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Introduction

*Robotics 2: NeXT Steps* requires the use of the same NXT LEGO® Mindstorms® kit used in *Robotics 1: NeXT Technology*. It is intended for youth who are already proficient in building a LEGO® NXT robot. Kits are available from LEGO® Education, which offers a special bundle that includes the robot, software, rechargeable battery, and storage bin. Youth who take this project also need access to a computer and the Internet.

Every activity begins with construction of a special robot configuration. Files and videos with instructions have been developed by the Carnegie Mellon Robotics Academy and are available to 4-H members via the Ohio 4-H Robotics website at [www.ohio4h.org/robotics](http://www.ohio4h.org/robotics).

Notes to the Project Helper

Congratulations! A 4-H member has asked you to serve as a project helper. You may be a parent, relative, project leader, friend, club advisor, or another individual important in the 4-H member’s life. Your duties begin with helping the youth create and carry out a project plan, as outlined in the Member Project Guide. This is followed by helping the youth focus on each activity, providing support and feedback, and determining what was done well, what could have been done differently, and where to go next.

As a project helper, it is up to you to encourage, guide, and assist the 4-H member. How you choose to be involved helps to shape the 4-H member’s life skills and knowledge of the importance of engineering and robotics.

**Your Role as Project Helper**

Your contributions are critical to delivery of the 4-H program. It is essential that your interactions support positive youth development within the framework of these Eight Key Elements:

1. Positive relationship with a caring adult
2. Safe environment, emotional and physical
3. Opportunity for mastery
4. Opportunity to value and practice service
5. Opportunity for self-determination
6. Welcoming environment
7. To be an active participant in the future
8. Engagement in learning

For more information on the Eight Key Elements, please refer to the *Advisors Handbook* available online at [www.ohio4h.org](http://www.ohio4h.org).
In addition, on a practical level, your role as a project helper means you will . . .

- Guide the youth and provide support in setting goals and completing this project.
- Encourage the youth to apply knowledge from this project book.
- Serve as a resource person.
- Encourage the youth to go beyond the scope of this 4-H project book to learn more about engineering and robotics.

What You Should Know About Experiential Learning

The information and activities in this book are arranged in a unique, experiential fashion (see model). In this way, youth are introduced to a particular practice, idea, or piece of information through an opening (1) experience. The results of the activity are then recorded in the accompanying pages. Youth then take the opportunity to (2) share what they did with their project helper, (3) process the experience through a series of questions that allow the learner to (4) generalize and (5) apply the new knowledge and skill.

What You Can Do

- Review the learning outcomes (project skill, life skill, educational standard, and success indicator) for each activity to understand the learning taking place. See page 35 for a summary of the learning outcomes.
- Become familiar with each activity and the related background information. Stay ahead of the learner by trying out activities beforehand.
- Begin the project by helping the learner establish a plan for the project. This is accomplished by starting the Member Project Guide.
- After each activity, briefly talk with the learner so that she or he has an opportunity to share results and answers to the review questions. This important step improves understanding from an experiential learning perspective. Help the learner focus on the project and life skills being addressed.
- Help the learner celebrate what was done well and see what could have been done differently. Allow the learner to become better at assessing his or her own work.
- In the Member Project Guide, date and initial activities as they are completed.

Notes to the Project Helper
Member Project Guide

Welcome to *Robotics 2: NeXT Steps!* This project is designed for 4-H members of all ages who have advanced-level robotics skills and who have completed *Robotics 1: NeXT Technology.* All activities are based on the LEGO® NXT system.

This project is designed as an individual project, although many 4-H members decide to complete it in small groups. The LEGO® NXT robot that was constructed for Robotics 1 is required, and access to a computer and the Internet are necessary. The project can easily be completed in one year. Members who want to continue in robotics are encouraged to design their own self-determined robotics projects.

Check your county’s project guidelines (if any) for completion requirements in addition to the ones below, especially if you plan to prepare an exhibit for the fair.

Project Guidelines
Step 1: Complete all seven activities.

Step 2: Take part in at least two learning experiences.

Step 3: Become involved in at least two leadership/citizenship activities.

Step 4: Write a project summary and take part in a project review.

**Step 1: Project Activities**

Complete all seven activities. The More Challenges activities are optional. When you begin an activity, jot down the date you start it. When you finish an activity, review your work with your project helper. Then ask your project helper to initial and date your accomplishment.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date Started</th>
<th>Date Completed</th>
<th>Project Helper Initials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Get a Grip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Data Driven Decisions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. What Type of a World Do We Live in?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. We’ve Got Trouble</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. And More Trouble</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Math-a-mania</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. That Seems Logical</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Step 2: Learning Experiences

Learning experiences are meant to complement project activities, providing the opportunity for you to do more in subject areas that interest you. What are some learning experiences you could do to show the interesting things you are learning about? Here are some ideas:

- Attend a clinic, workshop, demonstration, or speech related to engineering or robotics.
- Prepare an announcement for school, radio, television, or the Internet on an event related to engineering or robotics.
- Help organize a club meeting based on this project.
- Go on a related field trip or tour.
- Host a workshop to share tips and tricks about working on robots and other science, technology, engineering, and math subjects.
- Prepare your own demonstration, illustrated talk, or project exhibit.
- Participate in county judging.

Once you have a few ideas, record them here. Complete at least two learning experiences. Then, describe what you did in more detail. You may add to or change these activities at any time. Ask your project helper to date and initial in the appropriate spaces below.

<table>
<thead>
<tr>
<th>Plan to Do</th>
<th>What I Did</th>
<th>Date Completed</th>
<th>Project Helper Initials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstration</td>
<td>Showed club members the tools and supplies needed to assemble a robot.</td>
<td>5/5/YR</td>
<td>T.D.</td>
</tr>
</tbody>
</table>
Step 3: Leadership/Citizenship Activities

Choose **at least two** leadership/citizenship activities from the list below (or create your own) and write them in the table below. Record your progress by asking your project helper to initial next to the date as each one is completed. You may add to or change these activities at any time. Here are some examples of leadership/citizenship activities:

- Teach someone about programming a robot.
- Help another member prepare for his or her project judging.
- Help organize a club field trip to a science museum or to a manufacturing plant that has robotics.
- Organize a science, engineering, or technology event in your area.
- Encourage someone to take a science, engineering, or technology project.
- Arrange for someone from a local manufacturing firm to speak to your club about robotics.
- Plan your own leadership/citizenship activity.

<table>
<thead>
<tr>
<th>Leadership/Citizenship Activity</th>
<th>Date Completed</th>
<th>Project Helper Initials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organized a club field trip to the robotics lab at the local middle school.</td>
<td>5/5/YR</td>
<td>T.D.</td>
</tr>
</tbody>
</table>

...
Step 4: Project Review

Before your project review, use this space to write a brief summary of your project experience. Be sure to include a statement about the skills you have learned and how they may be valuable to you in the future.

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____________________________________________________________________

Arrange for a project review with your project helper, club advisor, or another knowledgeable adult. Completing a project review helps you evaluate what you have learned and assess your personal growth. Your review can be part of a club evaluation or it can be part of your county’s project judging.
Get a Grip

In *Robotics 1: NeXT Technology*, you built a robot that could drive around, detect an object with a touch sensor, listen for sounds, detect and follow a black line, and sense how far it was from an object using an ultrasonic sensor. Whew! That was a lot of learning! Fortunately, you have just scratched the surface of all the things your little robot can do!

In *Robotics 1*, the robot you built was referred to as the “driving base.” The robot is known as a **mobile robot**, also called a **rover**, because it can move from place to place under its own power. Mobile robots can have wheels, like your robot, or tank treads or perhaps even legs. Regardless of how they get around, mobile robots are very exciting and fun.

Now, we want to make your robot rover a bit more useful. Currently your little robot can drive around and get from place to place but . . . then what? The poor robot has no arms. You need to add a third motor with a **gripper** so your robot can interact with its environment in a meaningful way.

**What to Do**

Go to [www.ohio4h.org/robotics](http://www.ohio4h.org/robotics) and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select **Arm Control** to build and program your robot gripper.

Once you have built your gripper, try to have your robot retrieve at least four different kinds of objects. Good examples include a spoon, golf ball, ping-pong ball, small book, and a pen or pencil. Record your success in the table below and make notes about any special considerations.

<table>
<thead>
<tr>
<th>Object</th>
<th>My robot successfully retrieved this object. (Yes or No)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoon</td>
<td>Yes</td>
<td>The spoon has to be in just the right position in order for the gripper to grab it.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ONLINE EXTRA**

The **Fruit Picker Challenge** included with the online instructions is a great optional activity to apply what you’ve learned.
Talking It Over

SHARE An important part of programming using LEGO® NXT software is learning the meaning of special vocabulary. What are at least two LEGO® NXT programming words that are new to you? What do they mean?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

REFLECT Why are mobile robots more exciting than robots that cannot move from place to place?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

GENERALIZE What did you notice about how well your robot is able to retrieve various objects? Why is it so difficult to create a robotic hand that picks up whatever it is given?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

APPLY What other types of attachments could you create to make your rover more useful?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

More Challenges

Can you create a program for your robot and gripper that picks up the ball and puts it into a container? How about both balls deposited into the same container?
Background Information
The gripper is a type of end effector. End effectors are the items at the end of a robotic arm. Typically this device is what really makes the robot useful or “effective.” You built a standard two-fingered gripper, also referred to as a claw end effector. There are many different types of end effectors for robots. Some, such as grippers, electromagnets, and suction cups, are used to attach to or grip objects to move them from one place to another. Other specialized end effectors, such as welders, paint sprayers, grinders, and drills, enable robots to modify a product as part of an assembly line process. These end effectors are called process tooling because they are part of the manufacturing process. You can see videos of many different kinds of industrial robotic arms and end effectors at www.robots.com.

DID YOU KNOW
Shadow Robot Company in the United Kingdom has developed one of the world’s most advanced robot hands. The Shadow Dexterous Hand-C6 has 24 movements that imitate human hand movement and sensitivity as closely as possible. See more at www.shadowrobot.com.
The use of robots in industry is becoming common, with specialized robots performing all sorts of functions faster and more reliably than humans. RobotWorx, a company in Marion, OH, that supplied these images, is dedicated to helping other companies integrate robots into their production processes. It even buys and sells robots and robot parts. To learn more, go to www.used-robots.com.
Data Driven Decisions

In activity 1 you used the complete palette from the NXT programming software. The complete palette gives you a whole new set of tools that make your programs more powerful and useful, including the ability to use data hubs. A data hub lets you add new connections between your programming blocks so the program can better adapt to its environment.

What to Do

Go to www.ohio4h.org/robotics and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select Data Hubs to build and program your robot.

Use a stopwatch to time how long it takes your robot to run the program using four different volumes of music (use a radio or other source of music). Record your times on the chart below.

<table>
<thead>
<tr>
<th>Run</th>
<th>Volume Setting</th>
<th>Program Run Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now see if you can set the volume of the music so your robot runs for exactly 10 seconds.

Could you do it? (Circle one)   YES   NO

If you did get it to work, what volume setting did you use?   ____________

ONLINE EXTRA

The Robotics Academy also offers a tutorial on the Complete Palette. To be sure you’re getting the most from the LEGO® programming software, consider viewing the Complete Palette tutorial offered on the Robotics Academy website.

Extras included in the Data Hubs tutorial are the Smooth Approach Challenge and the Robot Throttle Challenge. Both are great optional activities to apply what you’ve learned.
Talking It Over

SHARE Why is it important to use the rotation sensor to control the loop instead of time?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

REFLECT What would happen if you set the loop control to “forever”?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

GENERALIZE Name at least one real device or robot that changes how it operates based on the input from sensors.
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

APPLY What other sensors could you use to control the speed of your robot?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

More Challenges

Can you design a robot that allows you to control its speed by using the light sensor and a flashlight? Share your results with your project helper.
Background Information

Control theories are different ways you can use devices, such as sensors, to change the output of a mechanical system in real time. For example, think about a car’s cruise control. When the driver sets the cruise control to the desired speed, the car has sensors so the cruise control can accelerate the car when going up a hill or let off the accelerator when going down a hill. This way the car stays as close as possible to the speed the driver desires. What happens if the driver pushes the brake? That’s right—the cruise control senses that the driver needs to change speed and shuts off immediately. This type of control theory is called a closed-loop system. It is “closed” because it is constantly monitored by sensors that allow the system to make adjustments to the output.

Adding more sensors to the control loop of a system makes it more accurate and quicker. Consider cruise control again. What happens if a driver doesn’t see a car in front of him slowing down? The driver doesn’t hit the brake, so the cruise control just keeps the speed where it was set. This probably will cause a serious accident. What if an ultrasonic sensor is added to the front of the car? Could the sensor be used to turn off cruise control if an object is too close to the front of the vehicle? This could help alert the driver to a problem and avoid the collision.

“Real time” is a synonym for the present. It means “as events happen.”
What Type of a World Do We Live In?

In activity 2 you learned about “data hubs” and used data to modify your robot’s actions in real time based on the sensor data. The particular data you used was a number. The number came from the reading of the sound sensor. That number was “fed” into your move block to control the speed of your robot. Now you will learn about the other types of data that your robot can process.

What to Do

Go to www.ohio4h.org/robotics and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select Data Types and Display to learn more about data.

Talking It Over

SHARE Why did the program have an “error” before you used the “number-to-text” block?

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

REFLECT The “number-to-text” block changes the output number of the sensor into “text” that can be displayed on the NXT screen. Why do you think the NXT screen cannot display the number?

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

GENERALIZE Name four devices in your house that display numbers on a screen like the one on the NXT robot.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

APPLY How can you get the robot to display the distance in centimeters instead of inches?

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

Learning Outcomes

Project skill: Programming a robot to display sensor data
Life skill: Understanding systems
Educational standard: Science: Engineering and Technology Core Idea 3.A: What are technological systems and how can they best be modeled and improved? Most devices can be broken down into subsystems, and they are also parts of larger systems. Systems also interact with other systems. Systems analysis and modeling are key tools in designing, troubleshooting, and maintaining technological systems.
Success indicator: Programs a LEGO® NXT robot to display sensor data
Background Information

For the NXT, data can be three different data types. Data can be numbers, text, or logic (true or false). When working with data wires it is very important to be careful about what side of the data hub you connect to. All data wires giving information to a block are carrying input and should be connected to the plugs on the left side of the data hub. Data wires carrying information away from a block to another block or carrying output should be connected to the plugs on the right side. In other words, if the data plug is on the right side of the data hub it is for output. If it is on the left side it can be used for input. See the image below for more detail.

[A] Input plug
[B] Output plug
[C] Number data wire (yellow)
[D] Logic data wire (green)
[E] Text data wire (orange)
[F] Broken data wire (gray)
Data wires carry specific types of data. Each data wire carries a specific type of data between blocks. For example, if a data wire is dragged from a logic plug on a block’s data hub, it can only be connected to a logic plug on another block’s data hub.

Data wires are identified with specific colors:

- Yellow wires carry number data
- Green wires carry logic (true/false) data
- Orange wires carry text data

If you try to connect a data wire to a plug of the wrong data type, the data wire appears “broken” and colored gray. You will not be able to download your program if it contains broken data wires.

**DID YOU KNOW**

The screen on your robot is called an LCD screen. LCD stands for **Liquid Crystal Display**.
We’ve Got Trouble

Now you have been introduced to displaying data on the screen of the NXT. This can be a very useful tool as you are troubleshooting your program. Many times in robotics you will create a program and it will not work quite like you thought it would. Figuring out what is wrong with your program is called **troubleshooting** and can be very frustrating to say the least. Many times you can use the data hubs in conjunction with the NXT screen to monitor what is happening with your sensors or to display a symbol so you can detect what step in the program has an error.

What to Do

Go to [www.ohio4h.org/robotics](http://www.ohio4h.org/robotics) and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select **Troubleshooting with Data Display** to learn how to troubleshoot your robot with sensor data on the screen in real time.

Given what you now know about displaying data values from a robot’s sensors in real time, create a general list of steps to use when solving a problem with your robot. It can have as many or as few steps as you think are necessary. Use the space below or attach a page to this one.

---

**Activity 4**

Learning Outcomes

- **Project skill:** Identifying and correcting problems in robot performance by displaying data values in real time
- **Life skill:** Solving problems
- **Educational standard:** Science: Engineering and Technology Core Idea 2.A: How are technological problems defined and researched? The first step to solving technological problems is to define the problem in terms of criteria and constraints or limits. It is important to find out how others have solved similar problems and to learn more about the nature of the problem itself.
- **Success indicator:** Identifies and corrects problems in the performance of a LEGO® NXT robot by displaying data values in real time
Talking It Over

SHARE Why is troubleshooting an important skill to develop as a robotics engineer?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

REFLECT The video asked, “Is it a threshold problem, a sensor problem, or a program problem?” When you are troubleshooting a problem with your robot you need to eliminate errors one at a time. Why is this important?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

GENERALIZE Give an example of a problem you had to work through that didn’t have an obvious answer. How did you solve it?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

APPLY Can your robotics troubleshooting steps be adapted to solving other problems? Explain.

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

ONLINE EXTRA
The Real-Time Distance Challenge, the Multiple Display Challenge, the Sounds with Motors Challenge, and the School Zone Challenge included with the online instructions are great optional activities to apply what you’ve learned.

More Challenges
Moving the position of the sound sensor was one way to solve the problem in the program. Figure out another way to fix the issue.
Background Information

Troubleshooting a computer program is often referred to as debugging. You might hear someone say, “I think you have a bug in your program.” This doesn’t mean that there is a real insect in your robot. It just means that something isn’t quite working as well as expected. But where did that term come from? Well, the story goes something like this. In 1947 the operators of one of the early computers at Harvard called the Mark II found a moth trapped in an electrical relay. This moth was causing a short in the electrical system and making the computer malfunction. This bug was carefully removed and taped to the Harvard Computation Laboratory log book.

So, from the first “bug,” we still call an error or glitch in a program a bug.

Sakichi Toyoda, founder of Toyota Motor Corporation developed the “5 Whys” method of troubleshooting. Basically, when there is a problem the troubleshooter asks “Why?” and then tries to determine the answer. By asking “Why?” five times, Toyoda found that you usually get to a root cause of the problem.
And More Trouble

Troubleshooting is an important part of programming and designing a robot. Another concept you need to understand is variables. Variables are a way to mathematically store data so you can use it later in your program. Variables are very useful in programming robotics. By using them in your programs you can collect information/data from the sensors of your robot and store this information to be analyzed later.

What to Do

Go to www.ohio4h.org/robotics and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select Variables to learn about variables and how you can use them in your NXT programming.

Run your program ten times and record the two light sensors’ readings from the “cave” on the chart below. Now calculate the average of “number 1” and “number 2” at the bottom of the chart.

<table>
<thead>
<tr>
<th>Run</th>
<th>Number 1</th>
<th>Number 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average (Mean)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Add each column together. This is the “sum” of the readings.

Divide the “sum” by 10 to calculate the average. This type of an average is called a “mean.”
Talking It Over

SHARE When you ran your program did you find that the readings varied greatly or were they pretty much the same each time?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

REFLECT You were asked to find the mean average of the sensor readings for ten “runs.” What do you think would happen to your average if you ran your robot five times instead of ten? What about fifty times?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

GENERALIZE Give at least four examples of averages being used in the real world.
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

APPLY Besides the example you were given, where do you think a robot might be more useful than a human for collecting data about the conditions of a specific location?
____________________________________________________________________
____________________________________________________________________

More Challenges

Design a program that collects light sensor readings from four different places in the “cave.”
Background Information

Math is a subject students often try to avoid. However, if you are interested in robotics, computers, electronics, or any kind of engineering, mathematics is a very important subject! One thing you need to do in any type of engineering is tests. No, not tests like you have in school. These tests help figure out if your designs work. When you test a design you have to keep track of your results on a chart like the one you used in this activity. Once you have the results, you use math to decide if your design is working the way you hoped it would. Here are a few math terms you will definitely use as you work in robotic design, research, and testing.

- **Average**: Any single number that represents the center of a set of values.

- **Mean**: This is the most commonly used type of average. To find the arithmetic mean of a set of numbers, add the numbers in the set and divide by how many numbers are in the set.

- **Mode**: The number that occurs the most often in a list.
  
  Example: 3 is the mode of 2, 3, 3, 4, 5, 5

- **Median**: The value for which half the numbers in the set are larger and half are smaller. If there are two middle numbers, the median is the mean of the two middle numbers.

  Examples:
  
  1, 2, 5, 7, 9, 12, 13, 15, 18—For this set the median is 9 (the number in the middle of the set.)

  1, 2, 5, 7, 8, 12, 13, 15, 18, 19—Since this set has an even number of numbers in the set both 8 and 12 are in the middle. So, to find the median we use the mean of these two numbers.

  
  \[ \frac{8 + 12}{2} = 10 \]

  The median for the set is 10.

- **Sum**: The result of adding a set of numbers.

  Example: \( 1 + 3 + 5 + 6 + 3 + 2 = 20 \)

- **Difference**: The result of subtracting two numbers.

  Example: The difference between 8 and 15 is \( 15 - 8 \) which equals 7.

**Statistics** is the science of collecting, organizing, and understanding data. It includes the planning of data collection such as creating surveys and experiments.
**Math-a-mania**

Now you have the ability to use the data from the sensors and store this information in a variable. The next step involves not only displaying the data but programming the robot to modify this data and use it to change the output action. This is called *calculation*.

**What to Do**

Go to [www.ohio4h.org/robotics](http://www.ohio4h.org/robotics) and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select *Calculations* to learn about the mathematical functions your robot can do and how you can use them in your NXT programming.

Change the operation of the “Math Block” in your program to “addition” and run the program.

How did this change the actions of the robot?

____________________________________________________________________
____________________________________________________________________

Repeat this with the “subtraction” function and the “multiplication” function and record your observations below.

Subtraction results: ________________________________________________

Multiplication results: ______________________________________________

*See the answer key on page 34.*
Talking It Over

SHARE Explain how the multiplication and division functions affected the action of the robot differently.
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

REFLECT Why do you think the addition and subtraction functions had little effect on the operation of the robot?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

GENERALIZE Think of a real example of when you would want a robot to calculate the value of a sensor. Describe it here.
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

APPLY Explain how the robot could calculate how far it traveled using the input from the motor rotation sensor and the math block.
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

ONLINE EXTRA
The Line Locator 2 Challenge included with the online instructions is a great optional activity to apply what you’ve learned.

More Challenges
Design a single program that changes speed by dividing the sound sensor readings by “2” for five rotations, then by “4” for five rotations.
Background Information

We hear a lot these days about digital, but what is it? Or, maybe a better question would be what isn’t digital? When considering what is or isn’t digital you first need an understanding of computers in general. Computers, when broken down, are really very, very simple. Reduced to their simplest part, all computers are no more complicated than a simple light switch. It’s either on or it’s off, true or false. This is because computers operate by the flow of electricity and you have only two choices: either the switch is on and the electricity is flowing, or it’s off and the electricity is stopped.

As the computer was developed it was decided it was too complex to write true and false for all the instructions, so binary was invented. Binary is a numbering system that has only two choices, 1 to represent “true” or 0 to represent “false.” By using and combining these two digits in a series, the computer solves math problems, makes yes/no decisions, and compares data.

To learn more about how computers work go to http://educate.intel.com/en/TheJourneyInside/ExploreTheCurriculum

Robots can be programmed to make decisions based on numbers, but they cannot make decisions based on opinion. Of the following questions, which could be made by a robot, a human, or both?

Which color is darker?

_____Robot   _____ Human   _____ Both

Where is the warmest place in the room?

_____Robot   _____ Human   _____ Both

How does the sunshine feel?

_____Robot   _____ Human   _____ Both

Is a painting beautiful?

_____Robot   _____ Human   _____ Both
Complete the decimal to binary conversion chart below:

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Binary</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>111</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

See the answer key on page 34.

Most power switches now use a symbol that looks like this:

This is actually a “1” and a “0” that represents the binary on and off.
That Seems Logical

You have reached the last programming activity of this project! We have covered many concepts in the first six activities, but this one is perhaps the most important. Logic! Simply put, logic is principles of correct reasoning; logic allows you to understanding what will happen in your program. Understanding logic is essential as you move forward and advance your programming skills. Your programming gives your robot the ability to process the input of its sensors and, if logical, your programming outputs the action you had in mind. Predicting what will happen before you run your program is a skill that requires many hours of study and practice. Even then, many times your little robot will not function as expected.

What to Do

Go to www.ohio4h.org/robotics and follow the links to access the instructions and videos at the Carnegie Mellon Robotics Academy. Select Logic Loops to learn how you can use logic to control your robot’s actions.

One key to mastering logic is being able to write your program in simple understandable steps. Make a list of the steps your robot program goes through in the program you wrote.

____________________________________________________________________
____________________________________________________________________
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Learning Outcomes

Project skill: Programming a robot to make a complex decision

Life skill: Reasoning

Educational standard: Science: Engineering and Technology Core Idea 2.A: How are technological problems defined and researched? The first step to solving technological problems is to define the problem in terms of criteria and constraints or limits. It is important to find out how others have solved similar problems and to learn more about the nature of the problem itself.

Success indicator: Programs a LEGO® NXT robot to make a complex decision

ONLINE EXTRA

The Multiple Display Challenge and the Automate Threshold Challenge included with the online instructions are great optional activities to apply what you’ve learned.
**Talking It Over**

**SHARE** Why is it important to understand logic when programming your robot?

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

**REFLECT** You used the “Or” logic function in your program. Using the truth tables in the Background Information, predict the behavior of your robot if you use the “And” operation.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

**GENERALIZE** The ability to use logic, or reasoning, is a valuable skill. Describe at least one real-life decision you made using logic as opposed to emotion.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

**APPLY** Using the same format from the question on the previous page, write out the steps to explain how to make a peanut butter and jelly sandwich.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________
In this activity you used the logic block to stop your robot if you clap your hands or if the robot runs into an object. The logic block can perform four operations: And, Or, Not, and XOr. These operations, called Boolean operations, are part of a system called **Boolean logic**. Boolean logic was named after George Boole, who first defined a mathematical system of logic in the mid-19th century. Boolean logic has many uses in electronics, computer hardware, and software. It is the basis of all modern digital electronics including computers. Each of these operations causes very different results in your program. To figure out how a Boolean operator affects your program you can use a tool called a **truth table**. A truth table is a way to express all the possible outputs of a Boolean operator.

### Truth Tables

<table>
<thead>
<tr>
<th>And</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>A AND B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Or</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>A OR B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Not</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>NOT A</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XOr</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>A XOR B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**More Challenges**

Design a single program that stops your robot if it detects a white line or hears a loud sound within 8 inches of an object.
Let’s look at some examples. In this activity you used an “Or” operator so your robot would stop if the touch sensor was pushed or if the sound sensor detected a loud noise. If you refer to the “Or” truth table on the previous page you can predict the behavior of the robot. Look under the “Input” side of the table. You know from the background information in activity 6 that the “0” represents “off” and the “1” represents “on.” So, if both sensors are not sensing anything both would be off and the operator would output an “off” or “false” result. However, if either sensor is triggered the truth table indicates the output result is “on” or “true.” You will also notice that if both the “A” and “B” inputs are true the output is also true. Now look at the “And” truth table. You will notice that the only situation that creates a “true” or “on” output is if both the “A” and “B” inputs are “true.” You can use these truth tables for your advanced programming to make sure that your robot works the way you intend.

The fastest computer in the United States, called Jaguar, is housed at the Oak Ridge National Laboratory in Tennessee. This supercomputer was built by Cray Incorporated and can solve 1,759,000,000,000,000 equations in a second! That’s 1.7 quadrillion operations every second. Jaguar has 224,162 processors and uses as much power as 115,833 standard household light bulbs.
**Glossary**

**Boolean logic.** A system named after George Boole that uses algebra for logical operations and that is the basis for all modern digital electronics.

**Calculation.** In robotics, programming the robot to modify data from sensors and use it to change the output action.

**Claw.** A kind of robot end effector that grips an object.

**Closed-loop.** A kind of control theory in which input from sensors is constant, allowing for constant adjustments.

**Complete palette.** The complete set of programming commands available for LEGO® NXT programming.

**Control theory.** Ways to use devices such as sensors to change the output of a mechanical system; in robotics, the art and science of using sensors to inform the robot’s processor about its environment.

**Data hub.** Part of the LEGO® NXT complete palette; allows connections between programming blocks.

**Data type.** The form of information in a database, either numbers, text, or logic (true or false).

**Debugging.** Finding whatever it is in a computer program that is causing the robot to behave in an unexpected way.

**Digital.** Electronic technology that generates, stores, and processes data in terms of two choices: true or 1, and false or 0.

**End effector.** A device at the end of a robotic arm.

**Gripper.** A device on the end of a robotic arm designed to grab an object and move it from place to place; grippers are one kind of end effector.

**Logic.** The science of formal principles of reasoning.
**mobile robot.** A robot with the capacity to move around from place to place under its own power; also called a rover.

**process tooling.** In robotics, a kind of end effector that enables a robot to modify a product being assembled during the manufacturing process. Examples include welders, paint sprayers, grinders, drills, etc.

**rover.** See mobile robot.

**statistics.** The science of collecting, organizing, and understanding data.

**troubleshooting.** Identifying and solving problems or difficulties.

**truth table.** A way to express all the possible outputs of a Boolean operator.

**variable.** In robotics, information and data from sensors that a robot is programmed to store and use later.
Answer Key

Answers to activities 1–5 and 7 will vary.

**Activity 6**

Change the operation of the “Math Block” in your program to “addition” and run the program.

How did this change the actions of the robot?
The robot adds 2 to the sound sensor reading and uses this as the power level for the move block.

Repeat this with the “subtraction” function and the “multiplication” function and record your observations below.

Subtraction results: The robot subtracts 2 from the sound sensor reading and uses this as the power level for the move block.

Multiplication results: The robot multiplies the sound sensor reading by 2 and uses this as the power level for the move block. The robot moves much faster.

Which color is darker?

_____Robot  _____ Human  ____ Both

Where is the warmest place in the room?

_____Robot  _____ Human  ____ Both

How does the sunshine feel?

_____Robot  ____ Human  ____ Both

Is a painting beautiful?

_____Robot  ____ Human  ____ Both

Complete the decimal to binary conversion chart below:

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>8</td>
<td>1000</td>
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<tr>
<td>9</td>
<td>1001</td>
</tr>
<tr>
<td>10</td>
<td>1010</td>
</tr>
</tbody>
</table>
## Summary of Learning Outcomes

<table>
<thead>
<tr>
<th>Activity</th>
<th>Project Skill</th>
<th>Life Skill</th>
<th>Educational Standard*</th>
<th>Success Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Get a Grip</td>
<td>Building and programming a robot to pick up and move objects</td>
<td>Mastering technology</td>
<td>ET Core Idea 1.C: <em>How do people use tools and materials to modify or create new technologies?</em> A tool is a physical or cyber object that extends people’s abilities to design, build, and utilize products, processes, and systems: to cut, shape, or put together materials; to move things from one place to another, or to grow and process food.</td>
<td>Programs a LEGO® NXT robot to pick up and move objects</td>
</tr>
<tr>
<td>2. Data Driven Decisions</td>
<td>Creating a program to make sensor values control motor speed</td>
<td>Mastering technology</td>
<td>ET Core Idea 1.C: <em>How do people use tools and materials to modify or create new technologies?</em> A tool is a physical or cyber object that extends people’s abilities to design, build, and utilize products, processes, and systems: to cut, shape, or put together materials; to move things from one place to another, or to grow and process food.</td>
<td>Programs a LEGO® NXT robot so that its speed is based on input from the sound sensor</td>
</tr>
<tr>
<td>3. What Type of a World Do We Live in?</td>
<td>Programming a robot to display sensor data</td>
<td>Understanding systems</td>
<td>ET Core Idea 3.A: <em>What are technological systems and how can they best be modeled and improved?</em> Most devices can be broken down into subsystems, and they are also parts of larger systems. Systems also interact with other systems. Systems analysis and modeling are key tools in designing, troubleshooting, and maintaining technological systems.</td>
<td>Programs a LEGO® NXT robot to display sensor data</td>
</tr>
<tr>
<td>4. We’ve Got Trouble</td>
<td>Identifying and correcting problems in robot performance by displaying data values in real time</td>
<td>Solving problems</td>
<td>ET Core Idea 2.A: <em>How are technological problems defined and researched?</em> The first step to solving technological problems is to define the problem in terms of criteria and constraints or limits. It is important to find out how others have solved similar problems and to learn more about the nature of the problem itself.</td>
<td>Identifies and corrects problems in the performance of a LEGO® NXT robot by displaying data values in real time</td>
</tr>
<tr>
<td>5. And More Trouble</td>
<td>Programming a robot to create, store, and retrieve a data variable</td>
<td>Solving problems</td>
<td>ET Core Idea 2.C: <em>How can the best possible solution be developed to solve a technological problem?</em> Finding the best solution is an iterative process involving decisions concerning tradeoffs among competing criteria, and multiple tests and improvements.</td>
<td>Programs a LEGO® NXT robot to create, store, and retrieve a data variable</td>
</tr>
<tr>
<td>6. Math-a-mania</td>
<td>Programming a robot to do a calculation using values from light sensors</td>
<td>Understanding systems</td>
<td>ET Core Idea 3.C: <em>What are control systems and feedback systems, why are they effective, and how can they be improved?</em> Technological systems often include control and feedback components (e.g. house thermostat, alarm systems, stop lights, toilets), which are important for analyzing malfunctions and improving efficiency.</td>
<td>Programs a LEGO® NXT robot to do a calculation using values from the light sensor</td>
</tr>
<tr>
<td>7. That Seems Logical</td>
<td>Programming a robot to make a complex decision</td>
<td>Reasoning</td>
<td>ET Core Idea 2.A: <em>How are technological problems defined and researched?</em> The first step to solving technological problems is to define the problem in terms of criteria and constraints or limits. It is important to find out how others have solved similar problems and to learn more about the nature of the problem itself.</td>
<td>Programs a LEGO® NXT robot to make a complex decision</td>
</tr>
</tbody>
</table>

*The educational standards cited here are from the National Research Council’s [Framework for Science Education Preliminary Public Draft](http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html) (2010). All of the standards cited are from the Engineering and Technology (ET) area. At the time of this printing, these standards are not in their final form, but information about them and the current status of the project can be found at [www7.nationalacademies.org/bose/Standards_Framework_Homepage.html](http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html).*
Photos
I pledge
My head to clearer thinking,
My heart to greater loyalty,
My hands to larger service, and
My health to better living,
For my club, my community, my country, and my world.

Additional copies of this book and other Ohio State University Extension, 4-H Youth Development publications are available through local OSU Extension offices and online at estore.osu-extension.org. Ohio residents get the best price when they order and pick up their purchases through local Extension offices.