robotic arm is the most critical to the success of the program. The robotic arm makes it possible to analyze soil and ice samples by bringing them to the lander deck where the scientific instruments are located. Because of the vast distance between Earth and Mars, spacecraft cannot be operated in real-time. It takes commands approximately 10-15 minutes to travel between Earth and Mars. Mission planners must write a sequence of concise and specific commands on Earth to send to the lander on Mars. Mission planners must be very careful and very specific about what they want the robotic arm to do if they are to be successful. In this activity, students will simulate sending commands to operate the robotic arm to complete each task. Students will be allowed to use only one-word commands.

2. Pair up students into teams of an Engineer and a Robotic Arm.
3. Blindfold the student portraying the Phoenix Robotic Arm.



Student portraying the Robotic Arm

4. Arrange objects in front of the Robotic Arm.
5. On the chalkboard, write a task, such as “Pick up the block and place it on the book.”
6. The second student is the Engineer. The Engineer is not allowed to touch the objects, but rather must accomplish the task by giving instructions to the Robotic Arm.
7. The Engineer gives a verbal direction to the Robotic Arm to locate the object and manipulate it as instructed. The Engineer is allowed to use only one-word commands, such as “forward,” “up,” “close.”
8. Count the number of commands it takes to complete the task.
9. Students reverse rolls and repeat activity.

Review:

This activity shows how robotic arms work and how difficult communication is between Earth and Mars due to a time delay. For a simple transmission, the time delay may mean the difference in success and failure. The movement required by the robotic arm has to be thoroughly thought out so that there is no miscommunication between the person relaying the message and the robot.

Extension:

If desired, pairs may compete with each other to complete the task with the fewest number of directions.

Evaluation:

Students should work in teams to complete the student sheet for this lesson.

Career Exploration: Robotic Engineering

The field of robotics engineering is a sub field of mechanical engineering. Robotics engineers design robots and develop new applications for them for use in a wide range of industries. With new possibilities for robotics due to advances in the computer sciences, robotics engineering is growing rapidly. From production line robots to experimental robotics for the medical, military, and automotive industries, the future of robotics engineering will certainly offer a range of opportunities for professionals entering the field.



One example of an engineering professional is Ayanna Howard. Ayanna is a robotics engineering professor at Georgia Tech University. She decided at age 11 that she wanted to create artificial limbs for people. She decided that robotics would be the way to

accomplish this goal. Ayanna’s NASA connection came when, in junior high school, people from the Jet Propulsion Laboratory (JPL) visited her school to judge their egg-drop contest. The presence of these scientists at her school inspired her to want to become a robotics engineer. Ayanna says that her advice to a student interested in science, math, or engineering is, “Don’t be afraid that by being interested in math or science you won’t be able to have fun. You can still join clubs and play sports. Don’t let anybody persuade you to give up. Know that you are going to experience adversity, but deal with it and keep going in spite of it.”

To accomplish her goals, Ayanna took math and

physics in high school and math, engineering, and computer science in college. Robotic engineers must also be able to work in a team. Each member of the team, whether they are programming the robot, working on the mechanics, or the electrical systems, all have a part in the completed project.



Robotics engineer works on robotic arm

Student Sheet – Lesson 16: Robotic Gripper

Group names - _____

Part 1

Answer questions below as a group about the observations with the robotic gripper:

- 1. What other kinds of maneuvers can you make if your elbow joint can be used?
- 2. Can you make even more maneuvers if you can use your elbow joint and your shoulder joint? _____ Explain.
- 3. Create a scenario of being aboard the International Space Station and using a robot helper to move garbage out of one module and into the supply ship for return to Earth. Describe the action by the robot (as if you are programming the robot to do this activity) and then describe which joints and degrees of freedom the robot would use to accomplish this mission. (The mobility or movement of the entire robot from one location to another will be assumed to already have been programmed.) (Use the back of this sheet, if necessary.)



Astronaut Megan McArthur, STS-125 mission specialist, works the controls of the remote manipulator system (RMS) robotic arm of the Space Shuttle orbiter, Atlantis

Part 2

Answer questions below as a group about the robotic arm simulation:

- 1. As the engineer, what was the hardest part of accomplishing the task? Why?
- 2. As the robotic arm, what was the hardest part of following the commands? Why?
- 3. List and compare the number of commands it took to accomplish the task for each person’s turn as the robot. Discuss why some robots were able to complete the task more quickly and how this relates to the concept of “programming” by the Engineer. (Use the back of the page, if needed.)



STS 109 Astronaut Nancy J. Currie, mission specialist, works the controls for the Remote Manipulator System (RMS) of Space Shuttle orbiter, Columbia

Name of Robot (Student)	Number of Commands Needed to Complete Task

Lesson 17: Robot Factory

Activity Credit: Capt Nick Ham, CAP Director of Aerospace Education
for Oregon Wing and the Salem Composite Squadron Cadets

Objectives:

Students will understand how an assembly line works and how robotics can be helpful in the process by simulating an assembly line.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design
- Understanding about science and technology

Technology Content Standards:

3. The relationships among technologies and the connections between technology and other fields.
13. Assess the impact of products and systems.
19. Selecting and using manufacturing technologies.

National Mathematics Standards:

10. Representation Standard
 - Select, apply, and translate among mathematical representations to solve a problem.

Materials:

For each group of 3-4 students (except one group):

- Item with multiple parts to assemble 20 sets, such as nuts and bolts (as shown below), LEGO blocks, simple models, etc. (The nuts and bolts in this exercise were chosen due to being inexpensive to purchase in large quantities at a hardware store and ease in transporting.)
- Robot Factory data gathering and question sheet

For other group:

- Quality Control Data Sheet

Background:

Robots used in manufacturing and industry vary in the complexity of tasks that they can do. Some robots are programmed to carry out specific actions over and over again without variation and with a high degree of accuracy. Other robots are much more flexible as to the sensory responses they can give to the orientation of the object or the task they are working to accomplish. The number of joints and degrees of freedom, as well as the end effector, can determine the kind of job the robot factory worker can do.

Robots in the assembly line can use electronic or laser vision for measuring, mechanical arms with specialized end effectors to manipulate parts, and a seemingly magical maze of production line movements to assemble everything from bagged dog food to modern aircraft.

Engineers spend hours designing the work flow and the types of robots, robot end effectors, and motions required to complete a single task. One of the reasons each of these tasks must be completed by a specifically designed and often unique robot is that the robot does not have the capacity to resolve problems and respond to different problems.

Typical applications of robots include welding, painting, assembly, pick and place, packaging and palletizing, product inspection, and testing, all accomplished with high endurance, speed, and precision.



Above: Human assembly lines of the past
Right: Robotic assembly lines of today



Procedure:

1. Divide students into groups of 3-4. All groups, except one, will be assembly line robots. The other group will be the Quality Control Specialist team

to evaluate

widget production quality.

2. Discuss manufacturing and the assembly line concept. Have students tell why they think robots would be effective as assembly line workers in doing repetitive tasks with greater accuracy than a human worker. Discuss factors that would affect human accuracy in repetitive tasks such as boredom, fatigue, distractions, etc.

3. Tell the students that their assembly line groups will be robots in a factory that produces widgets (a common term used in manufacturing to denote a specific item to be constructed). Each widget should be constructed with the same specifications and in a specified order.

4. Tell students that their widget product will be used in machines for interplanetary exploration or in an ROV (remote operated vehicle) where the widget must meet certain specifications and each widget must be the same.

5. Demonstrate how to put together a widget correctly. Have a single member of each group put together one widget correctly and have the groups time the process. Record the time on the Group Data Sheet; (box #1- Time for single robot to completely assemble widget).

6. Explain that each member of the assembling team is a robot, therefore, each robot is limited to movements that a robot arm can make and nothing more. In other words, if a piece is dropped, the worker can not look for it, bend over, or pick it up. Thus, each team should agree on an assembly method that they think will produce an accurate widget in the shortest time possible.

7. Have teams put together one widget using the assembly line method chosen and record the time on the Group Data Sheet; (box #2 - Time for assembly line



Widget parts ready for assembly



Completed widget

robots to complete one widget).

8. Have students brainstorm ways to make the widgets' assembly line more efficient prior to completing all 20 sets.

9. Give a "ready, set, go" signal for all groups to begin the assembly of their 20 widgets (use widget assembly directions to follow). Record the order that each group finishes on the board.

10. The Quality Control Specialist Team should inspect the quality of the products for each team.

11. Have groups answer questions on the Group Data Sheet and discuss with the entire class. Compare the percent of rejects per group. Discuss reasons for each widget being rejected.

Widget Assembly and Quality Control Order:

1. The first robot (cadet/student) in the assembly line will take the bolt on the word "go" and pass it to the next robot along the assembly line. The next robot will attach the small washer and then pass it along to the next robot.

2. The next robot will attach the large washer, and pass it to the next assembly robot.

3. The next robot will attach the gear (lock washer) and pass it along to the next assembly robot.

4. The next robot will place the nut on the widget as shown in the photo. This step may result in the most rejected components because the nut has to be exactly flush with the bottom of the widget.

5. The final robot will take the finished widget and place it in a shipment package or align it on the table in a specific format.

6. One or more persons in the class who have been designated as "Quality Control Specialists" should evaluate each team's completed set of 20 widgets. Any widget not completed correctly should be placed in the team's "reject area." Reasons for rejection:

- nut not flush on bolt
- too many or not enough widget components



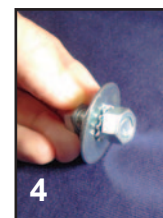
1



2



3



4

Widget complete and correct!



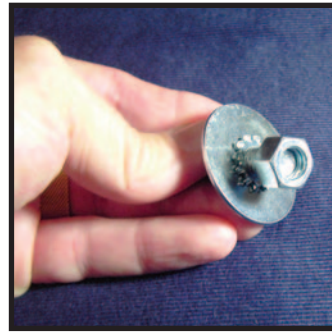
Sample of one type of widget alignment

c. widget components out of order

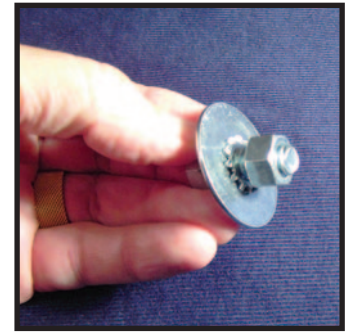
Photos of sample rejected widgets are to the right.

7. Team members should record the number of rejects on Group Data Form; box # 4 - Number of incorrect assemblies (rejects).

8. To calculate the percentage of rejects for the team, the # of rejects should be divided by 20 (the total number of widgets made by the team). The percentage should be recorded on the Group Data Sheet; box #5 - Percentage of incorrect assemblies (rejects).



Rejected widget - nut not screwed on enough



Rejected widget - nut screwed on too far

Extensions:

1. The Quality Control Specialist Team can be asked to evaluate the assembly of widgets for each team. Total quality and a percentage of error can be calculated for each team as a competition.

2. Another competition could be a timed and performance contest. The Quality Control Specialist Team can judge all teams using the following criteria (teacher should alter criteria as needed to meet teams' end products and times):

- 1 point per widget assembled with all specifications met in perfect order
- 5 points for the shortest length of time to complete widgets in perfect order NOTE: If no team meets the perfect order criteria, use a percentage formula to determine top "timed" performer:

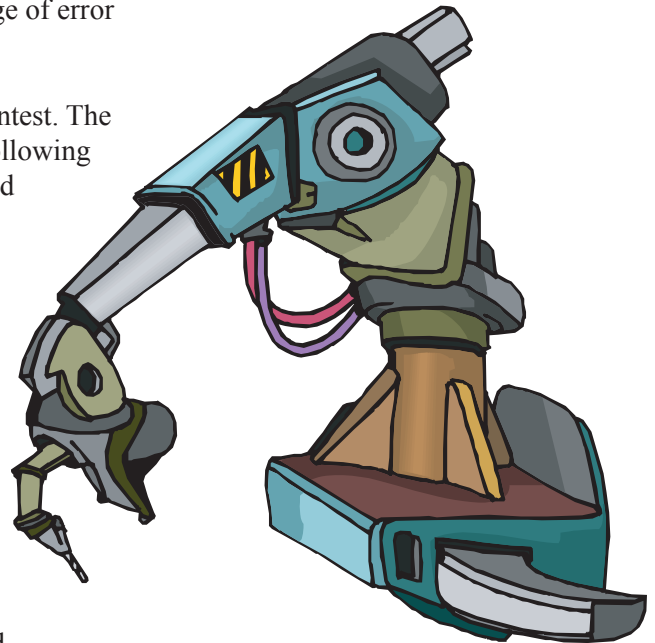
› shortest time / highest # perfect widgets
or

› highest # of perfect widgets/closest to shortest time

3. Students can write a list of steps that each robot would have to have programmed to get the particular job done in the production of the widget. (Example: Reach forward 3 inches and let end effector or hand down 2 inches. Open end effector. Grasp bolt in end effector. Close end effector. Rotate end effector 45 degrees. Move arm joint to the right 45 degrees. Open end effector to let bolt drop into the open end effector of the next robot.)

4. Instead of using nuts and bolts, other options for assembly line task could be putting together a sandwich, a puzzle, or a model.

5. The nuts and bolts assembly in this activity can be made harder by specifying shiny side up on all or creating different specifications that would cause the robot to have to use more judgment than just a simple step.



Review:

This activity shows how an assembly line robot would do a simple task to create a product. Quality control is very important to human assembly lines but the robot worker does a repetitive task without making

the mistakes of a human worker because the robot does not get bored or tired. This tasking of robots was one of the original ways that robots were used to assist humans.

Assembly Team Data Sheet: – Lesson 17 Robot Factory

Names of robots in group:

Table for recording times and quality

1. Time for single robot to completely assemble widget	
2. Time for assembly line robots to complete one widget	
3. Group time for completing all 20 widgets	
4. Number of incorrect assemblies (rejects)	
5. Percentage of incorrect assemblies (rejects)	



Salem Composite Squadron cadets prepare for robot team assembly

Answer the questions below after the activity is complete (use the back of the paper, if needed):

1. Which did you find to be more effective: the single person or the robot assembly line? _____
Explain.

2. Did the results of your production of widgets meet your expectations? _____ Why or why not?

3. How difficult was it for the team members to behave as robots instead of humans? Give an example.

4. What happened if one robot was working faster than another?
How did you reduce or eliminate this problem?

5. What sensory devices did your robots need (tactile, visual, etc.) and why did they need them?

6. Did each robot require the same end effector-hand?
What were the different movements required by each robot?

7. If you could do this activity over, what would you change and why?



Final assembled widgets

Quality Control Specialist Team Data Sheet: – Lesson 17 Robot Factory

Names in group:

Group	# of perfect widgets	# of rejects	Percentage of rejects (divide # of rejects by 20)	Comments
1				
2				
3				
4				
5				

Lesson 18: Engineering Challenge – System Engineering a Robot

Activity Credit: NASA's Space Place (<http://spaceplace.nasa.gov/en/kids/>) and the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California (<http://www.jpl.nasa.gov/>)

Objectives:

Students will learn how systems are integrated to solve problems as they design their own program to solve a chosen problem.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- Content Standard E: Science and Technology
 - Understandings about science and technology
- Content Standard F: Science in Personal and Social Perspectives
 - Science and technology in society
- Content Standard G: History and Nature of Science
 - Science as a human endeavor

National Technology Standards:

- Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.
- Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 9: Students will develop an understanding of engineering design.
- Standard 11: Students will develop abilities to apply the design process.
- Standard 12: Students will develop abilities to use and maintain technological products and systems.
- Standard 13: Students will develop abilities to assess the impact of products and systems.

Materials:

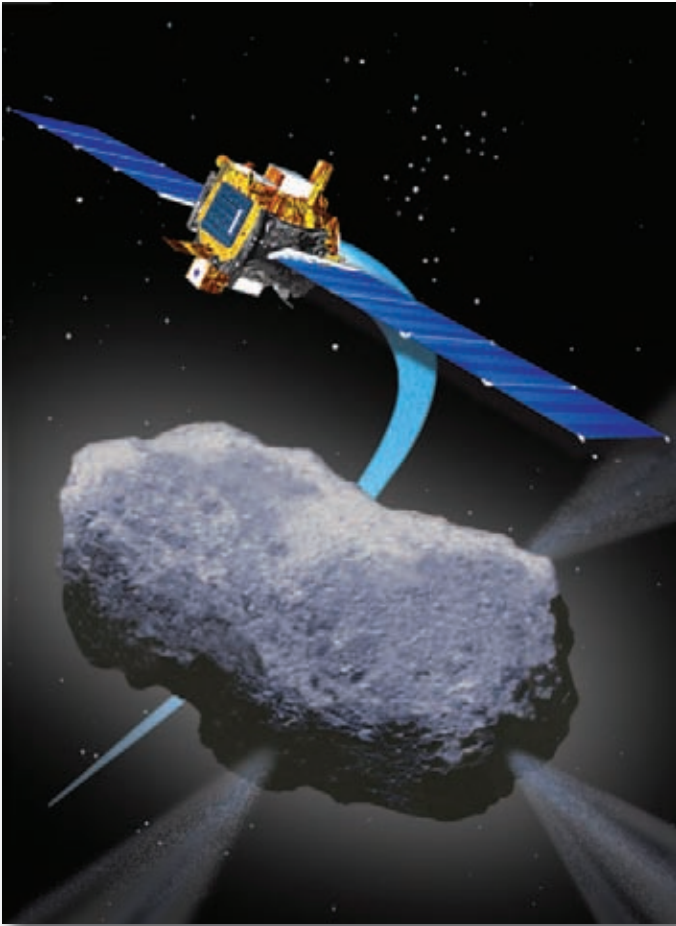
- Team engineer job cards with descriptions of what each member of the team should do
- Hand-outs with example problem and student worksheet and response sheet
- Chart paper and notebook paper
- Magic markers and pencils

Background:

Systems Engineering is an important part of the space program. Systems Engineering is concerned with figuring out how to make things work better, more safely, and more economically. Robots and space vehicles require many systems working together to achieve a mission in the best, most efficient way. When robots or space vehicles are engineered, the engineers have to consider not only the cost and effectiveness, but, also, the environment in which the robot or space vehicle will be working, as the space environment is a hostile place for humans and machines.

For example, a Mars rover that could collect the samples on the surface of Mars, and an space vehicle or orbiter that can bring the samples back to Earth, will take many engineers and systems to accomplish. A spacecraft in orbit will be required to catch the sample canister after it has blasted off the surface into Mars orbit. Mission controllers back on Earth will be so far away that a command signal would take several minutes to travel from Earth to the spacecraft. Therefore, the sample return spacecraft will be on its own, so a new technology is needed to accomplish the mission.

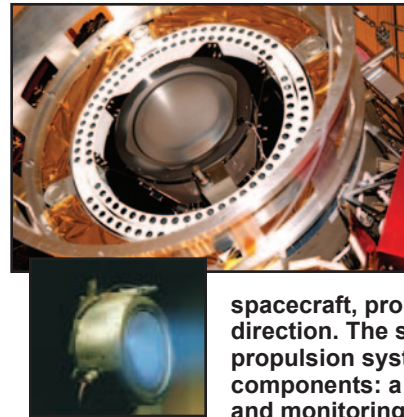
This new technology is called autonomous (independent) rendezvous technology. This would enable the spacecraft to size up the situation, decide what to do, and carry out its task with no help or communication with humans. An example of this was



Deep Space 1 (part of the New Millennium Program) - Launched on Oct. 24, 1998 and retired on Dec. 18, 2001 was used to collect images and science data from Comet Borrelly.

Deep Space 1 (part of the New Millennium Program.) Deep Space 1 was used to collect images and science data from Comet Borrelly. Even though the New Millennium Program was cancelled by NASA in 2009 due to funding reallocation, the field of systems engineering is still being used by NASA as a way to solve other space vehicle, rover, and robot-related problems. To find out more about the New Millennium Program (NMP), go to <http://nmp.nasa.gov/>.

Engineers who design spacecraft systems think carefully about the problem they are trying to solve, what capabilities the system must have, and how they can use all the new technologies, tools, techniques, and tricks they can think of to come up with the simplest, most effective, and fool-proof design possible.



One of the spinoffs from Deep Space 1 technology was the ion propulsion system (shown in the picture on the left.) An ion propulsion system converts power from the spacecraft power system into the kinetic energy of an ionized gas jet. That jet, as it exits the

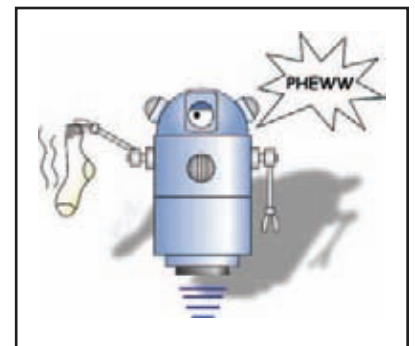
spacecraft, propels it in the opposite direction. The system, or any electric propulsion system, consists of four major components: a computer for controlling and monitoring system performance; a power source (on Deep Space 1 (DS1) this source was the solar concentrator arrays); a power processing unit for converting power from the solar arrays to the correct voltages for the engine; and the thruster, or engine, itself.

Procedure:

1. Introduce the idea of systems engineering using the background information on the previous page.
2. Discuss the example, "Autonomous Parallel Parking System," in this lesson.
3. Divide the class into groups of four. Each member of the group will be given a job card to assist the team in accomplishing their goal and solving the problem they choose. One member of the group will be the Project Engineer who provides leadership to discussions as the team moves through the steps of the design. Another member of the group will be the Facilities Engineer who provides correct templates and drawings to meet the robotic criteria that will give a visual solution to the problem. The next member of the group will be the Developmental Engineer who will lead production of robotic design and research and develop the systems needed to accomplish the task. The final member of the group will be the Test Engineer who will make records of the group's decisions for each step and record modifications to the design.

4. Have each group pick a problem to solve. The group may decide on their own problem for their robotic system to solve or choose from a set of problems provided by the teacher. Some suggested problems may include:

- Design a "cruise control" program that will drive a car at maximum speed (within the speed limit) while maintaining adequate stopping distance behind the vehicle ahead.
- Design a program that will park a car in a garage.
- Design a program for a robot to enable it to locate and pick up dirty socks lying on the bedroom floor and put them in a hamper.
- Design software to control a lawnmower so it will autonomously mow a rectangular lawn of



certain dimensions.

- Design a robot that will do some small task on an assembly line for making some product (even peanut butter and jelly sandwiches!).
- Design a program to control a device to autonomously clean the bottom and walls of a swimming pool.

5. Have each group research the problem and design a robotic system that will accomplish the task. Tell them to be sure to include drawings and diagrams that will illustrate the program. Also, remind them to record any modifications that were made to the original plan and why they had to be made.

Job Cards

<u>Project Engineer</u>	<u>Facilities Engineer</u>	<u>Developmental Engineer</u>	<u>Test Engineer</u>
Provides leadership to discussions as the team moves through the steps of the design.	Provide correct templates or drawings to meet robotic criteria.	Leads production of robotic design.	Makes records of team's decisions for each step and modifications of design.
			

There is a great CD-ROM available from NASA CORE at <http://corecatalog.nasa.gov/item.cfm?num=400.1-91> called Lunar-Nautics. Lunar-Nautics puts students in the driver's seat where they, once organized into mission teams with clear roles and responsibilities, work to conduct a lunar mission from start to finish. Students will design mission patches, lunar vehicles, and a lunar habitat for lunar explorers. Teams must work within a budget, complete design challenges, and much more. There is also a curriculum guide for this program with hands-on activities that can be found at http://www.nasa.gov/pdf/200173main_Lunar_Nautics_Guide.pdf. This guide is aimed at students in grades 6-8.

Example Problem (Imaginary Invention Only!)

Autonomous Parallel Parking

DESCRIPTION:

An autonomous system that will parallel park a car between two other cars without driver intervention.

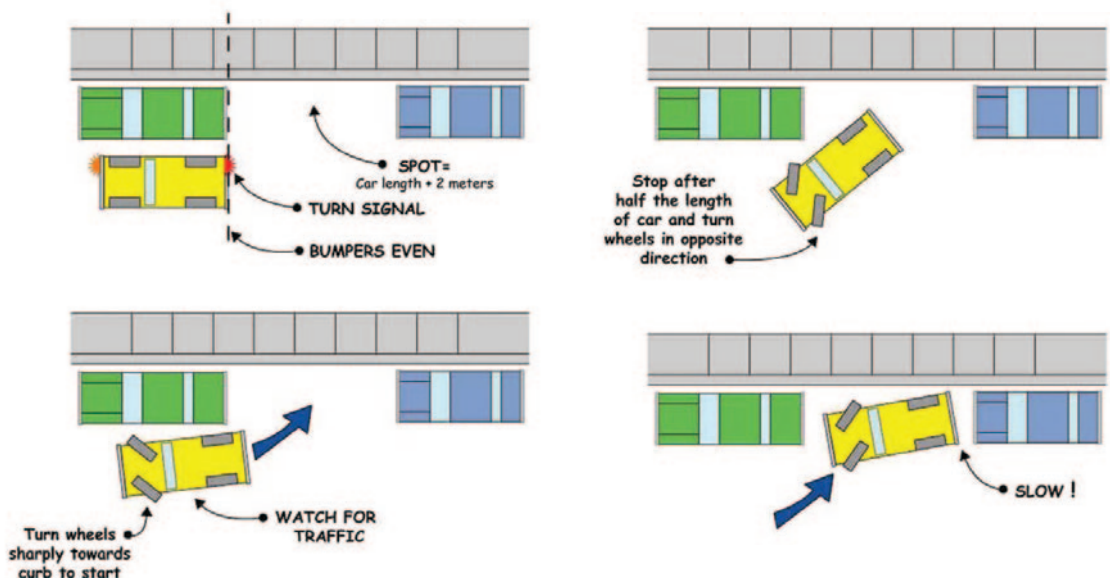
Notes: This system could be an option (although not a cheap one!) that a car buyer could purchase with a new car. If students have never had to parallel park before or have never driven before, here are some illustrations that will explain the procedure:

Sometimes, the longer you think about a problem such as this, the more complex it becomes. You keep adding "what ifs" and ways to deal with them. What if a car suddenly comes speeding up from behind just as the car starts backing up? What if a sensor on the car detects a bird flying by and the computer "thinks" the car is about to hit something? What if a pedestrian steps off the

curb behind the car? A really well-designed autonomous system will include pre-planned strategies for handling just about everything that could possibly go wrong.

REQUIREMENTS:

1. Upon stopping beside the car just ahead of a large enough parking space, driver shall be able to switch on autonomous parallel parking system.



2. Using computer-controlled steering, braking, and automatic transmission mechanisms on the car, the system shall be able to maneuver the car into a space equal to the length of the car plus 2 meters (about 6 feet), leaving 7 to 30 centimeters (3 to 12 inches) between the tires and the curb.
3. System shall be able to sense the distance to obstacles ahead, behind, and on both sides of car up to 10 meters (about 33 feet) away.
4. During parking maneuvers, no part of car shall be closer than 7 centimeters (3 inches) to any part of another car.
5. The car shall be parked with no more than one reverse maneuver and one forward maneuver.
6. If the car is on a hill, system shall turn front wheels against curb to prevent car from rolling downhill.
7. Once activated, autonomous parallel parking process shall take no more than 30 seconds.
8. System shall be able to detect unforeseen conditions or system failures, shut down, and signal for driver intervention.
9. System shall allow immediate driver intervention at any time.
10. System shall signal when car is in final parked position and return control of car to driver.

DESIGN (PARTIAL):

- System will include laser radar sensors (LIDAR) on both sides of front and rear bumpers and at least every 50 centimeters (20 inches) along the sides of the car, including the extreme front and rear. Sensors will be able to detect distance to objects up to 10 meters (about 33 feet) away, to an accuracy of 1 cm (about .5 inch). Sensors will be able to measure speed and acceleration relative to nearby objects.
- Data from sensors will be sent to onboard computer, which will calculate instructions for forward or reverse gears, acceleration, deceleration (including braking), and turning.
- These instructions will be passed to electronic controllers for the vehicle's transmission, accelerator, steering system, and brakes.
- New data will be collected from sensors and passed to computer for recalculation of all output instructions 10 times per second, thus forming a continuous feedback loop that

will immediately correct tiny errors and assure accurate placement of vehicle.

- Vehicle will include a driver panic button on the steering wheel, which will abort the process instantly and release all controls to driver.

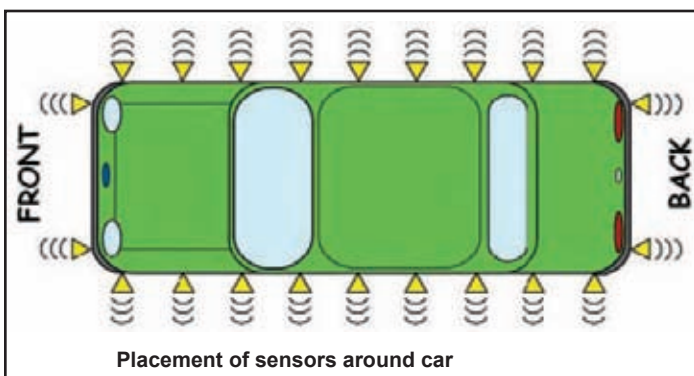
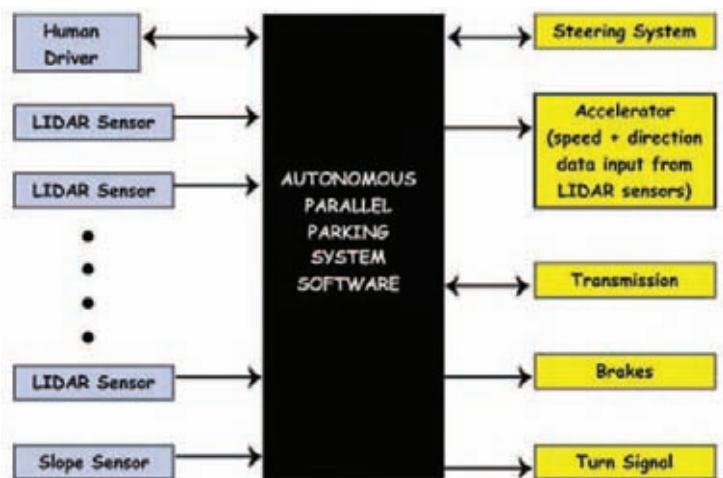
SOFTWARE INPUTS:

- Indication of which side of street (left or right) to park on - switch set by driver
- Operational mode (on or off) - switch set by driver
- Distance from obstacles - data from LIDAR sensors
- Speed (including direction) - data from LIDAR sensors
- Acceleration - data from LIDAR sensors
- Front wheel angle - data from sensor in steering system
- Slope of road - data from slope sensor

SOFTWARE OUTPUTS:

- Go/no go signal to rest of system (based on distance inputs from sensors)
- Instructions to turn indicators
- Instructions to transmission
- Instructions to accelerator
- Instructions to steering system
- Instructions to braking system
- Failure warning to human user

INTERFACES:



Evaluation:

Have each group share their designs with the class. The teacher will use an evaluation chart or rubric to evaluate each group. A sample of a possible evaluation chart is shown below.

Skill to be evaluated	5 points	4 points	3 points	2 points	1 point
1. Project Engineer provided leadership and team moved through the design process without problems.					
2. Facilities Engineer provided clear drawings for the steps in the process.					
3. Developmental Engineer lead the production of the systems needed to accomplish the task.					
4. Test Engineer made accurate records of team's decisions and modifications with reasons for the changes.					
5. Group presentation was clear and concise and solved the problem.					
6. Group worked well as a team with few distractions.					
7. Materials were used well and the plan thought out before construction of final product.					

Review:

This activity helps students understand systems engineering and how a robot requires many systems and a team with various specialities to accomplish the goal of the system. In terms of Mars mission spacecraft, the system should be autonomous, that is, enable the spacecraft to size up a situation, decide what to do, and carry out its task with no help or communication with humans. In other words, be an independent operating system such as the parallel parking system in the example problem in this activity.

Lesson 19: Rover Races

Activity Credit: ASU (Arizona State University) Mars K-12 Outreach Program

Objectives:

Students will experience some of the challenges of teleoperating a robotic vehicle on another planet by allowing a rover driver to design and execute a series of commands to guide a human rover over a simulated Martian surface.

National Standards:

National Science Standards:

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Transfer of energy

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard G: History and Nature of Science

- Science as a human endeavor

Technology Content Standards:

13. Assess the impact of products and systems
17. Information and communication technologies

Background:

Many students think that robotic vehicles (like the Mars Pathfinder Sojourner) can be driven much like they drive their toy radio-controlled cars. They imagine a rover driver watching a computer screen showing the rover on Mars and moving a joystick to make it go. This is not the reality. The time it takes for a command to reach the surface of another planet (such as Mars) varies with the distance between the planets involved. This prevents any real time “joy stick” driving. The commands travel via radio waves at the speed of light (186,000 miles / second) and can take many minutes to reach their destination. Much can happen to an interplanetary robotic vehicle during this communications lapse. If, for instance, a command were given from the Earth-base for the vehicle to go forward on Mars and the Earth-base got a reply (say 12 minutes later) saying that the rover was indeed traveling forward, it would then take another 12 minutes to send a command from the Earth-base to stop the rover. This communications delay gives greater chance for the rover to run into trouble, crash, or flip over. When this happens, the rover mission is over!

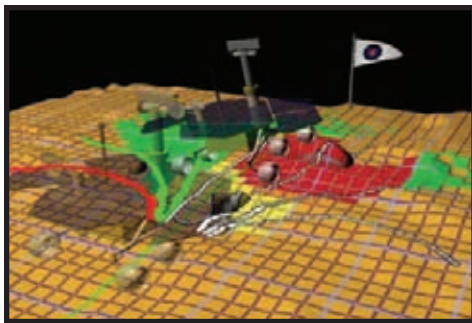
In real remote sensing operations using robotic vehicles, such as the Mars rovers Spirit and Opportunity, the rovers are programmed with stereo imaging capabilities and the ability to evaluate the terrain to avoid identifiable obstacles. The rovers were equipped with 3 antennas: a low-gain antenna that does not require aiming and transmits back to Earth or to a satellite at a low data rate; a high-speed UHF radio that communicates with two satellites already in orbit around Mars that send data back to Earth at perhaps 10 megabytes of data per day; and the high-gain antenna that communicates with Earth when it is visible to the rover. (There is a 20-minute round-trip delay because of the 200 million mile distance between Earth and Mars.)

Materials:

- Large playing area (classroom, gym, or outside area)
- Obstacles - laminated construction paper works well (note: do not use any materials that the blindfolded students will trip or fall over)
- One blindfold per team
- A clipboard and pencil for each driver and judge
- A stopwatch for the timer of each team
- Driver and scoring sheets
- Job cards with team numbers (You may want to color code each team's job cards.)



Procedure:



Left: Bottom cruise ring for Mars rovers (black inner ring contains the low and high-gain antennas)

Right: Stereo imaging capabilities of Mars rovers, Spirit and Opportunity

1. Divide the class into teams of 6 students. Students should be assigned one of the following jobs: the “rover driver;” the “team timer;” the “team judge;” the “rover;” and two “relaying devices,” (“driver relay” and “rover relay”).

2. Prepare a set of job cards for each rover team. Use 3” x 5” index cards to make a driver card, a rover card, a driver relay card, a rover relay card, a timer card, and a judge card for each team. (See page 80.) Make an anomaly card to put in an envelope for each rover.

3. (An anomaly is any occurrence or object that is strange, unusual, or unique. It can also mean a discrepancy or deviation from an established rule, trend, or pattern. Sample anomalies are on page 79. These can be copied and cut apart and/or the teacher can make others, if desired.)

4. Make a copy of the Anomaly Solutions from page 82 for each driver relay to have when anomaly interrupts the mission. NOTE: The anomaly solutions are on the Judge/Timer Sheet. But, a copy needs to be printed for the driver relay, too.

5. Set up the rover course for each team so that they have enough distance between them to avoid collisions. (See sample course on page 79.)

6. Use laminated, flat pieces of construction paper shapes to simulate rocks on the surface of Mars. Do not use any obstacle that could cause the blindfolded “rover” injury. Label each rock so rover will know which ones to use, as commanded.

7. Preface the activity with a discussion on planetary rovers and how they communicate information to Earth and receive instructions from the Earth team. Sites, such as http://marsrovers.jpl.nasa.gov/technology/bb_telecom_munications.html, can be helpful resources.

8. Drivers will receive the mission from the teacher. (See sample mission cards on page 78.) Drivers should



then be given time to chart the course for the rover without the rover or any team member, other than the judge, knowing the goal. After the drivers chart their courses on their Course Directions sheet, they should stand or sit at the end of the course with their backs turned so they cannot see the course.

Note: Have teams do a practice session prior to the timed race.

9. The other mission team members should get in their positions to begin the rover mission. (See sample rover course drawing on page 79.) All team members’ positions and jobs should be discussed.

10. The teams will all start at the same time on the teacher’s signal, with the timers from each team starting their stopwatches at the same time.

11. As soon as the start signal is given, the driver gives the first command to the driver relay and the driver relay takes the command to the rover relay. Drivers cannot give more than two commands of 5 words or less per relay. (The only exception to the limited words for commands is during the anomaly or problem part of the mission. Then, and only then, can the driver use more to describe the solution.

NOTE: Too many words are sometimes difficult to transmit with too many words to repeat.)

12. The rover relay gives the command to the blindfolded rover who executes the command and tells the rover relay when the command is complete.

13. The rover relay then takes the information to the driver relay who tells the driver that the command is complete.

14. The driver continues this command process until all steps have been completed and the mission has been accomplished.

15. Along the way, the teacher can say, “mission challenge,” and the mission is interrupted for each rover to hold up the “Anomaly Envelope” that the rover was given at the beginning of the race. The rover relay takes the envelope to the driver relay who takes it to the driver.

16. Each driver opens the envelope and reads the anomaly. The driver must then find a solution from the Anomaly Solutions page and tell the driver relay to carry the instruction to the rover relay, who gives the rover the solution.

17. The mission continues until it is complete or time is called by the teacher. The time of completion and the judges’ error points are recorded. (The judge should have been constantly watching and listening to the communications and actions to see if the rover runs into a rock or does not follow the instructions precisely. The judge must also have a list of possible anomalies and solutions so he/she can judge if the correct solution was followed by the rover. (One point is assessed for each incorrect action.) The team with the best time and the fewest errors is the best rover team.

Review:

This activity allows for teamwork and simulating the time delay involved in communicating with Mars rovers from Earth. Understanding some of the problems that occur with long-distance robotic communications can lead to new technologies or solutions.

Extensions:

1. Have students build their own rover models, explaining what type of instruments they would include and why they are necessary.
2. Have students research the types of rovers or other types of robotic spacecraft that are already traveling toward a destination or are being developed for solar system exploration.
3. Have students debate the pros and cons of sending robots versus astronauts to explore space.
4. Have students work with rover interactive at <http://www.nasa.gov/audience/foreducators/robotics/home/ROVER.html>.

Resource:

1. Rover interactive at <http://www.nasa.gov/audience/foreducators/robotics/home/ROVER.html>

Sample Mission Cards for Each Team

Team 1 Mission:

Retrieve rock 4, place it upside down on rock 3, and continue to finish line.

Team 2 Mission:

Retrieve rock 3 and place on top of rock 1. Then proceed to finish line.

Team 3 Mission:

Retrieve rock 3, place it under rock 2, and continue to finish line.

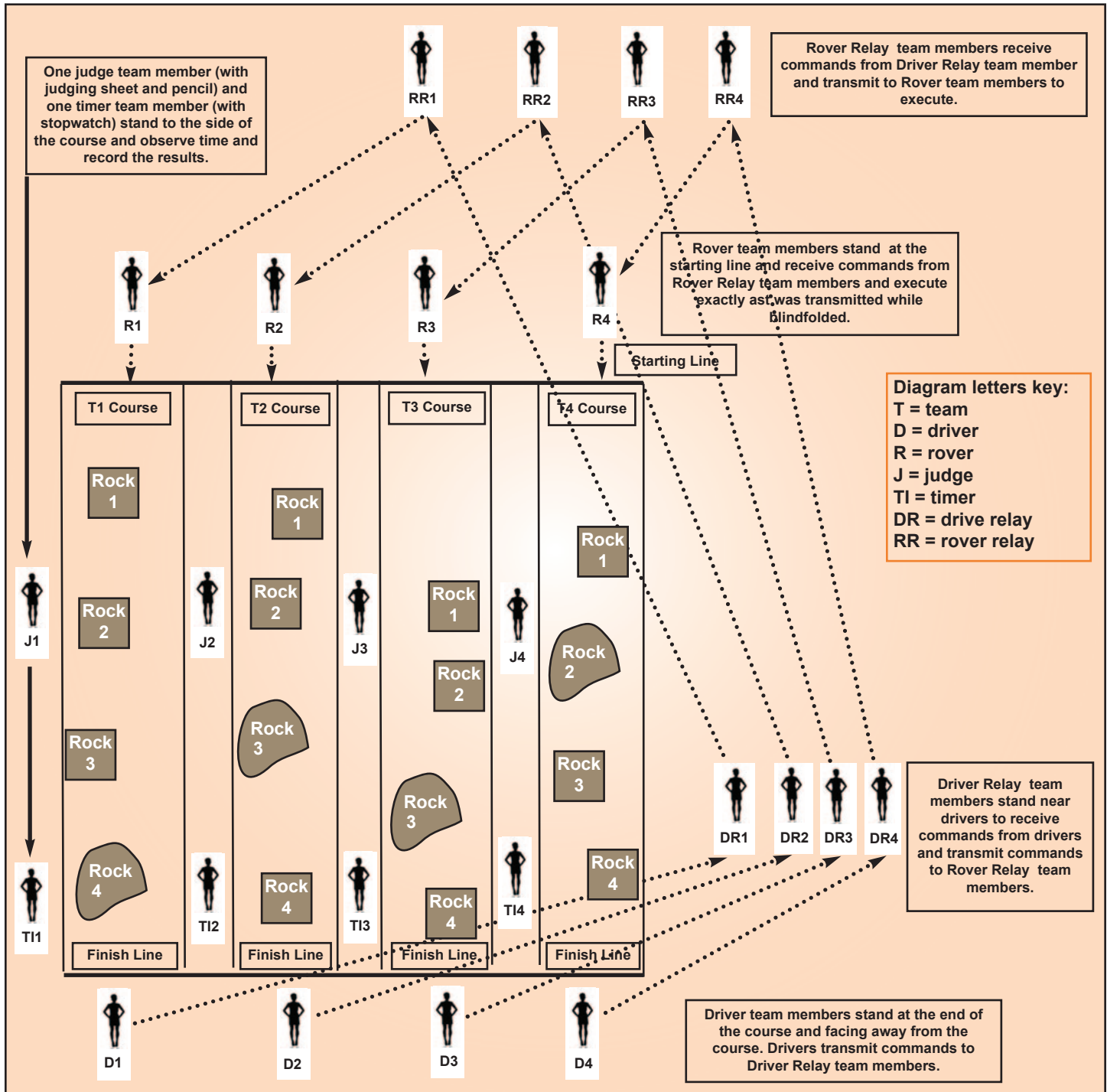
Team 4 Mission:

Retrieve rock 2 and place it next to rock 3 to the right. Then proceed to finish line.

NASA's next Mars rover -- Curiosity



Sample Rover Races Set-up and Materials



Problem 1:
You have your wheel stuck in a hole and cannot move forward.

Problem 3:
You have come upon a deep ravine that you cannot cross.

Problem 5:
Your communication system is having trouble receiving data. Please resend last command.

Problem 2:
You are experiencing low energy from your solar arrays and cannot complete the command.

Problem 4:
You are experiencing a dust storm and cannot proceed.

Problem 6:
One of your wheels is not working properly so you cannot continue.

Sample Team Member Cards (may be enlarged when printing):

Driver Team Member:

Team _____

Prior to beginning the mission, you are responsible for reviewing the mission and plotting the course by looking at the course and deciding the commands that must be given for the rover to successfully complete the mission. You may only send and receive messages through Driver Relay and you may only send 2 messages with 5 words or less per command. The only exception to the number of words is during the anomaly portion of the mission. At that time you may express the solution in as many words as are needed. Follow each command with the word "stop." You may not look at the course during the mission.

Driver Relay Team Member:

Team _____

You are responsible for listening carefully to the driver's commands and repeating them precisely to Rover Relay. You may only say each command once to Rover Relay so speak carefully.

Rover Relay Team Member:

Team _____

You are responsible for listening carefully to Driver Relay's commands and repeating them exactly as you heard them to the rover. The rover must execute each command without you repeating the command or giving any other assistance.

Timer Team Member:

Team _____

You are responsible for timing the mission from start to finish. You will record the time it took your team to complete the mission successfully.

Rover Team Member:

Team _____

You are responsible for listening to the commands from Rover Relay and following the directions given exactly as they are given. You may not make decisions or adjust the commands in any way. Remember: You are a robot that simply follows commands that are sent to you.

Judge Team Member:

Team _____

You are responsible for keeping track of each incorrect step that is made (when the rover steps on a rock or gets out of the course for his/her mission). The points that are assigned for each mistake will be recorded on the judging sheet.

Lesson 19: Rover Races

Information Sheet and Course Directions for Driver

Name of Driver _____ Name of Team _____

1. Your teacher will give you a card with your team's mission.
2. Before the mission begins, walk the course, write down the course directions for the rover to follow on the Commands List below, and count your steps as you walk through the course to ensure your commands will work.
3. When the rover is in the correct position to collect the sample you are required to gather (according to calculations on Commands List), use the Rock Sample Retrieval command. Remember to use the word "stop" after each command.
4. The rover should follow the commands you have written down and sent through the Driver and Rover Relays nothing more. Do not change your original plan except for the insertion of solution commands to solve the problem that will be sent to you from the rover.

Here are some simple commands that you may use to make your plan for your mission and direct your rover:

Right	(R)
Left	(L)
Backward	(B)
Forward	(F)
Stop	(S)
Rock Sample Retrieval	(RSR)

Commands List: (Example: 1. Forward 3 steps. Stop.
2. Turn left 45 degrees. Stop.)

- | | |
|-----|-----|
| 1. | 11. |
| 2. | 12. |
| 3. | 13. |
| 4. | 14. |
| 5. | 15. |
| 6. | 16. |
| 7. | 17. |
| 8. | 18. |
| 9. | 19. |
| 10. | 20. |

Anomaly Solutions:

I had to add these commands due to the problem facing my rover:

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.
- 8.

After completing the mission, answer these questions with your team (use the back of this paper if necessary):

1. How well did your group work as a team? What could your team have done better?
2. What problem did your rover have during the mission? How did you solve it?
3. What were some communication problems with getting the mission finished quickly?
4. How does this activity demonstrate the difficulty that NASA has with completing robotic rover missions? Give an example.

Lesson 19: Rover Races

Judges and Timers Sheet

Name of Judge: _____ Circle Your Team: Team 1 Team 2 Team 3 Team 4

Name of Timer: _____

Judge: Make a tally mark (example: l l l) each time your team's rover crashes into a rock or incorrectly follows commands from the rover relay.

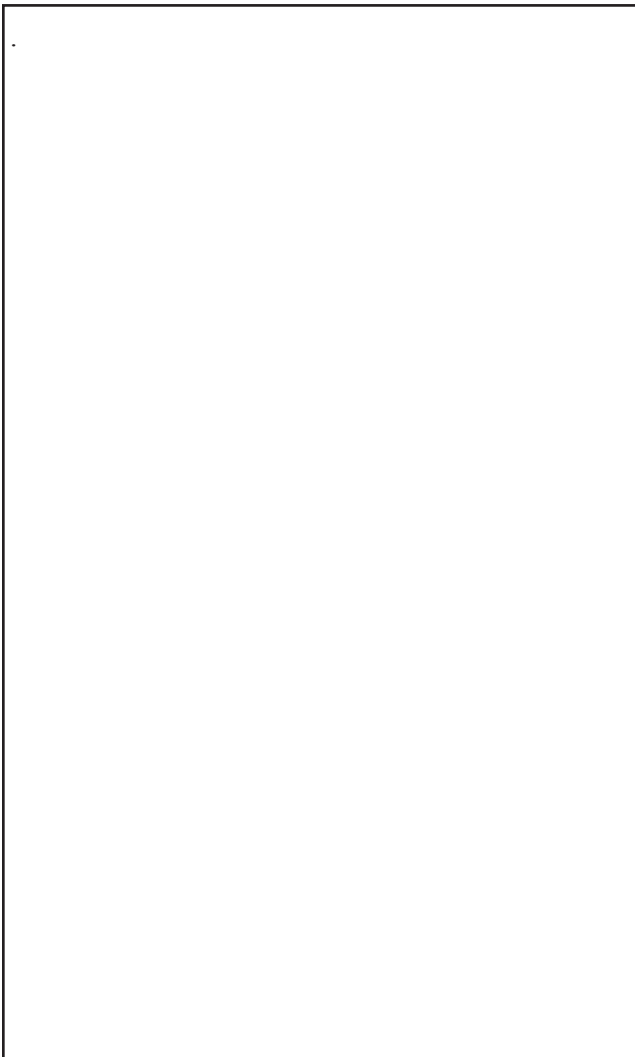
Total Rock Crashes and Incorrect Moves =

Timer:

Total Time to Complete the Course =

For Judge:

Draw a diagram of your team's course before the mission begins. Then, draw a line of the path your rover actually traveled. Put an x in the spots where you had problems.



Rover Races: Anomaly-Solution Page

Wheels:

If wheel is stuck:

- B3 steps
- F5 steps quickly. Stop.

If wheel stops moving:

- Shut down for 5 seconds. Stop.
- Reboot (clap hands 5 times). Stop.

Communication:

Did not receive last command:

- Resend the last command. Stop.

Low energy from solar arrays:

- Go to back-up battery source (Do 10 jumping jacks to start the back-up power.) Stop.

Weather:

Dust storm

- Power down for 1 minute. (Stop and count to 60.)
- Reboot and continue mission. Stop.

Terrain:

Approaching ravine:

- B2 steps
- Turn 90 degrees L. Stop.
- F2 steps.
- Turn 90 degrees R. Stop.

Lesson 20: Do the Roomba: A Curriculum for Learning Roomba from iRobot.com

Activity Credit: Drew Houston (this idea was developed out of his Master's Thesis work at Drexel University during 2008) and the iRobot.com site

Objectives:

Students will become familiar with the iRobot Create platform and begin the process of learning how this robot platform performs. The experimentation with the iRobot Create will reinforce how robots work.

National Standards:

National Science Standards:

- Content Standard A: Science as Inquiry
 - Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- Content Standard E: Science and Technology
 - Abilities of technological design
 - Understandings about science and technology
- Content Standard F: Science in Personal and Social Perspectives
 - Science and technology in society
- Unifying Concepts and Processes
 - Evidence, models, and explanation

National Technology Standards:

- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 9: Students will develop an understanding of engineering design.
- Standard 12: Students will develop abilities to use and maintain technological products and systems.

Materials:

- iRobot Create (about \$130.00 - includes iRobot Create Programmable robot; battery case, not including batteries; Create robot serial cable; Create robot fourth wheel; Create robot screws - 8 pack)
- iRobot Create command module or PC to program the iRobot (the command module allows the iRobot to move without wires attached and C or C++ can be used as the programming language; the PC can be used to program the iRobot Create by attaching the included robot serial cable to the iRobot's Mini-Din connector and uses OI or Open Interface serial protocol)
- iRobot Create owner's guide - helps to understand how the platform works and how to program it using OI
- Optional accessories or sensors can be added

For pricing and more about the iRobot Create, including the Owner's Guide download and some interesting projects, go to the iRobot Create Website at <http://store.irobot.com/shop/index.jsp?categoryId=3311368>.

iRobot Create with Command Module



Background and Resources:

The iRobot Create is a robotics education tool that helps answer two concerns with using robotics in education - the cost and making resources accessible to educators. Robotics encourages students to go into STEM (science, technology, engineering, and mathematics) fields and also encourages problem solving skills, math abilities, engineering principles, creativity, and teamwork.

The iRobot Create can be used with a regular computer hook-up or a Bluetooth device may be added to give a wireless capability. Java programming language can be used to support this setup.

Top right chart is a cost estimate to support a 20-student classroom (costs are estimated).

A single robot kit can effectively support 4 students. Modifications to the iRobot Create are encouraged. Such additions as sensors and robotic arms with end effectors can be used to get the iRobot Create to accomplish different tasks. Additional resources can be found at:

- eGFI (Engineering, Go For It!) Website - <http://teachers.egfi-k12.org/curriculum-learningroomba/>. The powerpoint presentation at the bottom of the page called "Robotics Toolkit," is a useful tool for teaching pre-college engineering education.

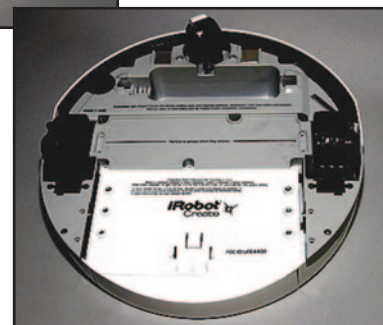
- For Java programming basics aimed at pre-college students, go to <http://csis.pace.edu/~bergin/KarelJava2ed/Karel++JavaEdition>.

- The iRobot store is a good resource as well as a place to order the iRobot Create - <http://store.irobot.com/shop/index.jsp?categoryId=3311368>. Not only does the site have the products for the iRobot Create, but it also has FAQs, Manuals, and Projects.

Item	Roomba iRobot Create
5 Roombas (iRobot Create Programmable Robot with Battery and Fast Charger)	\$1100
5 BlueTooth Adapters	\$200
3 Virtual Wall Units	\$120
1 Webcam	\$60
1 Network Switch	\$60
6 Computers	\$3600
Total w/o computers	\$1540
Total w/ Computers	\$5140



iRobot Create
Left: top view
Below: bottom view



Procedure:

1. Divide the class into groups of 3-4.
2. Set up the iRobot Create (Roomba) with Bluetooth hardware, cable connection, or command module. Make sure the Roomba is charged and the batteries are installed and working. If using the Bluetooth hardware (ElementDirect Bluetooth Adapter Module), plug the module into the Create expansion port.
3. When using Bluetooth technology, be sure to network the computers with the teacher's computer being designated as the communication hub between the network and the Roombas. The teacher's computer needs to have Bluetooth capabilities. Setting up a Bluetooth adapter differs depending on the operating system that

the computer is running on. Directions for setting up Bluetooth adapter for either Mac or PC platform can be found at the eGFI site mentioned in the Background Information.

4. The classroom computers need to be configured in a network such that all the computers can communicate with each other uninhibited by firewalls. Some school districts have policies for setting up networks and have IT professionals who are able to do so. If not, and the computers are specifically purchased for supporting a robotics curriculum, there are many guides available online for setting up a local network.

5. Follow the directions for working on the Roomba Network (found on page 12) found in the eGFI link to the Teacher's Guide - <http://gicl.cs.drexel.edu/wiki-data/images/1/1c/LearningRoomba-Introduction-TeachersGuide.pdf>. This guide is helpful for learning and working with the iRobot Create Roomba.



6. Five modules are provided as a base to build the desired curriculum. These modules can be found at <http://teachers.egfi-k12.org/curriculum-learningroomba/>.

Module 1 is Robotic Introduction and includes the introduction of robotics and forms the base for all the other modules. The topics include: designing a robot, setting up the robot network; an explanation of programming; and how to build simple programs for a robot.

Module 2 is Robot Configurations and it discusses the different types of robot platform configurations including differential drive, tricycle drive, Ackerman steer, synchro-drive, skid steer, roller wheeled, legged robots, and non-ground robot configurations.

Module 3 is Controlling Movement and teaches concepts related to moving a differential drive robot in its environment. The tasks include controlling the robot's motors to have the robot drive forward, turn, and get to a location. The module also discusses why a robot does not always travel to the same location even with the same commands.

Module 4 is Sensors and Actuators and addresses the topic of a robot's components in a Sense-Plan-Act (SPA) architecture. Different types of sensors and actuators are introduced along with their potential uses.

Module 5 is Localization and the problem of figuring out where a robot is located in the environment is discussed. The problem of mapping an environment is also addressed. General solutions to the problem are provided along with an explanation of an external camera-based approach.

7. After students are familiar with the iRobot Create and the programming procedures, they may want to identify a problem and solve it using the iRobot. Sensors can be added, as well as robotic arms with end effectors or other peripheral devices.

8. Evaluate each group on how well they understand their robot using the K-W-L-H technique. **K** stands for helping students recall what they Know about the subject.

W stands for helping students determine What they wanted to learn.

L stands for helping students identify what they Learn as they work with the robot.

H stands for How the students can learn more.

K What do you know about your robot?	W What do you want to learn?	L What did you learn?	H How can you learn more?



Top: iRobot Create modified with robotic arm and end effector that can pick up paper

Right: iRobot Create modified with mini computer and camera



Review:

This activity involves using an affordable mobile platform to experiment, learn, and have fun with robotics. The uses can be from simple programming to more difficult programming depending on the skill of the user.

Lesson 21: Calculator Controlled Robots

Activity Credit: NASA's Calculator Controlled Robots: Hands-On Math and Science Discovery at http://www.nasa.gov/pdf/239512main_Calculator_Controlled_Robots.pdf

Objectives:

Students will learn how to use a graphing calculator to operate a robot and complete the mission by using commands from the calculator.

National Standards:

National Mathematics Standards:

1. Number and Operations Standard
 - Compute fluently and make reasonable estimates
3. Geometry Standard
 - Use visualization, spatial reasoning, and geometric modeling to solve problems
4. Measurement Standard
 - Apply appropriate techniques, tools, and formulas to determine measurements

National Science Standards:

- Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- Content Standard E: Science and Technology
- Abilities of technological design

National Technology Standards:

- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
- Standard 12: Students will develop abilities to use and maintain technological products and systems.

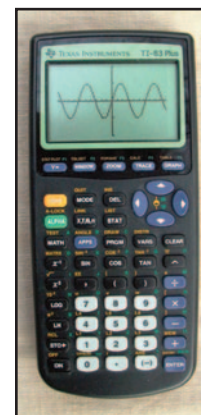
Materials:

For each group of 5 or less:

- 1 Norland Calculator Robot Kit (\$99.95)- can be purchased from Norland Research at <http://www.smallrobot.com/scimath.html>
- 1 Graphing Calculator (TI 73, 83, 83 plus, 86 and 89 work with the calculator robot kit-\$95.00) - (Some students have to buy these calculators for math or science classes, so check to see if there are calculators already in your school.)
- TI 12 inch link cable - (\$4.95) and TI slide cover - (\$4.95) - these can also be purchased from Norland Research
- 4 AA batteries
- several meter sticks
- graph paper
- student directions and results sheet

For the Crawler-Transporter explorer extension:

- Estes Alpha Rocket (assembled)
- building materials for transporter base, such as Styro foam meat trays, popsicle sticks, cardboard, pipe cleaners, straws, or glue



TI 83 plus

Background:

About the calculator robot - These robots get their motion commands by sending an electronic pulse to each servo motor in the robot base. (A servo motor is a combination DC motor, a gear reduction unit, a position-sensing device, and a control circuit that has the function of receiving a control signal to turn the motor in the direction needed to position the shaft correctly.) These pulses or commands are sent via the calculator with a series of inputs from the user. The directions for assembling the robot set about an hour for assembly. All that is required is to install the bumper on the front, mount the wheels, plug in the link cable, and install batteries. The directions that come with the kit give instructions about using the software. Two lines of programming code will make the robot move, but several lines are needed to get the robot to solve the task you wish to be accomplished. The mission that should be programmed into the robot for this activity is to navigate a maze to retrieve and return an object to and from an original starting point. This is accomplished by inputting the correct series of commands for the turns and movements, as well as getting the package attached to the bumper and returned to the beginning of the maze.

About the NASA Crawler-Transporter that will be built as a part of this calculator-controlled robot activity - The Crawler-Transporter has been used by NASA to transport the Space Transportation System (the Space Shuttle and fuel tanks) from the Vehicle Assembly Building (VAB) to the launch pad on a Mobile Launcher Platform (MLP). It traveled at approximately 1 mph for approximately 4.2 miles from the VAB to launch pad 39B, the commonly used launch pad for Shuttle launches. (A short video of STS-131 being moved to the launch pad can be found at http://www.nasa.gov/mp4/432402main_ksc_030410_sts131_rollout.mp4.)



Norland Calculator
Robot kit with calculator



Crawler shown in front of VAB



STS 101 Atlantis aboard the crawler prior to launch



After delivering shuttle Discovery to the launch pad for the STS-124 mission, the crawler-transporter is moved to the foot of the pad

Procedure:

1. Teacher or students should first assemble the robots according to the directions included in the kit. Make sure that batteries are working and that cable connections are secure.

2. Have students practice with the Programming Procedures (on the next page) and get familiar with the software for the robot.

3. Have students lay out a maze for their robots to follow with meter/yard sticks on each side about one foot (30.48 cm) apart.

4. Start with two straight runs with a right angle in between them.

5. Create the new program MAZE (see Programming Procedures on next page, if needed).

6. The programming of steps to accomplish the maze should have the appearance of the example below:

Send ({ABC,xxx}), where:

xxx is the number of seconds of run time in centiseconds

<u>A - Time or Bumper</u>	<u>B - Left Wheel</u>	<u>C - Right Wheel</u>
1 = timed movement only	0 = backward	0 = backward
2 = move until bumper hits	1 = no motion	1 = no motion
3 = time or until bumper hits	2 = forward	2 = forward

For example:

Send ({122,600}) (1= timed movement only; 2= left wheel forward; 2 = right wheel forward; and 600 = 6 seconds)

Get (R) (Always needed to close a Send command)

The robot will move forward for 6 seconds.

Students will also need to know how fast their robot travels. For example, if their robot takes 5.27 seconds to travel the distance of one meter/yard stick or 100 cm (39.37 in.), it is traveling at approximately 18.98 (rounded to the nearest hundredth) cm (7.47 in.) per second ($r = d / t$ or $r = 100 \text{ cm} / 5.27$ or $r = 39.37 \text{ in.} / 5.27$).

When the students have discovered how to make their robot rotate for one turn, they will need to determine how many seconds the rotation must last for a 90-degree turn.

7. Students will need to construct a simple paper cube to be the object that their robot retrieves when it goes through the maze.

An example is below:

8. Present the challenge to the student groups: The official test maze that your robot should complete consists of four straight runs and three turns. At the end of the maze there will be a package cube that must be recovered (students need to attach something to the front of the robot bumper to retrieve the cube) and returned to the starting line.

Teacher note: The cube can be attached with tape or velcro or any creative way the students can design.

9. Grading scale:

Robot retrieves cube and returns it to start:	A+
Robot retrieves cube and spins in circle for joy:	A
Robot makes it through, but misses cube:	B
Robot makes it halfway through the maze:	C

10. Have students analyze the results of their robot maze activity and answer the questions on their student data sheets.

Crawler-Transporter Exploration Extension Procedure:

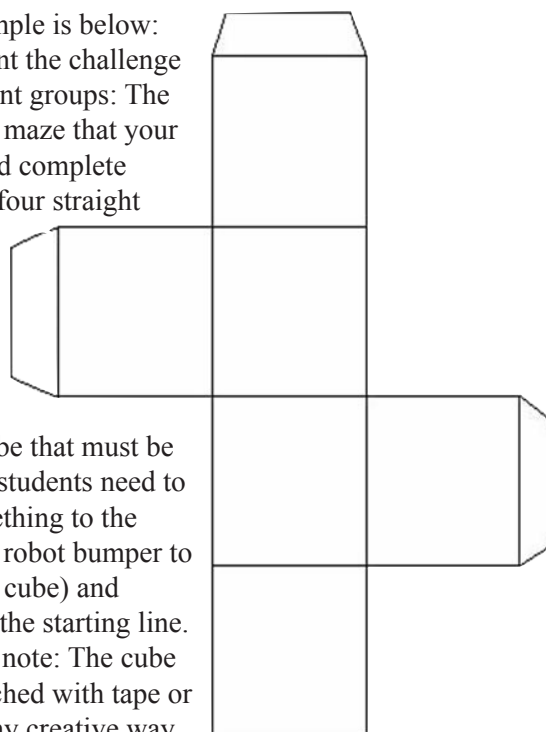
1. Have students build a simple rocket according to the instructions in the rocket kit. (These can be done at home or before class if time is limited.)

2. Have student groups design a mobile launch platform (Crawler-Transporter) on graph paper that will support the rocket and fit on the robot. The design must keep the "multimillion dollar rocket" secure through turns and rises in elevation. It must also allow for access to the calculator buttons needed to run the robot.

3. Have students use the design they created to build a mobile launch platform from materials provided by the teacher. (One example is shown on the left.)

4. The maze from the introduction activity will represent the "Crawlerway" at Kennedy Space Center (KSC) which connects the VAB to the launchpad. Students should use the Crawler-Transporter that they built and the MAZE program to transport a rocket from the beginning of the Crawlerway to the end.

5. Have students evaluate their efforts and answer the questions.



Programming Procedures:

Programming the Calculator Robot for straight lines and turns:

1. Discuss how many different ways you can program your robot to turn. (Note: There are several ways to make the robot turn: one wheel stopped and the other moving forward or backward, one wheel moving forward and the other moving backward, et cetera. A sample right turn would be: Send ({120,42}) followed by Get (R).) Let students practice turning until they are comfortable with this process. (Look at Group Date Sheet for more help.)

2. Practice getting from a point A to a point B in a straight line. (Note: Calibrate the robot to move in a straight line by correcting wheel speed.)

- Run the CALI program. Press PRGM and use the arrow to scroll down to : CALI. Press ENTER. Place the robot on the floor, then press ENTER again. Press ZOOM. Note which way the robot veers and press the bumper to stop the robot.
- Slow down the faster wheel of the two wheels by pressing the button under the DN on that side. Due to the design of the electronics, you may have to change this 70- 100 units to see much speed change.
- Press ZOOM and the speed of the wheel should change. Press the bumper and continue adjusting the speed until the robot goes straight. For simplicity, it's best to change the speed of just one wheel.
- Once your robot is going straight, make a note of which wheel was adjusted and the correction number. To leave the CALI program, press ON, then 1, then CLEAR.
- Edit the CORRECT program. (Press PRGM, then use the arrow to highlight EDIT. Use the arrow to scroll down to : CORRECT. Press ENTER.) If you had to slow the left wheel, change "255" in the program Line 1 to the appropriate value. If you slowed the right wheel, change the "0" in program Line 4 to the appropriate value. To insert numbers, press 2nd, then [INS]. To finish, press 2nd, then [QUIT].
- Run the CORRECT program and press the bumper to stop the robot. Your correction is now set in the robot's memory until the power switch is turned off. Whenever you switch on the robot, run the CORRECT program to reestablish the wheel correction.

Note: The instructions above were from Lesson 1 in the Calculator Controlled Robots: Hands-On Math and Science Discovery curriculum guide. The entire guide can be accessed at http://www.nasa.gov/pdf/239512main_Calculator_Controlled_Robots.pdf.

Programming the Calculator Robot for this activity:

Turn on your graphing calculator. Press PRGM and arrow to highlight NEW. Press ENTER, then spell out [MAZE] by pressing the appropriate keys. Press ENTER and you're ready to enter the first command for the program.

Line 1: Press PRGM, then use the arrow to highlight I/O. Use the arrow to scroll down to **B: Send** (and press ENTER. Press 2nd and then press (for open brace. Type in 122 , 600. Close the braces and parentheses by pressing 2nd,[)], then). Press ENTER. The first line should appear: :Send({122,600})

Line 2: Is blank

Line 3: Press PRGM, then arrow to highlight I/O. Use the arrow to scroll down to **A: Get** (, and press ENTER. Press ALPHA, the [R]. Press) then ENTER. The third line should appear as: :Get(R)

Line 4: Press PRGM, then use the arrow to highlight I/O. Use the arrow to scroll down to **B: Send** (and press ENTER. Press 2nd and then press [{]. Type in 120 , 42. Close the braces and parentheses by pressing 2nd, [}], then). Press ENTER. The fourth line should appear as: :Send({120,42})

Line 5: Press PRGM, then arrow to highlight I/O. Use the arrow to scroll down to **A: Get** (, and press ENTER. Press ALPHA, then {R}. Press) then ENTER. The fifth line should appear as: :Get(R)

Line 6: Press PRGM, then use the arrow to highlight I/O. Use arrow to scroll down to **B: Send** (and press ENTER. Press 2nd and then press [{]. Type in 122 , 600. Close the braces and parentheses by pressing 2nd, [}], then). Press ENTER. The sixth line should appear as: :Send({122,600})

Line 7: Is blank

Line 8: Press PRGM, then arrow to highlight I/O. Use the arrow to scroll down to **A: Get** (, and press ENTER. Press ALPHA, then [R]. Press) then ENTER. The eighth line should appear as: :Get(R)

Adjust command times as necessary. Add forward motion and turns as needed. A sample left turn is, :Send({102,42}).

Answers to questions 1-3 for Crawler-Transporter on Data Sheet:

1. The weight and placement of the MLB and rocket may change the traveling and turning characteristics of the robot.
2. At one mph NASA's Crawler-Transporter is traveling at 44.7 cm/s (17.6 in/s). It's faster by 24.7 cm/s (9.72 in./s).
3. Answers will vary. The Crawler-Transporter uses hydraulic lifts to keep the Space Transportation System vertical as it goes up the incline at the launch pad.

Background Information on the Crawler-Transporter can be found at: <http://en.wikipedia.org/wiki/Crawler-transporter>.

Build a paper model of the Crawler-Transporter by going to <http://www.axmpaperspacescalemodels.com/CrawlerTransporter.html>.

Review

This activity introduces programming in TI-BASIC. (TI-BASIC is the unofficial name of a BASIC-like language built into Texas Instruments or TI graphing calculators, such as the TI-83 series, TI-84 Plus series, TI-89 series, TI-92 series, and TI-73. TI does not officially

name the language, but only refers to it as "extensive programming capability.") This activity can be expanded using the website provided at the beginning of the lesson for NASA's Calculator Controlled Robots: Hands-On Math and Science Discovery curriculum guide.

Calculator Robot Group Data Sheet

Group members: _____, _____,
_____, _____, _____

Turns and Mazes Introduction Activity:

1. Practice going straight and turning with the robot. If you need programming help, ask your teacher for additional programming assistance.
2. Set up a maze with meter/yard sticks to create sides about one foot (30.48 cm) apart. Start with two straight runs with a right angle turn in between them.
3. Which ways might be best for navigating your maze? How can you get your robot to make the 90-degree turn in your practice maze?
4. The programming of steps to accomplish the maze should have the appearance of the example below:
Send ({ABC,xxx}), where:

A - Time or Bumper

1 = timed movement only

2 = move until bumper hits

3 = time or until bumper hits

B - Left Wheel

0 = backwards

1 = no motion

2 = forwards

C - Right Wheel

0 = backwards

1 = no motion

2 = forwards



xxx is the number of seconds of run time in centiseconds.

For example: **Send ({122,600})** (1= timed movement only; 2= left wheel forward; 2 = right wheel forward; and 600 = 6 seconds)

Get (R) (Always needed to close a Send command)

The robot will move forward for 6 seconds.

Your group will also need to know how fast your robot travels. For example, if your robot takes 5.27 seconds to travel the distance of one meter/yard stick or 100 cm (39.47 in.), it is traveling at approximately 18.98 (rounded to the nearest hundredth) cm (7.47 in.) per second ($r = d / t$ or $r = 100 \text{ cm} / 5.27$ or $r = 39.37 \text{ in.} / 5.27$).

When your group has discovered how to make your robot rotate for one turn, you will need to determine how many seconds the rotation must last for a 90-degree turn.

5. The official test maze has been set up by your teacher. At the end of the maze there will be a paper cube to be retrieved and returned to the start line. The chart below will help you plan your strategy for completing the maze.

6. Answer the questions below:

List five different environments where it might be too dangerous for humans to explore, but a robot could go and send back valuable information.

1. _____

2. _____

3. _____

4. _____

5. _____

Describe three situations where humans couldn't reach and you would need a small robot to explore.

1. _____

2. _____

3. _____

Runs and Turns	Time Needed	Commands
Run 1 (In centimeters/inches)		
Turn 1 (Left or Right)		
Run 2 (In centimeters/inches)		
Turn 2 (Left or Right)		
Run 3 (In centimeters/inches)		
Turn 3 (Left or Right)		
Run 4 (In centimeters/inches)		

Crawler-Transporter Exploration Extension Directions, Results, and Data

Directions:

1. Follow the directions to build a rocket from the kit your teacher provides. (Follow all manufacturer's recommendations and the National Association of Rocketry's Model Rocket Safety Code when building and launching rockets.)
2. On graph paper, design a mobile launch platform (the Crawler-Transporter) that will support your rocket and fit on the robot. The design must keep your "multimillion dollar rocket" secure through turns and rises in elevation. It must also allow for access to the calculator buttons needed to run the robot.
3. Use your design to build a mobile launch platform from materials provided by your teacher.
4. The maze from the introductory lesson on Turns and Mazes will represent the "Crawlerway" at Kennedy Space Center (KSC) which connects the VAB to the launchpad. Use your Crawler-Transporter and the **MAZE** program to transport a rocket from the beginning of the Crawlerway to the end.
5. As an added challenge, you can add a 10° incline ramp to the end of your Crawlerway.
6. Your teacher can decide whether or not you can launch the rocket when the challenge is complete.

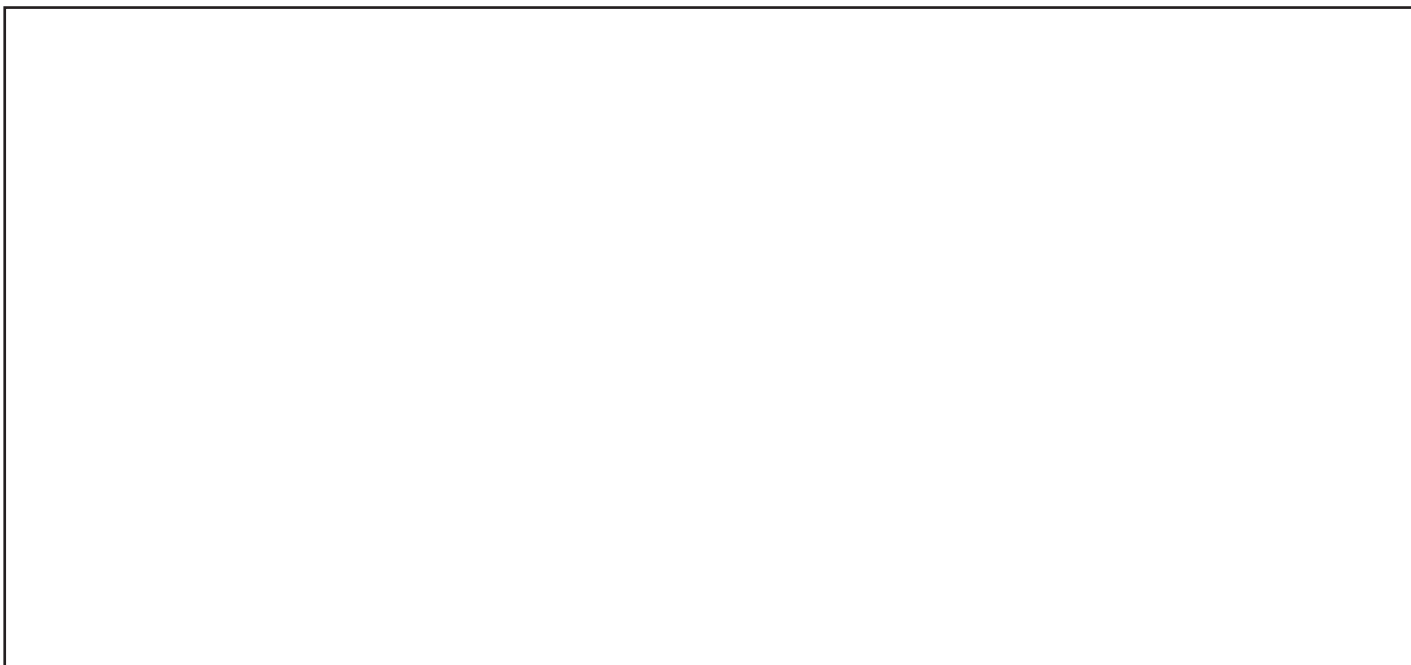
Answer the questions below after you have completed this part of the activity:

1. Did you have to change the time durations in the MAZE program for the successful transport of the rocket? If so, why did that occur? _____

2. When NASA's Crawler-Transporter is loaded with the MLP (Mobile Launch Platform) and the Space Transportation System, it weighs about 17 million pounds and creeps along at only one mile per hour. Calculate which is faster, the Crawler-Transporter or a robot that travels at 20 centimeters per second? _____

By how many centimeters/inches per second? _____

3. The Crawler-Transporter has to keep the Space Transportation System vertical as it goes up a 10° incline ramp at the launchpad. Below, draw a design of how you would keep your rocket vertical if the robot had to go up a 10° incline. Label all parts of your diagram.



Summary and Additional Resources

And now for LEGO Robotics.....

As most people who are interested in educational robotics know, the program that has seen much success and participation from schools all across the country, is the LEGO Mindstorms NXT robotics program. This program is well constructed and includes lesson plans and all needed information, as well as competitions to show the skill of the teams. The LEGO NXT is ideal for middle and high school teaching. The LEGO Mindstorms Education Base Set, along with the lessons created by Carnegie Mellon, are available from many sources. Use a search engine to locate a supplier that you would like to use. Here are some tips for starting a LEGO robotics group:

1. Decide on the size and number of student teams.

Teams of 2 or 4 students per robot work well. Teamwork is a big part of the activities, as well as in the modern workplace. (Some competitions, such as FIRST LEGO, limit the team size to 10 students.)

2. Work on writing grants and partnering with local technology businesses to get funding for the robotics kits that you will need to purchase to support your program.

3. Define roles for the robotics teams allowing team members to experience each role and share in the responsibility for all parts of the process from building to programming. One member of the team can be the Engineer (builder), another member can be the Software Specialist (programmer), another member can be the Information Specialist (gets the necessary information for the team to move forward), while another member can be the Project Manager (makes sure things get done).

4. Identify technical and logistical requirements, such as the types of robots, computers, classroom / practice area, network, multimedia presentation to present material to entire class, etc.

5. Pricing can be found on the LEGO Education website. Some approximate costs associated with the program are:
LEGO Mindstorms Education Base Set = \$280
Education Resource Set = \$80
Programming Software LEGO NXT 2.1 and site license = \$340

Grant Information:

1. The LEGO Children's Fund Grants guidelines and application can be downloaded at:

<http://www.legochildrensfund.org/Guidelines.html>

This Foundation awards grants to qualified tax-exempt organizations (as determined under section 501(c) (3) of the Internal Revenue code) including educational organizations as defined in USC 26 § 170 (C) with specific, identifiable needs primarily in these areas of support:

- Early childhood education and development that is directly related to creativity
- Technology and communication projects that advance learning opportunities

2. The Air Force Association awards grants of \$250 each to teachers promoting aerospace education and the STEM subjects in their classrooms.

<http://www.afa.org/acf/aid/grants.asp>

3. Another organization with local chapters - AFCEA (Armed Forces Communications and Electronics Association) may be a source of funding.

<http://www.afcea.org/education/scholarships/STEMTeachers.asp>

4. Toshiba America Foundation offers science and math education grants. **<http://www.toshiba.com/taf/>**

5. Lowe's Toolbox for Education grants are another possible source. **<http://www.toolboxforeducation.com/>**

6. LEGO has a website dedicated to locating and applying for grants with some ideas and a "how to" for writing grants. **<http://www.legoeducation.us/about/item.aspx?ap=2&art=314>**

7. Civil Air Patrol's Air Force Association grants for members who are educating youth in STEM subjects - **<http://www.capmembers.com/ae>**

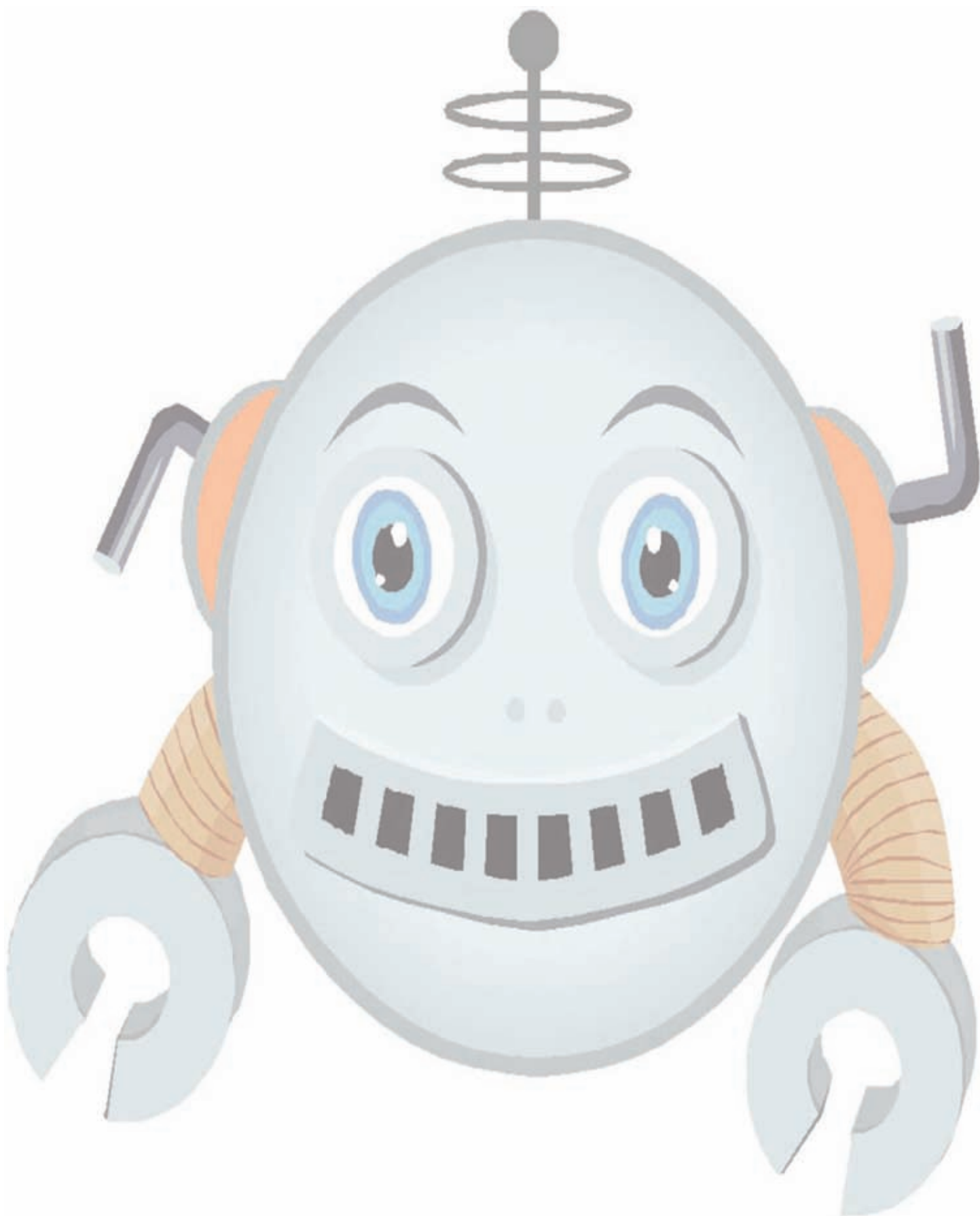
Robotics Competitions:

There is also a surprising amount of robotics competitions that are geared toward school age children, particularly ages 9 and up. Some of these include: BotBall, First Lego League, FIRST Robotics Competition, Robofest, VEX, and BEST.

- Botball information and registration can be found at:
<http://www.botball.org/>.
- FIRST LEGO League Website -
<http://www.firstlegoleague.org/>
- FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition -
<http://www.usfirst.org/roboticsprograms/frc/default.aspx?=&966>
- Robofest information can be found at:
<http://www.robofest.net/>
- VEX robotics competition -
<http://www.vexrobotics.com/competition/>
- BEST (Boosting Engineering, Science, and Technology) - engineering based robotics can be found at:
<http://best.eng.auburn.edu/>

Other robotic resources:

- A good pdf (slide format) on the basics of NXT Programming can be found at:
<http://admin.robofest.org/2010/NXTG10.pdf>.
- NASA robotics page: **<http://robotics.nasa.gov>**
- NASA - Kennedy Space Center has interactive media that includes multimedia, simulations and virtual tours.
<http://imedia.ksc.nasa.gov/index1.htm>
- Tufts University LEGO engineering resource site:
<http://www.legoengineering.com/>
- A robotics resource using LEGO (from Tech Start Education Foundation of Oregon.) LEGO NXT tutorial.
http://webclass.superquest.net/sboost/tutorials/NXT_Tutorial/index.html
- Carnegie Science Center of Pittsburgh has a website called Roboworld that contains educational resources, workshop opportunities, and a section on careers in robotics. **<http://www.visitroboworld.com/visitroboworld/about.aspx>**





www.capmembers.com/ae

