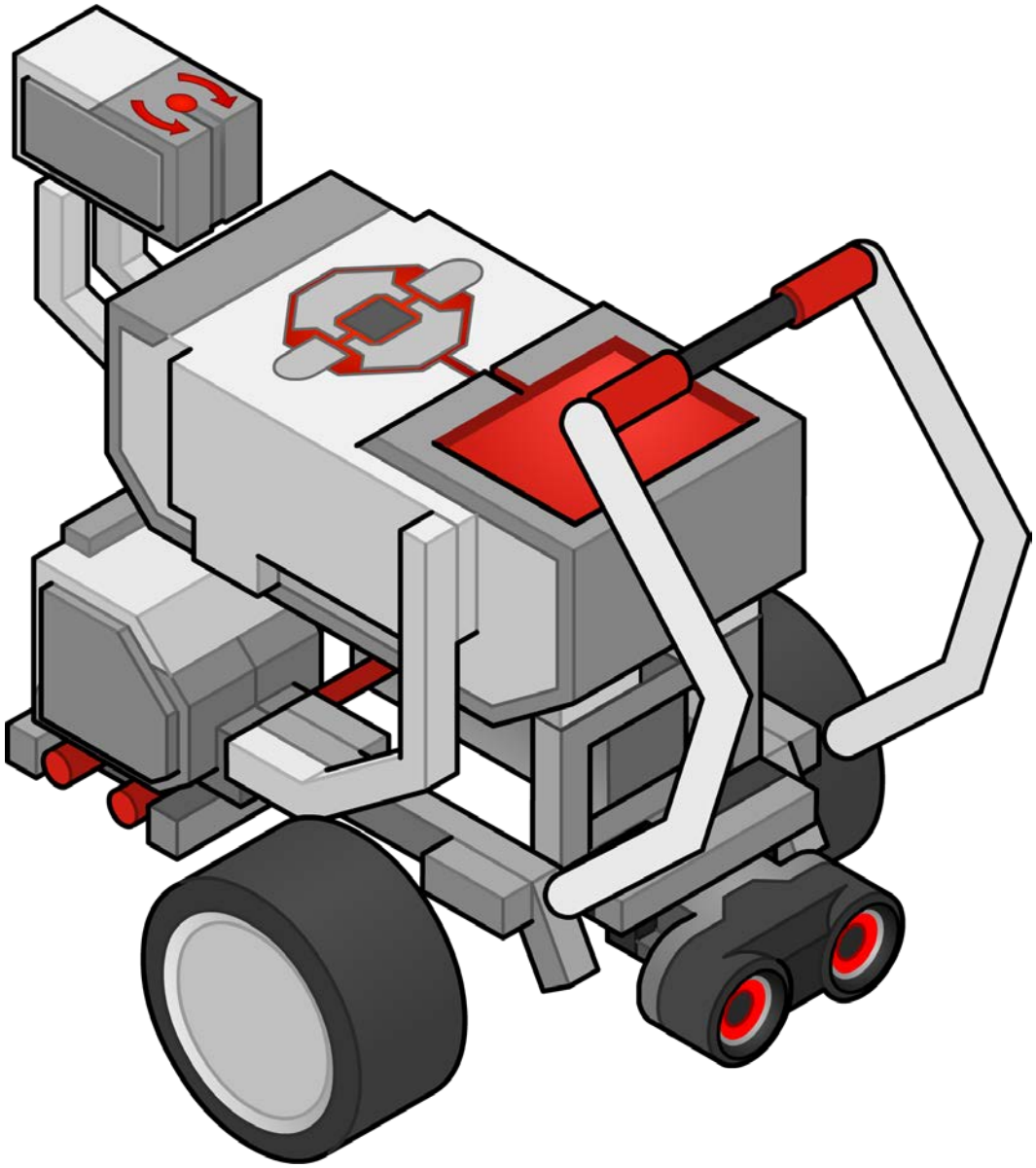


Introduction to Programming
LEGO® MINDSTORMS® EV3
Teacher's Guide

The Introduction to Programming EV3 Curriculum was produced by Carnegie Mellon's Robotics Academy

Preface

There is a growing recognition that *Computational Thinking Practices* are critical for all students to learn. They form the cornerstone of the language of innovation, and will drive all future STEM discoveries. They are a new set of "basic skills" that all students need to know.

But what are they? At first glance, concepts like "consider problems analytically" and "use data to inform decisions" seem abstract and difficult to comprehend. Educational robotics systems like the EV3 provide a much-needed tool to make them real and approachable.

Consider the first few activities in this curriculum: students program a robot to drive fixed distances in set patterns. Even these simple programming constructs require precise, thoughtful communication between student and robot – how far should the robot move? How far should it turn? As the challenges become more complex, students learn to break the large problems down into simpler ones, and construct solutions with care, one step at a time.

Sensors add the element of data and make key information about the robot's environment available; numeric abstractions become a reality – 35 centimeters to the nearest wall, turn 90 degrees – enable the student to make smart decisions about the robot's behavior.

These practices – precise logical thinking, using data to make decisions, analyzing problems, and building solutions in teams – are critical in all forms of problem-solving, not just robotic ones.

Robotics activities are concrete, contextualized, and provide immediate feedback – important factors in satisfying a student's desire for success and creating the motivation to continue learning. Students also learn about the robotics technologies themselves, which impact all modern industries, from agriculture to healthcare, banking, manufacturing, transportation, energy, and security. The pervasiveness of robotics technologies, from airplane autopilots, to bank machines, to smartphones, to self-driving cars helps students to be "engaged learners" as they believe that the content that they are studying is important or will be valuable to them.
The Introduction to Programming curriculum is just that: an introduction. For many teachers this will be your first experience at teaching robotics and programming. If you need help, the Robotics Academy has lots of free resources on its website and regularly offers teacher courses. If you have questions or find issues, we would love to hear from you.

Enjoy your school year.

Ross Higashi

Ross Higashi,
Robotics Academy Learning Scientist

Robin Shoop,
Robotics Academy Director

Table of Contents

3 FAQ
4 Checklist

1 Introduction

5 What is the Introduction to Programming EV3 Curriculum?
6 Why should I use the Introduction to Programing EV3 Curriculum?
6 What are the Curriculum's Learning Objectives?
6 When should I use the EV3 Curriculum in my class?
7 How do I use the Curriculum?
8 What topics are covered in each Unit?
9 What "Big Ideas" does the Curriculum teach?

10 Standards

10 Math Practices
10 Math Content
11 Common Core English/Language Arts
11 Next Gen Science Standards
12 Computer Science Standards

13 Classroom Setup

How should student work stations be setup?
What are the System Requirements?

14 In the classroom

14 General layout of all Units
14-17 Batteries, Firmware, Ports, Menus
18 -19 Big Ideas that all students will learn
20 Using the EV3 Software

21 The Movement Unit

21-28 The Moving Straight Chapter
29-35 The Turning Chapter

36 The Sensor Unit

36-42 The Touch Sensor Chapter
43-49 The Ultrasonic Sensor Chapter
50-55 The Gyro Sensor Chapter
56-62 The Color Sensor Chapter

63 The Robot Decisions Unit

63-69 The Loop Chapter
70-76 The Switch Chapter
77-82 The Switch Loops Chapter
83-86 The Line Follower Chapter

87 The Final Challenge

87-89 Final Challenge Resources
90-91 The Search and Rescue Challenge

92 Reproducibles

Pages 92 - 142 Unit Quizzes, Answer Keys, Handouts, Worksheets and Rubrics

Note: We have been asked by practicing teachers NOT to make these public and so they are not printed with this document. They are made available with the curriculum.

Frequently Asked Questions (FAQ)

Before starting

- Will *Introduction to Programming* help me teach to Standards?

  Yes! See Standards, pages 10 - 12.

- What do I need to prepare for class?

  See Checklist, page 4 and Best Workstation Setup page 15.

- What topics are covered?

  See Topics, page 8 and General Layout, page 14.

- What's the lesson structure?

  See How To Use, page 5.

- I already have programming tutorials in my software. Is this the same thing?

  No. Introduction to Programming focuses on building critical thinking skills through programming, rather than rote knowledge of code. See What are the Big Ideas taught..., page 9.

During class

- How do I begin with *Introduction to Programming* in my class?

  See How do I use the Introduction to Programming Curriculum in my classroom, page 7.

- Are there notes available to help me teach the lessons?

  Yes. Every page in Introduction to Programming is summarized and annotated starting on page 14. There are additional notes at the beginning of each chapter.

- What do I do about students who go faster/slower than the others?

  All lessons are self-paced, so minor variation in pacing is not a problem. You can also include or omit activities marked as Optional, and even let students work ahead on later chapters.

After class

- Are there quizzes or homework?

  Each Chapter includes one or more Reflection Questions designed to let students apply their skills and knowledge to a more sophisticated and writing-intensive task.

  You can find additional Handouts, Worksheets and Rubrics starting on page 92.

Checklist

- [ ] **Identify the Focus of your Lesson**
  Robotics can be used to teach to lots of standards. This curriculum is designed to introduce students to how to program, an important part of robotics, but not the only thing that you can teach through robotics. Please read pages 5 - 12 of this guide to learn more.

- [ ] **Set up the student workstations**
  See page 13, Workstation Setup.

- [ ] **(Recommended) Build the Driving Base for each robot**
  Since mechanisms aren't the focus of this module, pre-building the basic robot for your students can save multiple weeks of class time and allow them to begin work immediately on Day 1. The plans can be found in the Moving Straight Unit page 23.

- [ ] **Become familiar with the lessons**
  See page 7 to become familiar with the lesson flow. The general layout of the Introduction to Programming the EV3 Curriculum is found on page 14. Review the first couple lessons starting with Moving Straight on page on page 21.

- [ ] **Determine overall pacing for the module**
  Identify key dates that you would like to have each project due by; make these clear to students in your syllabus or assignment sheets.

- [ ] **Review Big Ideas and Computational Thinking**
  See pages 18 and 19.

- [ ] **Review and print the Reflection Questions for each chapter**
  Chapter review questions, answer guides, and rubrics begin on page 92.

  Note: The reflection questions can be used as class discussion questions, given as homework, or as a quiz.

What is the Introduction to Programming EV3 Curriculum?

10 Projects and One Capstone Programming Challenge

The Introduction to Programming EV3 Curriculum is a curriculum module designed to teach core computer programming logic and reasoning skills using a robotics engineering context. It contains a sequence of 10 projects (plus one capstone challenge) organized around key robotics and programming concepts.

Each project comprises a self-contained instructional unit in the sequence, and provides students with:

- **An introduction to a real-world robot** and the context in which it operates
- **A challenge** that the robot faces
- **A LEGO-scale version of the problem** for students to solve with their robots
- **Step-by-step guided video instruction** that introduces key lesson concepts (e.g. Loops) by building simple programs that progress toward the challenge task
- **Built-in questions** that give students instant feedback on whether they understood each step correctly, to aid in reflection and self-pacing
- **Semi-guided "Try It!" exploration activities** that expose additional uses for and variants on each behavior
- **Semi-open-ended Mini-Challenges** which ask students to use the skill they have just learned to solve a relevant small portion of the final challenge
- **The Unit Challenge** based on the original robot's problem, for students to solve in teams as an exercise and demonstration of their mastery of the concept
- Additional **Reflection Questions** found in the back of this Teacher's Guide allow you to assess the depth of students' understandings while challenging them to apply their learning to a higher-order problem-solving and writing task.

Why should I use the Introduction to Programming EV3 Curriculum?

Introduction to Programming provides a structured sequence of programming activities in real-world project-based contexts. The projects are designed to get students thinking about the patterns and structure of not just robotics, but also programming and problem-solving more generally.

By the end of the curriculum, students should be better thinkers, not just coders.

What are the Learning Objectives of the Introduction to Programming EV3 Curriculum?

- Basic concepts of programming
  - Commands
  - Sequences of commands
- Intermediate concepts of programming
  - Program Flow Model
  - Simple (Wait For) Sensor behaviors
  - Decision-Making Structures
    - Loops
    - Switches
- Engineering practices
  - Building solutions to real-world problems
  - Problem-solving strategies
  - Teamwork

When should I use the Introduction to Programming EV3 Curriculum with my class?

Introduction to Programming the EV3 is well-suited for use at the beginning of a robotics class, as it will allow students to engage immediately and begin building core programming and problem-solving skills before undertaking more ambitious open-ended projects later in the course. This curriculum module should take approximately 6 weeks.

How do I use the Introduction to Programming EV3 Curriculum in my class?

Introduction to Programming is designed for student self-pacing in small groups, preferably pairs. Each pair of students should work together at one computer, with one EV3 robot.

Curriculum tasks are designed to involve some – but not extensive – mechanical consideration, so that hands-on design tasks may remain authentic without becoming logistically difficult.

Solutions will not require parts in excess of those included in the 45544 EV3 Core set, so it is sufficient to leave each team with one kit (although access to additional parts may allow students to construct more creative solutions to problems).

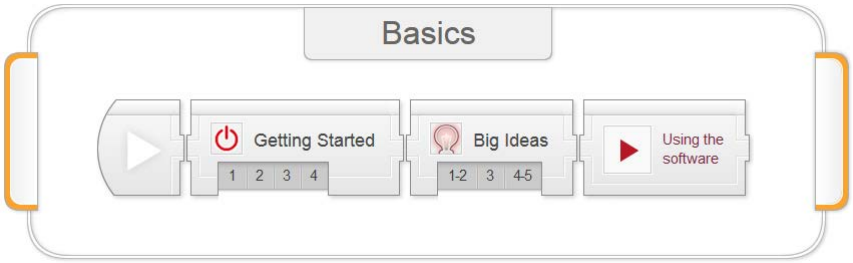
A typical plan for an Introduction to Programming chapter is:

1. View the introductory video as a class, or in individual groups, then review the challenge task for the unit
    - In a group, identify and note key capabilities the robot must develop, and problems that must be solved in individual engineering journals or class logs (e.g. on sticky paper posted on the walls)
2. Groups proceed through the video trainer materials at their own pace, following the video instruction directly, and constructing solutions to the Try It! and Mini-Challenge steps as they go
3. Each group constructs its own solution to the Unit Challenge
    - Groups may be asked to document their solutions in journals or logs, and especially to explain how they overcame the key problems identified at the start of the unit
4. Assign the Reflective Question for the chapter
    - Students answer the Reflection Question for the chapter individually, as an in-class or homework assignment
    - Reflection Questions for each chapter can be found in the Reproducibles section of this Teacher's Guide

What topics are covered in each Unit?

Unit Name	Main Topics
1. Moving Straight	Motors, Sequences of Commands, Block Settings, Downloading and Running Programs, Move Steering Block
2. Turning	Turning, Types of Turns, Move Steering vs. Move Tank Block
3. Move Until Touch	Sensors, Wait For Block, Touch Sensor, Move Until Behaviors
4. Move Until Near	Ultrasonic Sensor, Thresholds
5. Turn for Angle	Gyro Sensor, Compensating for Sensor Error
6. Move until Color	Color Sensor
7. Loops	Loops, Patterns of Behavior
8. Switches	Switches, Conditional Reasoning
9. Switch-Loops	Obstacle Detection Behavior, Repeated Decisions Pattern
10. Line Follower (Mini-Unit)	Line Following (a Repeated Decisions Pattern Behavior)
11. Final Challenge	Cumulative Application of Skills and Knowledge

What are the Big Ideas taught in the Introduction to Programming EV3 Curriculum?



Robotics can be something you teach *with*, as well as something you teach *about*. *Introduction to Programming* uses robots, and covers robotics content, but ultimately seeks to give students experience and access to a much broader set of skills and perspectives called Computational Thinking.

- **Big Idea #1: Programming is Precise**

  If you want a robot to do something, you need to communicate that idea with mathematical and logical precision, or it won't quite be what you intended.

- **Big Idea #2: Sensors, Programs, and Actions**

  Data from sensors gives a robot information about its environment. A program uses that data to make decisions, and the robot Acts on those decisions. Data underlies the core of the entire process.

- **Big Idea #3: Make Sense of Systems**

  To understand the way something works, construct a mental "model" of it in your head that captures the important features and rules of the system. This helps you make sense of it, and also gives you a tool to "play out" (similar) new scenarios in your head to predict what would happen.

- **Big Idea #4: Break Down Problems and Build Up Solutions**

  To solve a difficult problem, try breaking it down into smaller problems. Then, solve the smaller problems, building up toward a solution to the big problem.

- **Big Idea #5: Computational Thinking Applies Everywhere**

  These skills – mathematical and logical clarity, using data, systems thinking with mental models, and problem solving – are not just for robotics. They are key to solving many problems in the world.

A video introduction to these topics can be found in the "Big Ideas" block of the Basics section of the product.

What Standards does the Introduction to Programming EV3 Curriculum address?

Common Core Mathematics Practices

Skills math educators at all levels should seek to develop in their students

Standard (CCSS.Math.Practice)	Introduction to Programming the EV3
MP1 Make sense of problems and persevere in solving them	Chapters are all based around solving real-world robot problems; students must make sense of the problems to inform their solutions
MP2 Reason abstractly and quantitatively	Programming requires students to reason about physical quantities in the world to plan a solution, then calculate or estimate them for the robot
MP4 Model with mathematics	Many processes, including the process of programming itself, must be systematically modeled on both explicit and implicit levels
MP6 Attend to precision	Robots require precise (and accurate) input, or their output action will be correspondingly sloppy
MP7 Look for and make use of structure	Understanding the structure of the physical environment, the interrelated components of robot hardware and software, and commands within a program are vital to successful solutions
MP8 Look for and express regularity in repeated reasoning	Any programmed solution to a class of problems relies on the programmer recognizing and exploiting important patterns in the problem structure. There is also an emphasis throughout the module on recognizing common programmatic patterns, as well as patterns within a solution that invite the use of Loops.

Common Core Mathematics Content

Standard (CCSS.Math.Content)	Introduction to Programming the EV3
6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities	Students use ratio language to describe and make use of the relationship between quantities such as Wheel Rotations and Distance Traveled
6.RP.A.2 Understand the concept of a unit rate a/b associated with a ratio a:b with b!=0, and use rate language in the context of a ratio relationship	The relationship between Wheel Rotations and Distance Traveled is a rate, customarily understood through a unit rate such as "# cm per rotation".
6.R.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems	Students are required to apply ratios and rates when they build their prototype examples of their real world robots.
7.RP.A.3 Use proportional relationships to solve multistep ratio and percent problems.	Comparisons between rate-derived quantities are common during robot navigation tasks.

Common Core English Language Arts

What Standards does the Introduction to Programming EV3 Curriculum address? (continued)

Standard (CCSS.ELA-Literacy)	Introduction to Programming the EV3
WHST.6-8.1 Write arguments focused on discipline-specific content. [See also: WHST.6-8.1.a to WHST.6-8.1.e]	Reflection Questions ask students to analyze, evaluate, and synthesize arguments in response to robotics and programming problems
WHST.6-8.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.	Reflection Question tasks include composing technical critiques, technical recommendations, and creative synthesis.

Next Generation Science Standards (NGSS)

Standard	Introduction to Programming the EV3
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	Solving challenges requires students to create and evaluate both hardware and software designs according to scenario scoring criteria. Some Reflection Questions require students to make recommendations between competing alternatives based on criteria that they define.
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.	When solving more difficult and complex challenges, students are guided toward iterative testing and refinement processes. Students must optimize program parameters and design.
HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	Problem Solving methodology for challenges directs students to break down large problems into smaller solvable ones, and build solutions up accordingly; challenges give students opportunities to practice, each of which is based on a real-world robot
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	Some Reflection Questions require students to make recommendations about real-world policies (e.g. requiring sensors on automobiles) based on the impact of that decision

What Standards does the Introduction to Programming EV3 Curriculum address? (continued)

Computer Science Principles Framework (CSP)

Learning Objective	Introduction to Programming the EV3
1.1.1 Use computing tools and techniques to create artifacts. [P2]	Challenge activities result in the creation of a (simple) algorithmic solution and an accompanying program that implements it.
1.1.2 Collaborate in the creation of computational artifacts. [P6]	Students work in teams to accomplish tasks.
1.1.3 Analyze computational artifacts. [P4]	Students perform debugging on their own code, as well as analyze and evaluate others' code and suggested code in Reflection Questions.
1.3.1 Use programming as a creative tool. [P2]	Students use programming to solve model challenges based on challenges real robots face.
2.2.1 Develop an abstraction. [P2]	Robots gather information about the world through sensors, which turn physical qualities of the world into digital abstractions. Students must understand and work with this data to develop then implement their solution algorithms.
2.3.1 Use models and simulations to raise and answer questions. [P3]	Students construct and use a "program flow" model of programming itself to understand how the robot uses data to make decisions and control the flow of its own commands.
4.1.1 Develop an algorithm designed to be implemented to run on a computer. [P2]	Students develop solution algorithms to each challenge and mini-challenge problem before implementing them as code. Reflection Questions also ask students to evaluate algorithms expressed as pseudocode.
4.2.1 Express an algorithm in a language. [P5]	Students develop code to robotics challenges in the EV3 Programming Language.
5.1.1 Explain how programs implement algorithms. [P3]	Students must communicate solution ideas within groups and as part of class discussion, as well as in Reflection Questions.
5.3.1 Evaluate a program for correctness. [P4]	Students test and debug their own code, and evaluate others' in the Reflection Questions.
5.3.2 Develop a correct program. [P2]	Programmed solutions to challenges must work.
5.3.3 Collaborate to solve a problem using programming. [P6]	Students develop solutions in teams.
5.4.1 Employ appropriate mathematical and logical concepts in programming. [P1]	Relationships such as "distance per wheel rotation" are important to making solutions work.
7.4.1 Connect computing within economic, social, and cultural contexts. [P1]	Reflection Questions ask students to make evaluative recommendations based on the impacts of robotic solutions in context.

What is the best setup for student workstations?

Ideally, each pair of students will work together at one computer, with one EV3 robot.

Set up each workstation with:

- **LEGO® MINDSTORMS® Education EV3 Programming Software** installed from its DVD
  - Education version required*
- Access to the **Introduction to Programming LEGO® MINDSTORMS® EV3** curriculum software
  - This can be installed locally or on a local network server via DVD
  - This may also be accessed remotely via internet, if your school's network infrastructure and policies allow
- Two pairs of **headphones** with **headphone splitters**
  - One pair for each student
  - Avoid using speakers, as multiple workstations in the same classroom will generate too much overlapping noise
- One **45544 LEGO® MINDSTORMS® Education Set**

What are the System Requirements for the Introduction to Programming EV3 Curriculum?

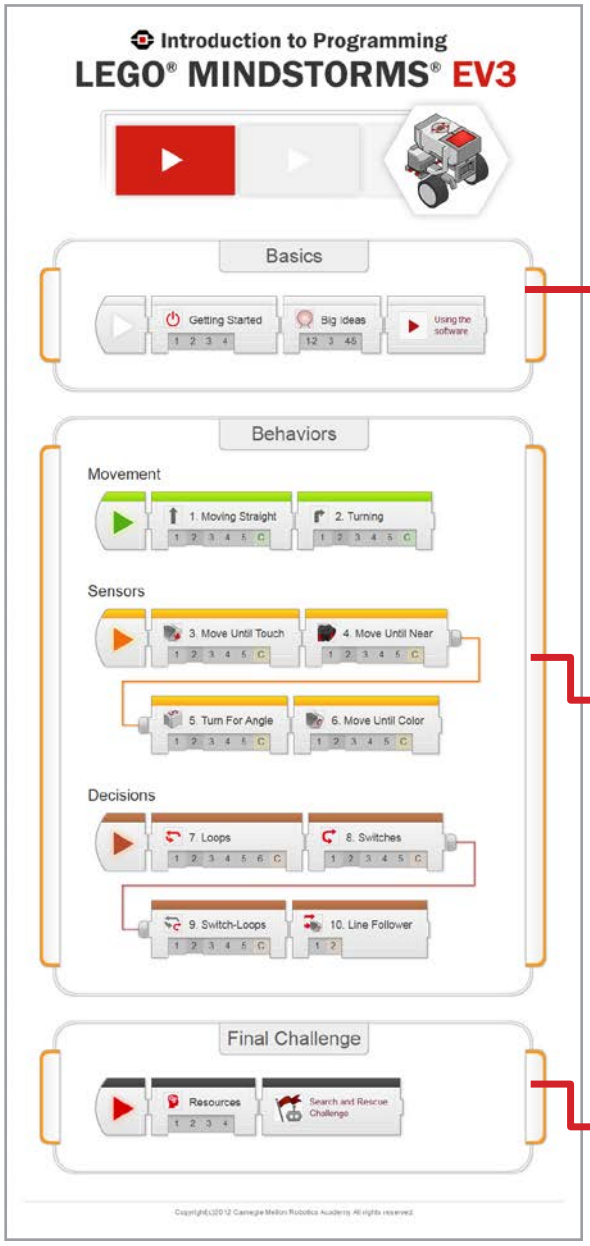
LEGO® MINDSTORMS® Education EV3 Programming Software: See packaging

Introduction to Programming EV3 Curriculum

- HTML5-compatible browser (Firefox, Chrome, Internet Explorer 10+)
- Tablets (iPad, Android, Windows) with HTML5 browsers should work as well, if accessing the curriculum from the Internet

* Retail versions of the EV3 set do not include the Gyro Sensor or software support for it by default

What is the general layout of the Introduction to Programming EV3 Curriculum?



Introduction to Programming LEGO® MINDSTORMS® EV3

This is the main menu. Click any section to open the first step, or click a page number to go directly to the page.

Basics Unit

Getting Started: Set up the robot and learn about its basic operation and maintenance

Big Ideas: Five big ideas that will be important throughout the course

Using the Software: General usage patterns in the EV3 Programming Software

Behaviors Unit

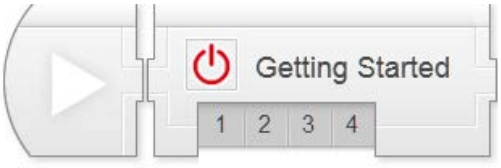
Movement: Use sequential commands to make the robot move and turn

Sensors: Use Sensors to stop the robot in different situations

Decisions: Use Loops and Switches to control the program with smarter decisions

Final Challenge Unit

Combine the techniques of earlier units to tackle a more complex challenge



Basics> Getting Started Chapter

The Getting Started portion is designed to get a new EV3 user up and running as quickly as possible. Instructors should follow along with all steps, but the first two pages in the chapter could be considered optional for students.

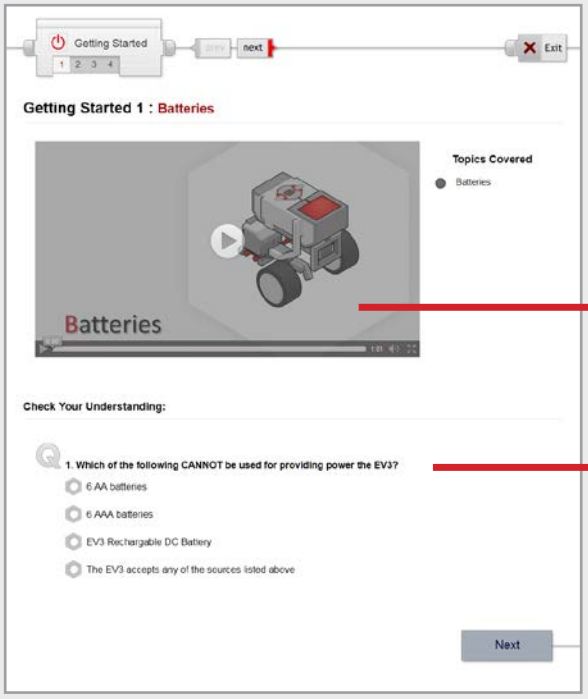
Key Concepts: EV3 operation and maintenance, battery requirements, firmware

- **Getting Started 1: Batteries**
  Walks through the options and procedures for powering the EV3
- **Getting Started 2: Firmware**
  Introduces the concept of firmware and walks through the process of updating the EV3 to the latest version
- **Getting Started 3: Ports**
  Identifies and describes the functions of the various ports on the EV3
- **Getting Started 4: Menus**
  Walks through and explains the main areas and functions available through the EV3's on-screen menus

Hints:

- Go through Battery and Firmware installation prior to using the robots with students. You may want students to view these videos as well for familiarity, should issues arise.
- The Ports (3rd) and especially Menus (4th) videos are very helpful for students.

Teacher's Edition Note: This chapter's notes will point out common structural elements such as Check Your Understanding Questions. In later sections, common notes will be omitted, as they are the same throughout the product.



Getting Started 1: Batteries

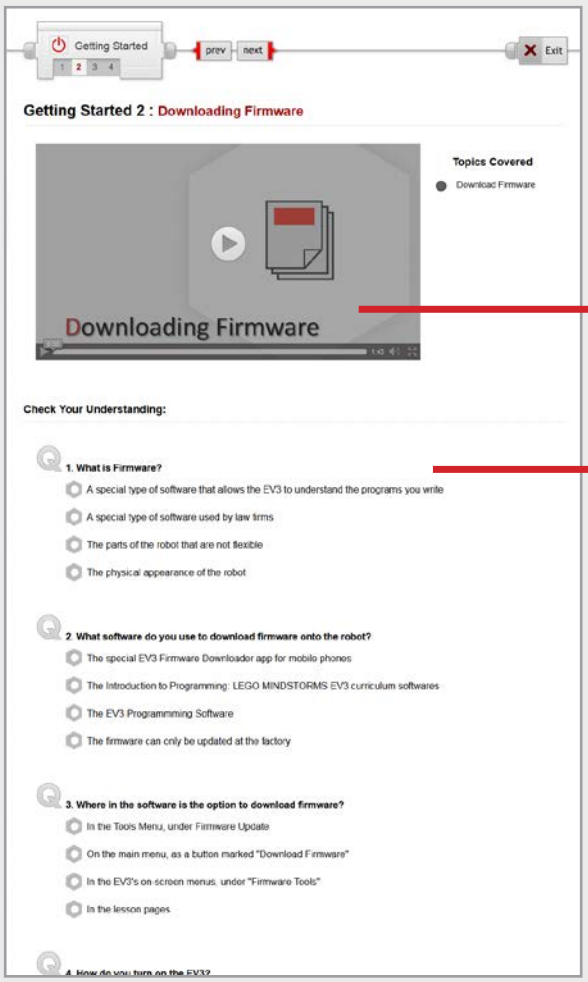
This step walks you through the process of charging and installing the rechargeable battery pack in the EV3.

Batteries Video

Walks you through the process of charging and installing the battery. Follow along with the video as it covers each step!

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.



Getting Started 2: Downloading Firmware

This step explains the idea behind Firmware, and walks you through the process of loading firmware onto the robot.

Firmware Video

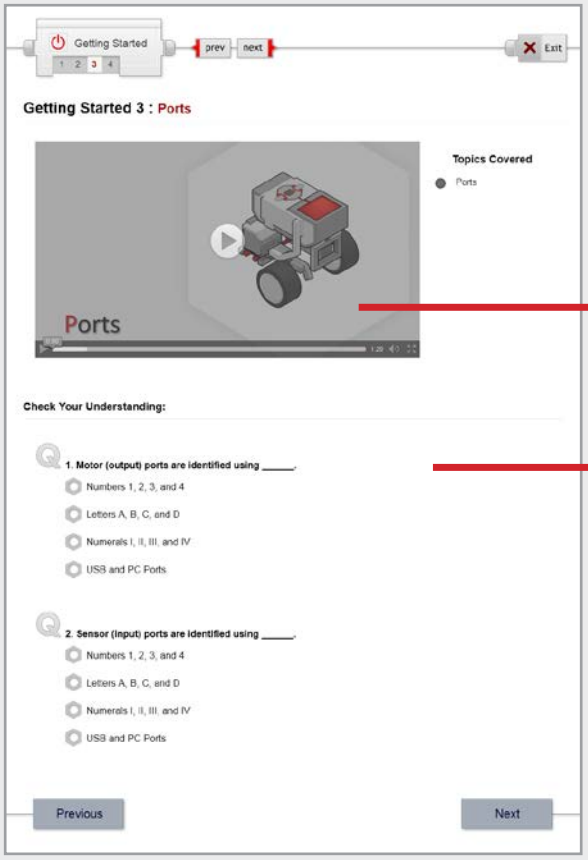
Walks you through the process of loading Firmware onto the robot. Follow along with the video as it covers each step!

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Bottoms of pages will sometimes be omitted from the Teacher's Guide if they do not contain important notes.

That is the case here – the next page of the guide will go straight to the third Getting Started video.



Getting Started 3: Ports

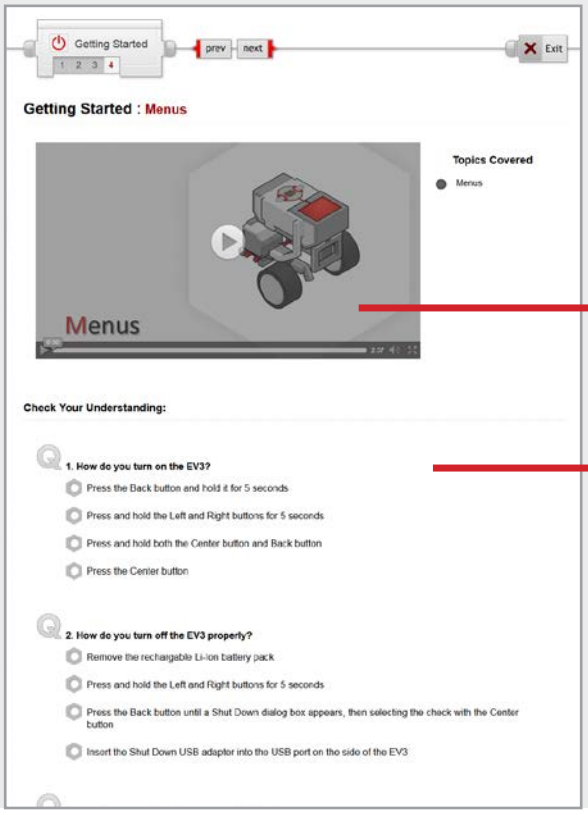
This step provides an overview of the Ports on the EV3 brick.

Ports Video

Identifies and explains the function of each port on the EV3 brick.

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.



Getting Started 4: Menus

This step explains the general interface conventions and tours the main areas of the EV3 on-brick menu interface.

Menus Video

Shows you how to use the EV3 on-screen menus to control robot settings, run programs, and more.

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Basics - Big Ideas

Big Ideas 1 & 2

Big Ideas 1 & 2 Video

This video introduces two concepts:

Big Idea #1: Programming is Precise
If you want a robot to do something, you need to communicate that idea with mathematical and logical precision, or it won't quite be what you intended

Big Idea #2: Sensors, Programs, and Actions
Data from sensors gives a robot information about its environment. A program uses that data to make decisions, and the robot Acts on those decisions. Data underlies the core of the entire process

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Big Idea 3

Big Idea 3 Video

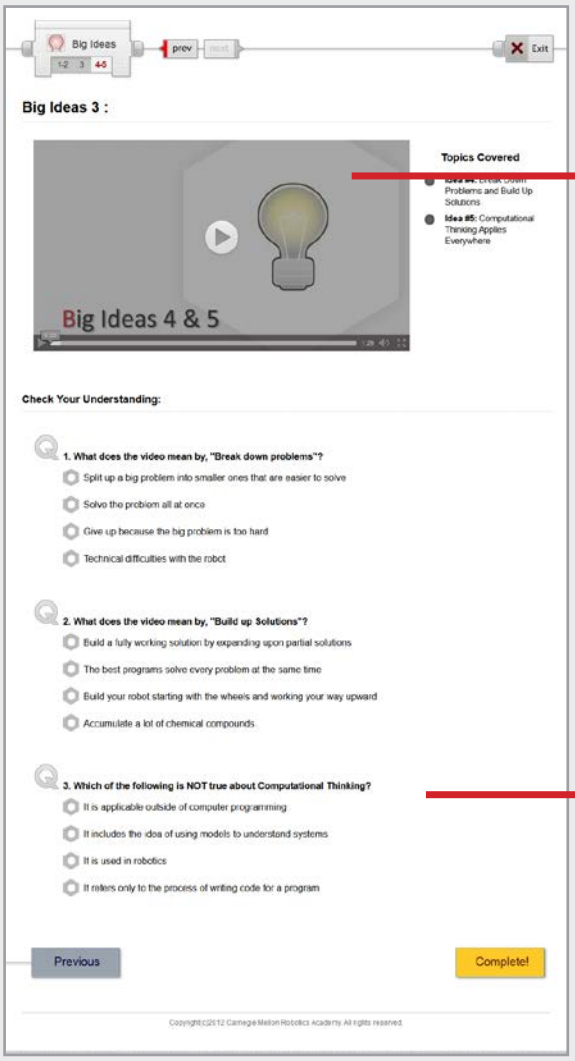
This video introduces:

Big Idea #3: Make Sense of Systems
To understand the way something works, construct a mental "model" of it in your head that captures the important features and rules of the system. This helps you make sense of it, and also gives you a tool to "play out" (similar) new scenarios in your head to predict what would happen

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Basics - Big Ideas



Big Ideas 4 & 5

Big Ideas 4 & 5 Video

This video introduces two concepts:

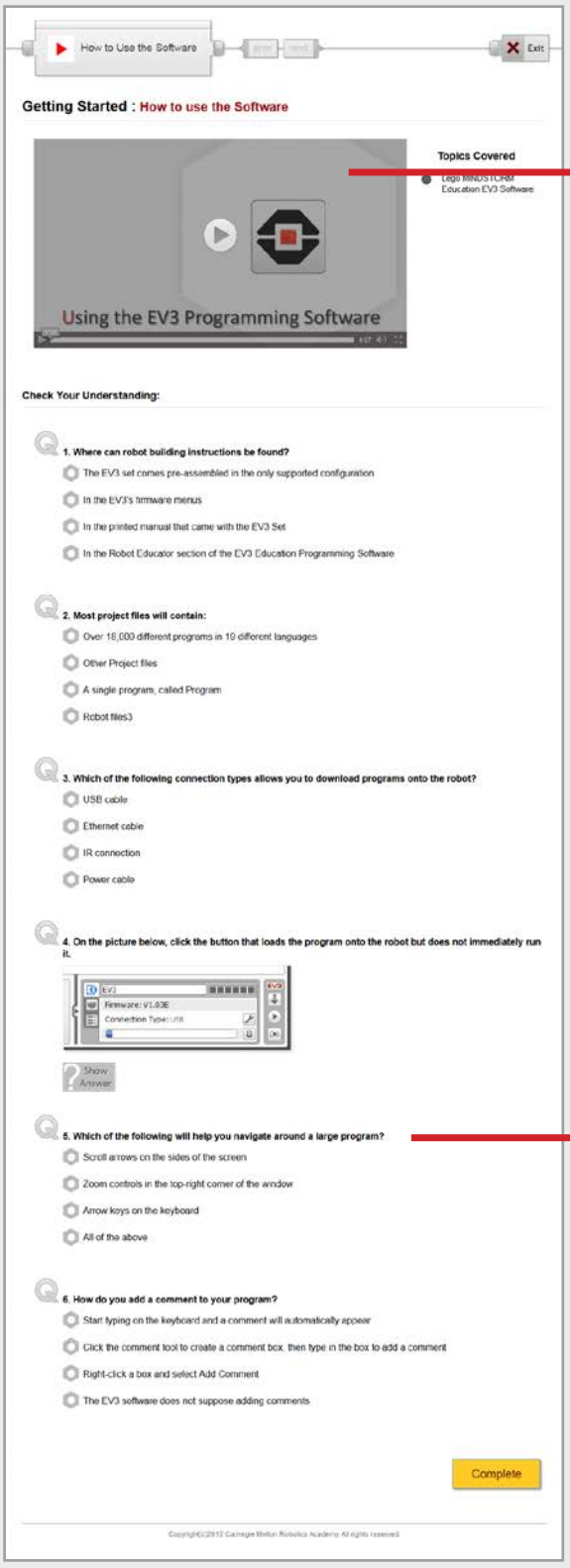
Big Idea #4: Break Down Problems and Build Up Solutions
To solve a difficult problem, try breaking it down into smaller problems. Then, solve the smaller problems, building up toward a solution to the big problem.

Big Idea #5: Computational Thinking Applies Everywhere
These skills – mathematical and logical clarity, using data, systems thinking with mental models, and problem solving – are not just for robotics. They are key to solving many problems in the world.

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Basics: Using the EV3 Software



Using the Software

Using the EV3 Software Video

This video provides introductory tips and trick of how to use the EV3 software

- How to Open the Software
- Finding Building Instructions
- Beginning Programming
- How to Link Blocks
- Mode Settings
- Configuring Blocks
- Saving
- How to Run the Program
- Navigating to the Program on the EV3
- Scrolling on the Software Interface
- Commenting Your Code

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Answer them before moving on.

Introduction to the Moving Straight Unit

Movement > Moving Straight Chapter

In Moving Straight, students program the robot to move forward, then explore variations such as moving for different distances or at different speeds.

Key Concepts: Writing and running programs, Move Steering Block, Rotations and Distance, Sequential commands

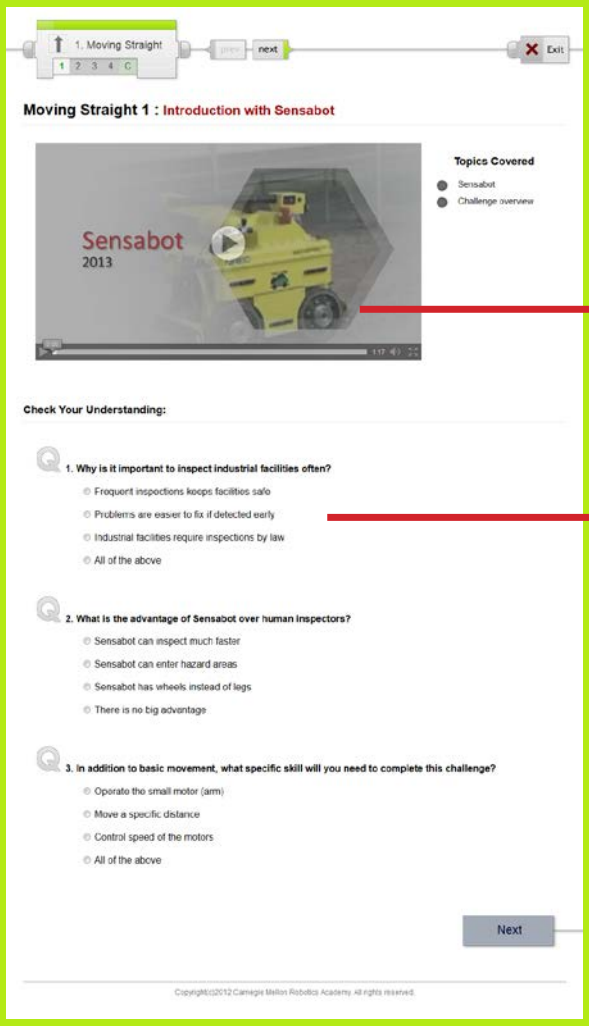
- **Moving Straight 1: Introduction to Sensabot**
  Introduces the real-world robot (Sensabot), and the challenge modeled after it (Sensabot Challenge)
- **Moving Straight 2: Robot Config**
  Contains building and setup instructions for the rest of the chapter
- **Moving Straight 3: Steering Forward**
  Introduces the Move Steering Block and programming the forward movement
- **Moving Straight 4: Arm Control**
  Introduces the Medium Motor Block and programming the arm to move
- **Moving Straight 5: Review**
  Explains sample solutions to mini-challenges from this chapter
- **The Moving Straight Challenge**
  Requires students to make the robot move to 3 marked lines by controlling the distance of each movement

Hints:

- Remember that each chapter is based around the real-world robot theme and challenges. Use these contextual surroundings to help ground discussions and decision-making processes (e.g. “Do you think guessing to find the correct distance would be appropriate, since Sensabot needs to perform this task reliably in the real world?”). [NGSS: MS-ETS1, CCSS.Math.Practice.MP1]
- The Distance a robot moves is (Wheel Circumference * Wheel Rotations). This is because the turning of the robot’s wheels are what propel it along the ground. [CCSS.Math.Practice.MP4, CCSS.Math.Content.7.RP.A.2]

Teacher’s Edition Note: This chapter’s notes will point out common structural elements such as Check Your Understanding Questions. In later sections, common notes will be omitted, as they are the same throughout the product.

Movement - Straight



Moving Straight 1: Introduction

This module introduces the Sensabot real-world robot that the chapter Challenge is based on.

Sensabot Video

Introduces the real-world robot and summarizes the chapter Challenge. Students should watch this video before beginning work on the chapter.

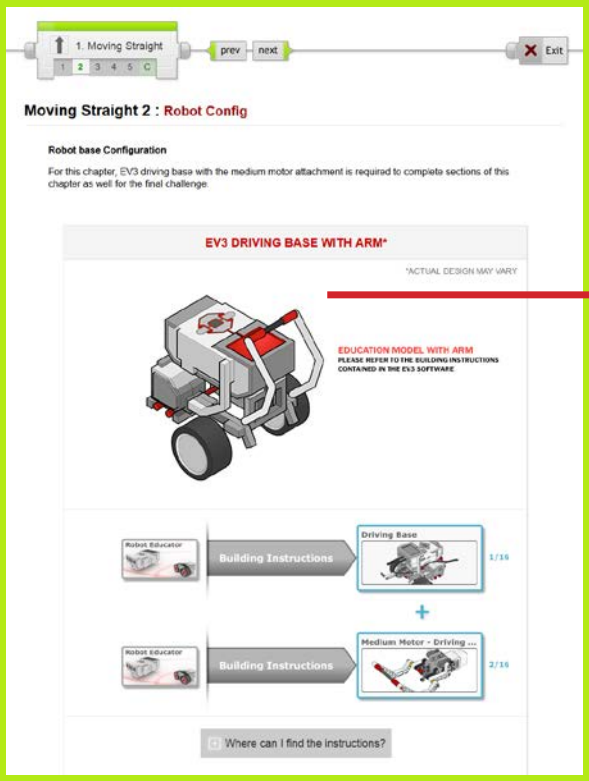
Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Students should answer them before moving on.

These generally correspond to Remembering and Understanding tasks in Bloom's Taxonomy.

Higher-level enrichment and assessment will be handled by Try It! exploration items and Mini-Challenge activities in later steps.

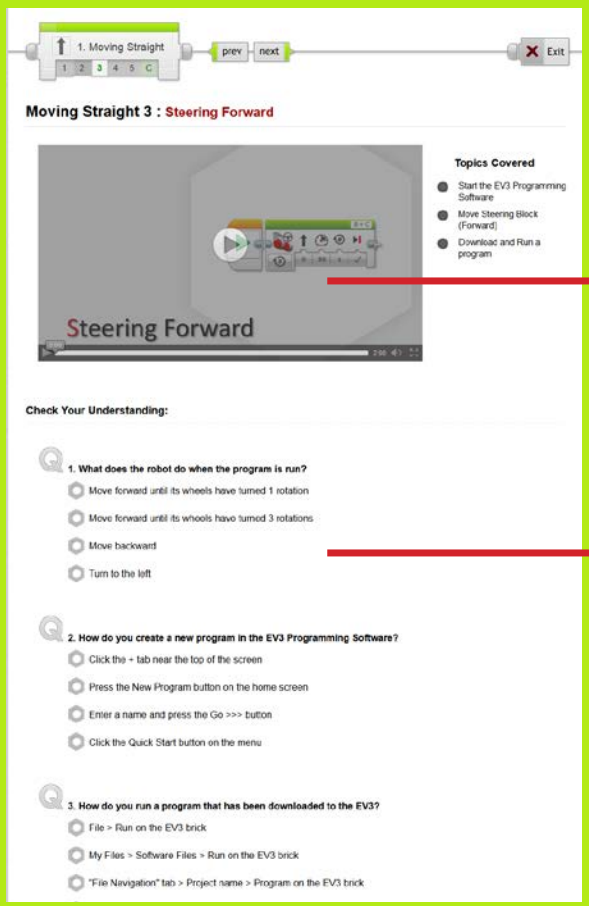
Movement - Straight



Moving Straight 2: Robot Configuration

The Building Instructions are located inside the LEGO Programming Software. Follow the instructions on this page to view them.

As of EV3 Software version 1.0.1, the instructions cannot be printed, and must be viewed on-screen.



Moving Straight 3: Steering Forward

This step introduces the Move Steering Block, and walks students through programming a straight forward movement.

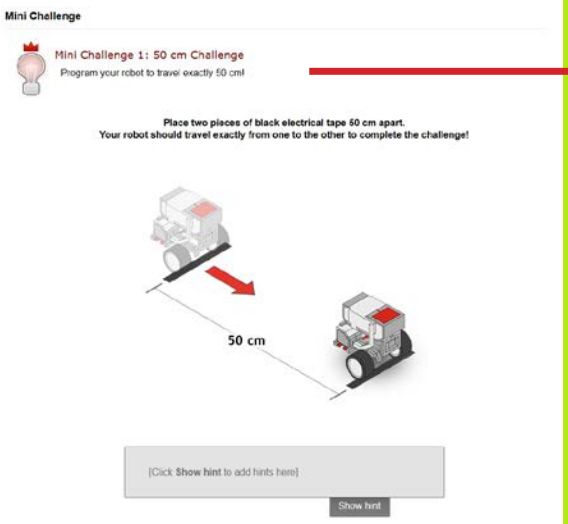
Step-by-Step Video

Walks students through the process of starting up the software, writing the Moving Straight program, and running it. Make sure students follow along with the instructions as the video plays (pause as needed).

Check Your Understanding Questions

Quickly check comprehension of the topics covered in the video. Students should answer them before moving on.

Movement - Straight



Moving Straight 3 (cont'd)

Mini-Challenge: 50 cm challenge

Challenges students to make the robot move a specific distance by adjusting the Rotations setting.

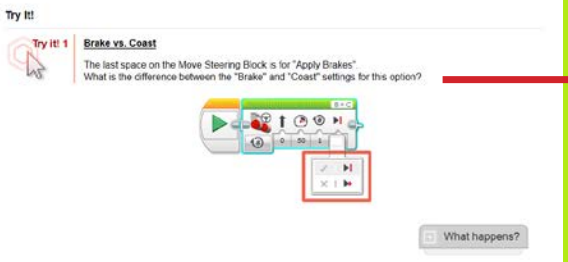
Mini-challenges ask students to perform a task that is very closely related to what they have already done in the video-guided portion.

Hints are provided, and can be revealed (one at a time) by clicking the Show Hint button on the box below the picture.

Mini-Challenges typically align to Applying tasks in Bloom's Taxonomy.

Optional Activity Cutoff Line

Activities below this line are helpful but not critical to the completion of the Challenge. Use these activities to help with class pacing.



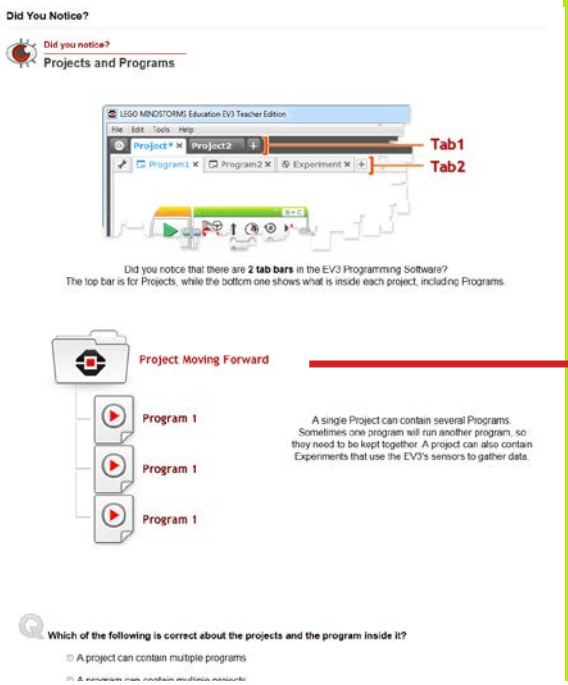
[Optional] Try It!: Brake vs. Coast

Prompts students to try changing the Brake setting on the Move Steering Block to "Coast" and see what happens.

Try It! activities prompt students to explore an additional feature or area of the software.

The What Happens? button will show the result so students can confirm their observations.

Sometimes this exploration is for enrichment, but often it is important to the Challenge. Use the Optional Cutoff to identify when an activity is critical.



[Optional] Did You Know?: Projects and Programs

Explains the relationship between Projects and Programs in the EV3 Programming Software.

Did You Know? activities provide additional background information on various topics.

Movement - Straight

Moving Straight 3 (cont'd)

[Optional] Did You Know?: Rename Program

Programs can be renamed within Projects, although this is typically only done when a Project contains multiple programs.

[Optional] Did You Know?: EV3 Menus

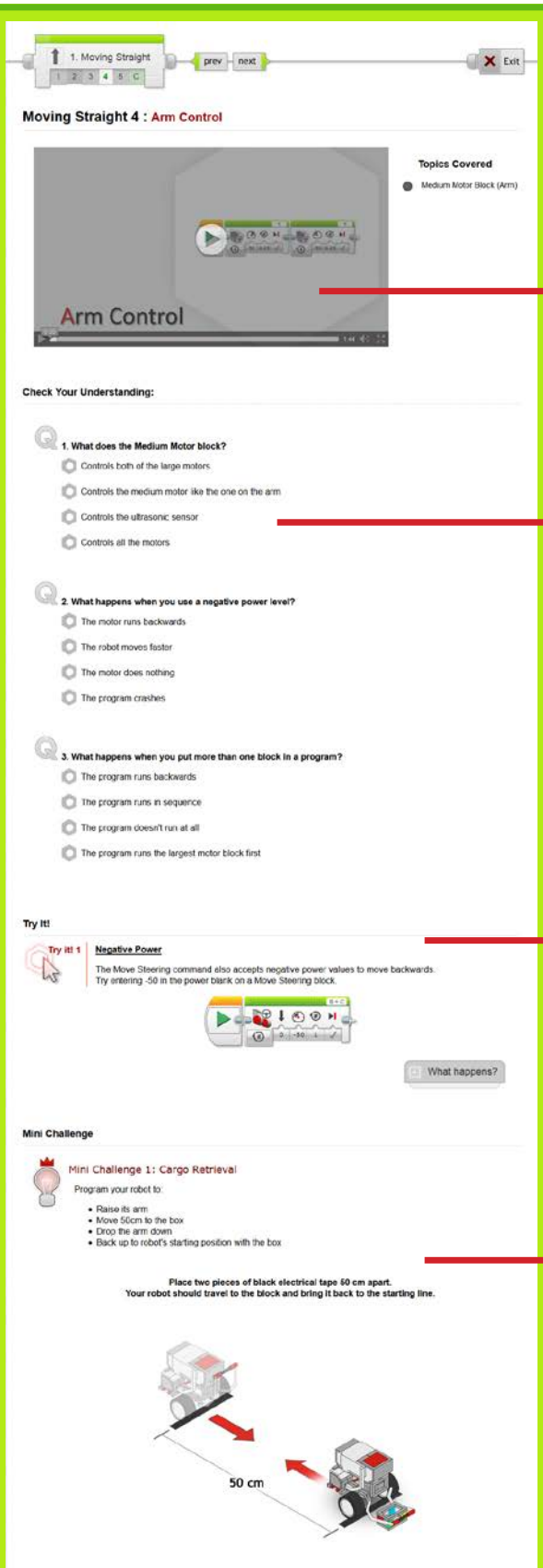
A brief overview of useful functions in the EV3 on-screen menu system. See the Basics unit or the EV3 manual for more in-depth information.

[Optional] Did You Know?: Auto-Detecting Ports

The EV3 has the built-in capability to locate and identify any motor or sensor plugged into it. This means you don't have to worry about port numbers, as long as there is only one of a given device type attached (e.g. only one Touch Sensor).

However, since there are two motors on the robot, you do need to pay attention to which one is the left and which is the right.

Movement - Straight



Moving Straight 4: Arm Control

This step introduces the concept of sequential commands. The Medium Motor Block, which controls the single arm motor is added to the program..

Step-by-Step Video

Walks students through adding a second and third command to the program, using the Medium Motor Block to control the robot's arm. Students should follow along with the video.

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Students should answer them before moving on.

Try It!: Negative Power

Negative power levels make the robot move backward.

Mini-Challenge: Cargo Retrieval

Challenges students to build on their previous programs by making the robot move forward, then lower its arm, then move back to its starting location.

Movement - Straight

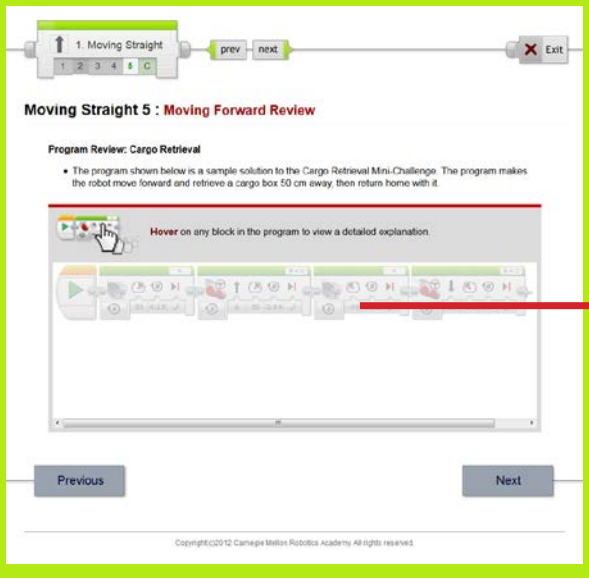
Moving Straight 4 (cont'd)

Did You Know?: Getting the Program Stuck

Explains one of the common problems with sequentially-executed programs: if any of the commands cannot complete (e.g. if the arm hits the ground and cannot lower any further), the entire program will be "stuck" and unable to progress.

Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Students should answer them before moving on.

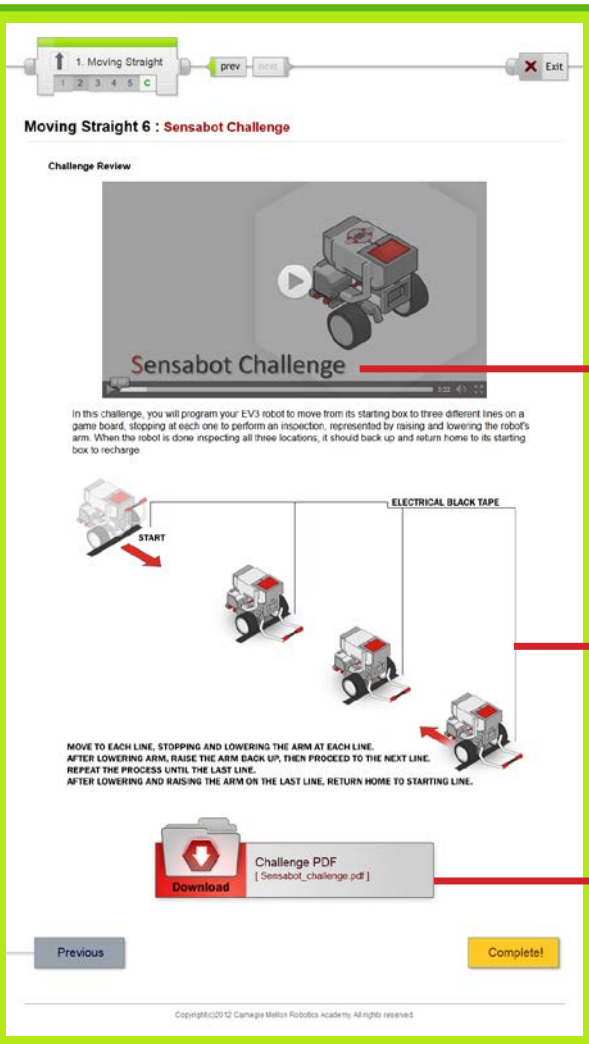


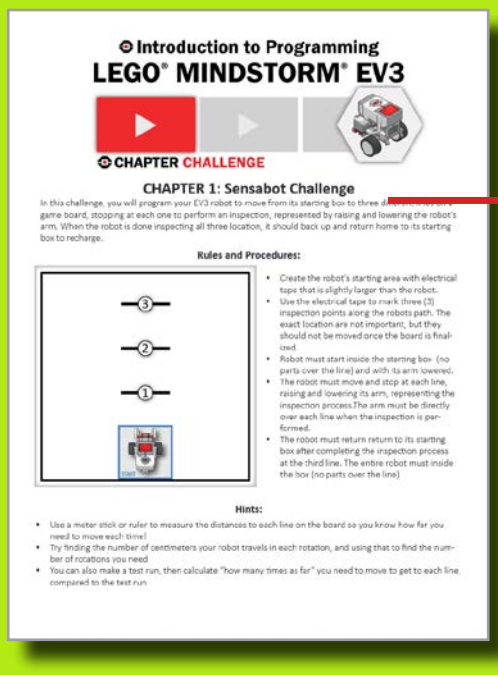
Moving Forward 5: Review

Review steps come at the end of the guided portion of a unit, just before the main Challenge. Sample solutions to the Mini-Challenges are shown here in picture format.

Placing the mouse cursor over any block in the program will show a detailed explanation identifying the block, describing the literal command it issues, and explaining what action it performs in context.

Movement - Straight





Moving Straight Challenge

This step lays out the details for the Sensabot Chapter Challenge. Students should work in their teams to complete the challenge objectives.

Challenge Video

Describes the challenge in video format. The robot must move to three marked locations on a game board, and raise and lower its arm at each location to represent taking a sensor reading.

Challenge Diagram

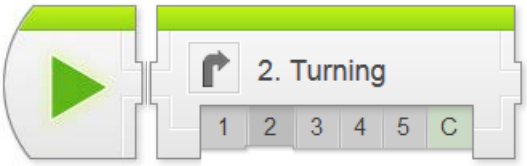
A non-technical summary of the Sensabot Chapter Challenge.

Challenge PDF

A link to the official rules and gameboard layout for the Challenge in PDF format. Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in the attached printable document.

Sensabot Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Introduction to the Turning Unit

Movement > Turning Chapter

In Turning, students program the robot to turn in place, then explore variations such as turning in the opposite direction, and turning in a wide arc.

Key Concepts: Turning, Types of Turns, Steering setting

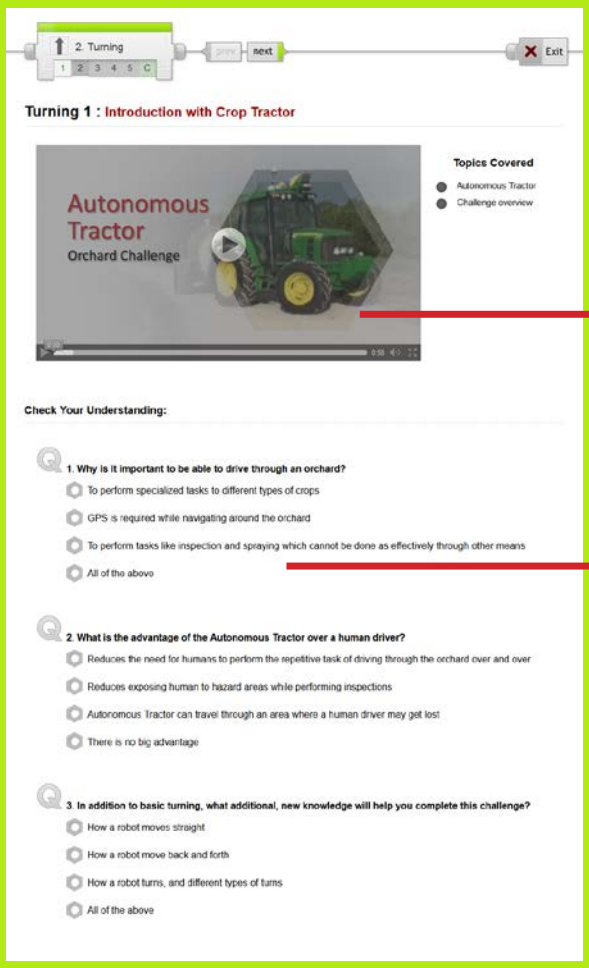
- **Turning 1: Introduction to Autonomous Tractor**
  Introduces the real-world robot (Autonomous Tractor), and the challenge modeled after it (Orchard Challenge)
- **Turning 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter
- **Turning 3: Turning in Place**
  Uses the Steering slider on the the Move Steering Block to create turns
- **Turning 4: Other Turns**
  Uses other settings on the Steering slider to create wide turns
- **Turning 5: Review**
  Explains sample solutions to mini-challenges from this chapter
- **The Orchard Challenge**
  Requires students to program the robot to navigate rows of trees in an orchard

Hints:

- The “angle” turned by a robot is generally in reference to its heading. A 90 degree turn means that the robot’s heading has changed by 90 degrees.
- When turning, a robot’s wheels travel along a curved path. The shape and angle of the turn is determined by how far each wheel travels along that path. [CCSS.Math.Practice.MP4, CCSS.Math.Content.7.RP.A.2]

Teacher’s Edition Note: Notes on the purpose of common structural elements such as Check Your Understanding Questions are omitted from this section onward. To review these general notes, please see the Movement > Moving Straight chapter.

Movement - Turning



Turning 1: Introduction

Introduces the Autonomous Tractor and the Orchard Challenge.

Autonomous Tractor Video

Introduces the real-world robot and summarizes the chapter Challenge. Students should watch this video before beginning work on the chapter.

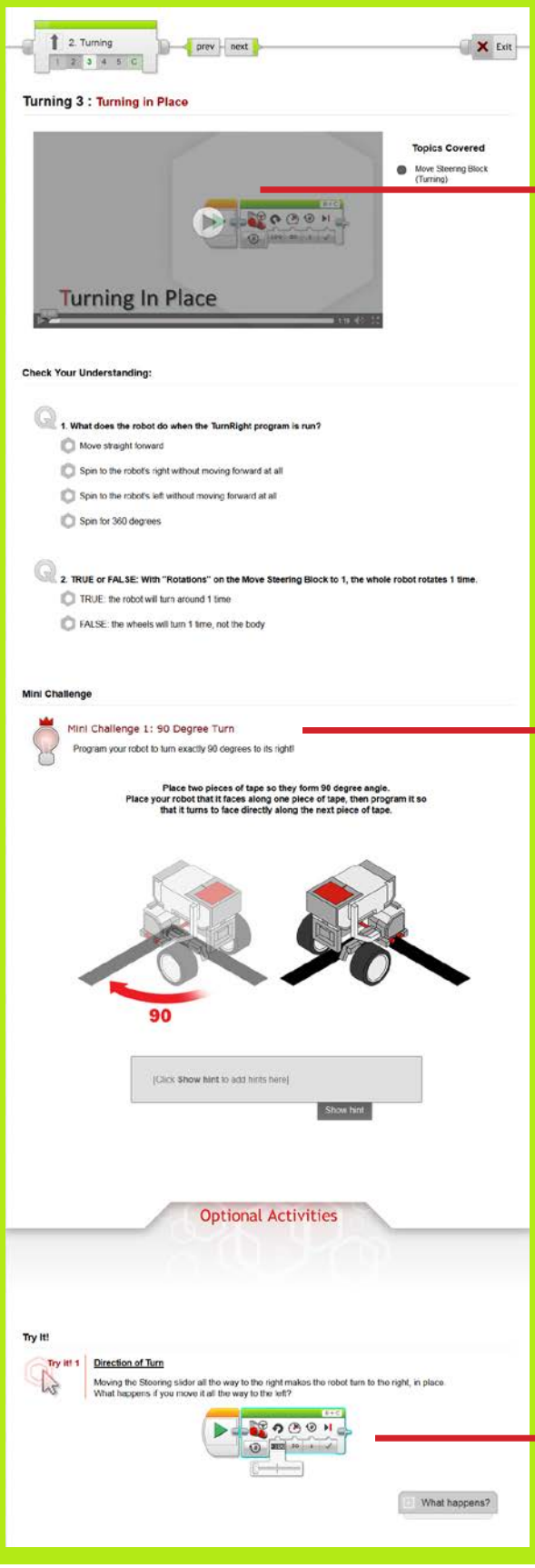
Check Your Understanding Questions

These questions are designed to quickly check comprehension of the topics covered in the video. Students should answer them before moving on.

Turning 2: Robot Configuration

Building Instructions for the robot are the same as Moving Straight.

Movement - Turning



Turning 3: Turning in Place

This step introduces the Steering slider to make the robot turn to the side. For now, only the center and ends of the slider are used. Intermediate settings produce "wide" turns and are explored in the next step.

Mini-Challenge: 90 Degree Turn

Challenges students to make the robot turn a specific amount (90 degree change in the direction the robot is facing).

This activity is directly analogous to the "50 cm mini-challenge" in the previous chapter, and pointing out the parallels in the two problems is appropriate.

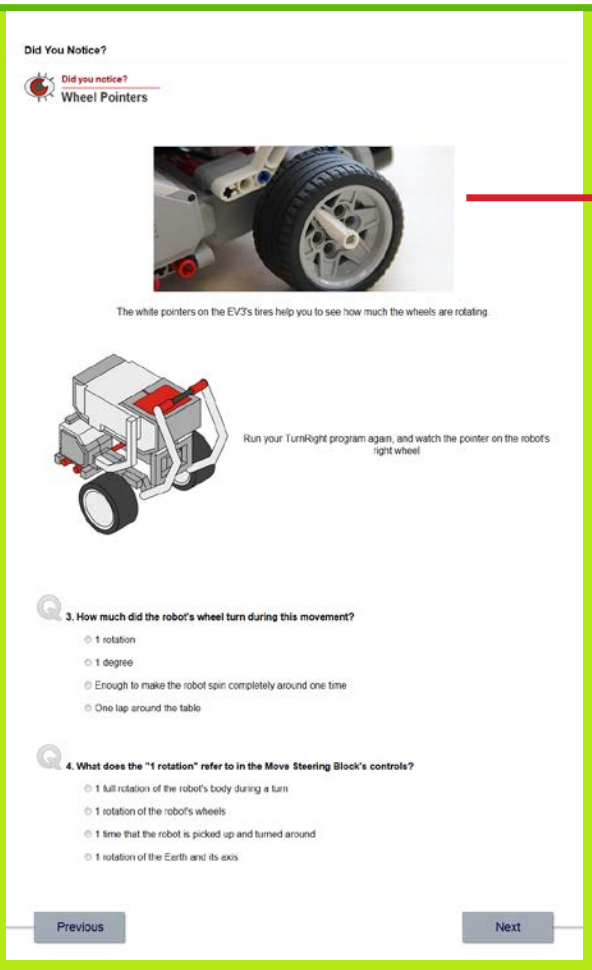
The ratio of Wheel Rotations to Body Turn on the REM-EV3 driving base model is approximately 2:1; that is, it takes 2 wheel rotations to turn the robot around exactly 1 time. Turning the robot 90 degrees, then, would take 0.5 wheel rotations (180 degrees).

[Optional] Try It!: Direction of Turn

Prompts students to try moving the Steering slider to the other side. This produces a turn in the opposite direction.

The direction of turn always matches what you would get if you turned a steering wheel in the same direction ("left" or "right").

Movement - Turning

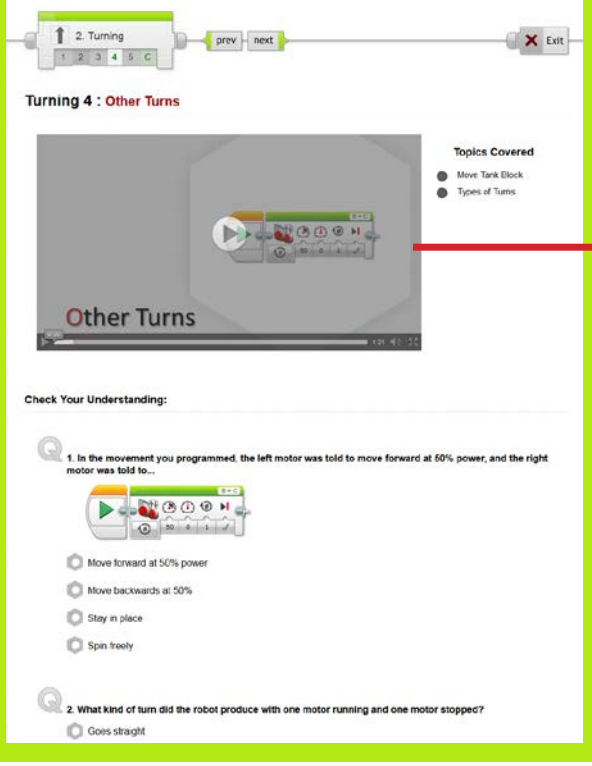


Turning 3 (continued)

[Optional] Did you notice?: Wheel Pointers

Calls attention to a design feature of the robot: pointers on the robot's wheels help you see which direction each wheel is turning, and how much.

The amount a wheel turns (e.g. 360 degrees of wheel rotation) is proportional – but not identical – to the amount the robot's body will turn.

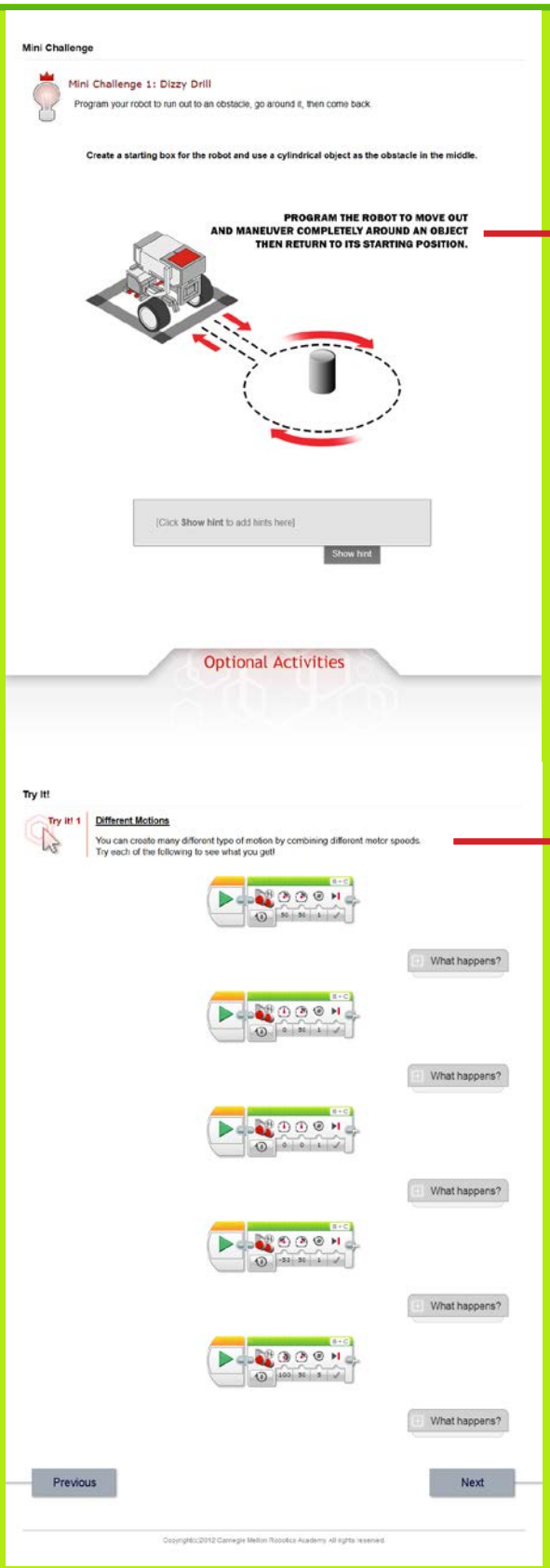


Turning 4: Other Turns

This step introduces off-center "wide" turns using the Move Tank Block, which controls the robot's two wheel motor powers separately.

Any time the robot's wheels move at different speeds, the robot's path will curve. The specific shape of the curve is determined by the combination of powers used.

Movement - Turning



Turning 4 (continued)

Mini-Challenge: Dizzy Drill

Challenges students to make the robot move around an obstacle using a combination of straight moves and turns (wide or in-place).

[Optional] Try It!: Different Motions

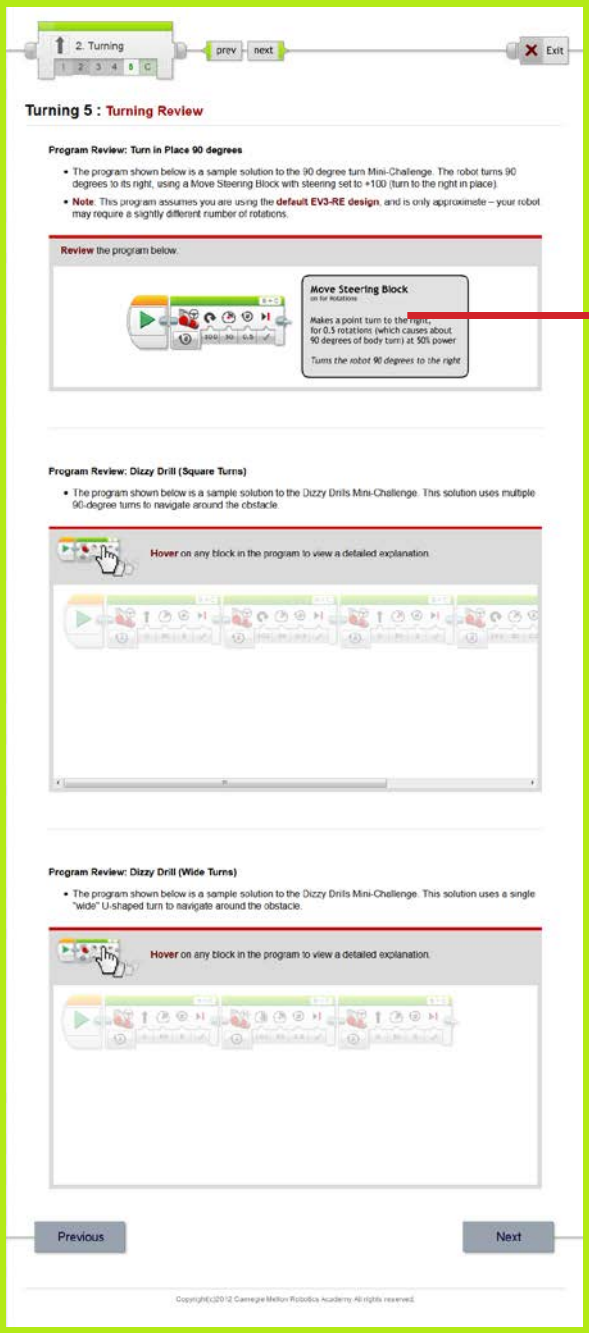
Prompts students to try different combinations of motor powers. This produces differently-curved turns.

Helper Activity: Role-play the robot

One student acts as the robot, while another student issues left-foot and right-foot commands with different power levels.

For instance, "left foot 50; right foot 0" means taking a small step forward with the left foot and holding the right foot in place. Straightening out your body from this stance will make you turn slightly to the right, pivoting around your right foot just as the robot does with a Move Tank Block set to left 50, right 0.

Movement - Turning

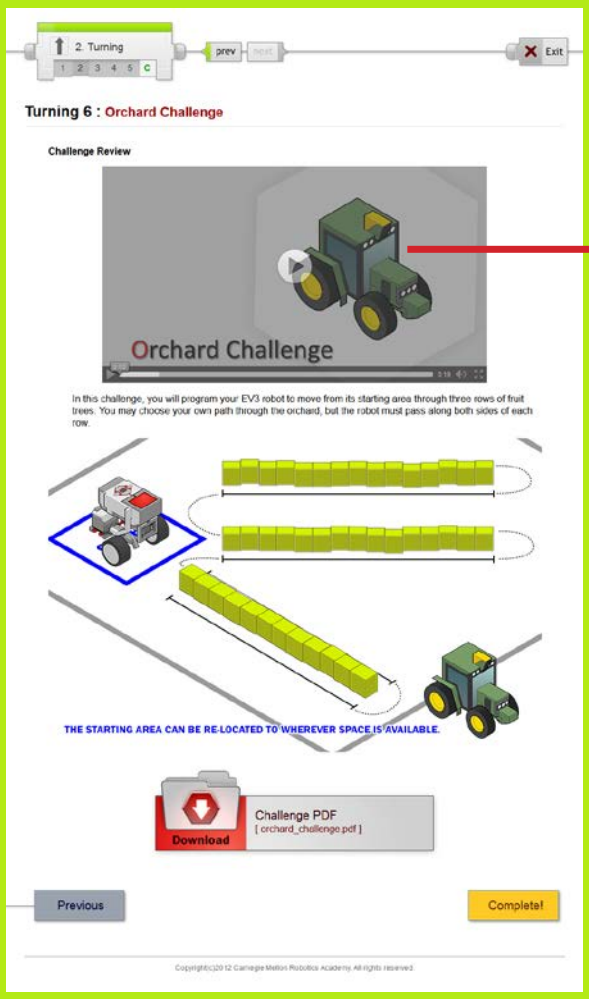


Turning 5: Turning Review

Sample solutions to the mini-challenges can be found on this page.

Dizzy Drills has two sample solutions provided: one for a strategy that uses two right-angle turns to go around the back of the obstacle, and one that uses a single U-shaped turn to swing around the obstacle.

Movement - Turning



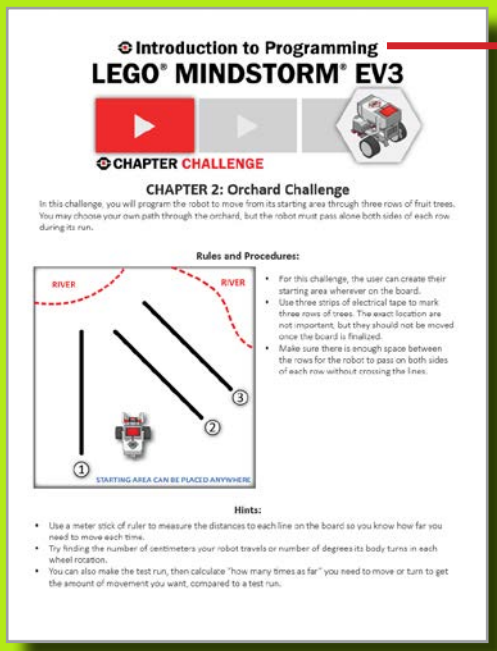
Orchard Challenge

This step lays out the details for the Orchard Challenge. Students should work in their teams to complete the challenge objectives.

Teams get to choose where they start their robot for this challenge. It is to their advantage to pick a specific spot and use it every time, rather than moving the start position or aligning the robot sloppily.

The route shown in the picture is just an example, not the required (or necessarily easiest) route.

Retain this Challenge board intact, if possible, as it will be re-visited in the Switch-Loops chapter.



Orchard Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.

Introduction to the Touch Sensor Unit

Sensors > Move Until Touch Chapter

In Move Until Touch, students program a robot to wait until its Touch Sensor is pressed before proceeding with other commands, then combine that behavior with Motors On and Motors Off commands to make the robot stop and go based on Touch Sensor commands.

This chapter is an exception to the pattern of "bookending" every set of activities with real-world robots and challenges. While the chapter is still challenge-based, it is focused on the idea of sensors rather than a specific robot that uses them.

Key Concepts: Wait Block, Touch Sensor, Forward Until Pattern

- **Touch 1: Introduction to Sensors**
  Introduces the idea of Sensors, the Touch Sensor, and some of the Touch Sensor-based behaviors in the lesson

- **Touch 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter

- **Touch 3: Wait for Touch**
  Uses the Wait for Touch Block to make a robot wait for a Touch Sensor press before continuing

- **Touch 4: Forward until Touch**
  Combines Motor On and Motor Off commands with the Wait for Touch Block to make the robot move forward until the Touch Sensor is pressed

- **Touch 5: Review**
  Explains sample solutions to mini-challenges from this chapter

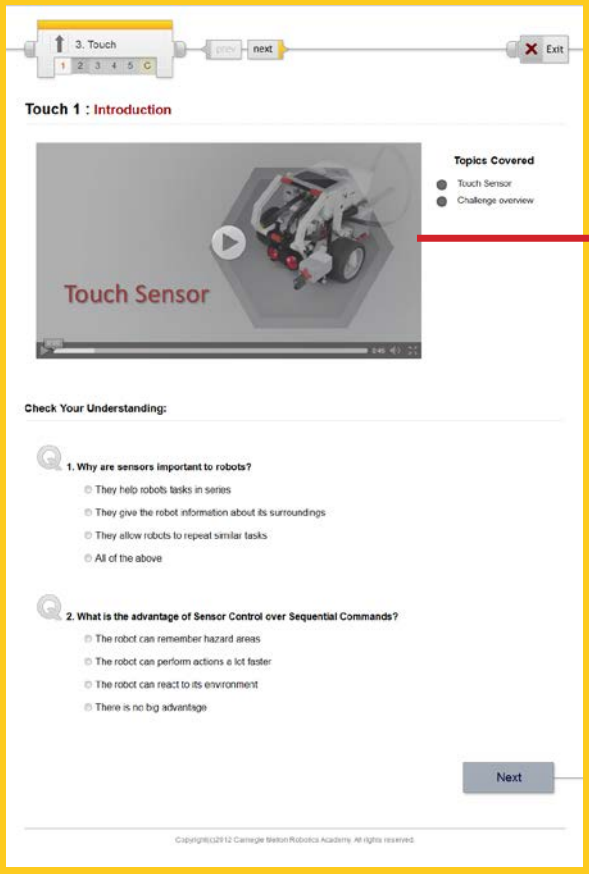
- **The Arm Position Challenge**
  Requires students to program a Touch Sensor-based "raise arm" behavior that moves the arm to its "closed" position regardless of where the arm starts.

Hints:

- All of the chapters in the Sensors unit follow the general pattern laid out in this chapter: Introduction, Wait for (Sensor), Forward until (Sensor), Challenge.

- The Touch Sensor does not have a real-world robot because simple touch switches are not commonly found on real-world robots; typically, robots shouldn't physically collide with their surroundings to sense them.

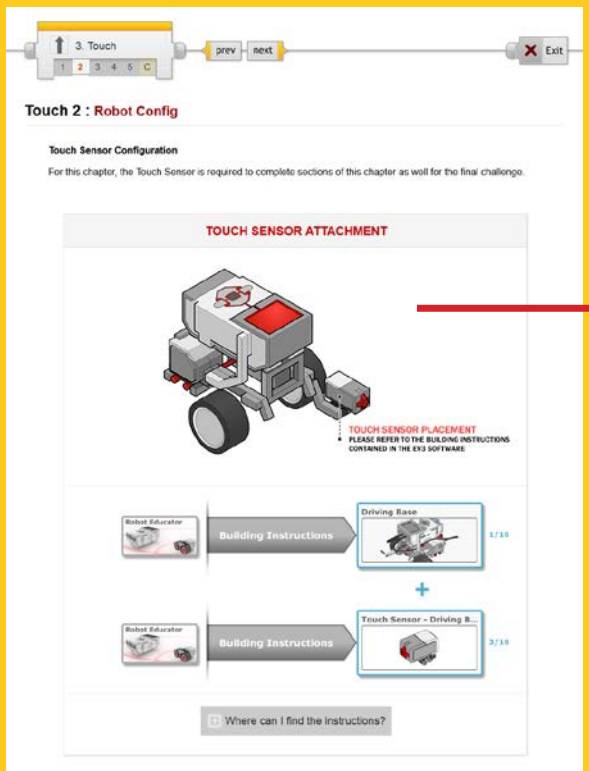
Touch Sensor



Touch 1: Introduction

Introduces the idea of Sensors on the robot.

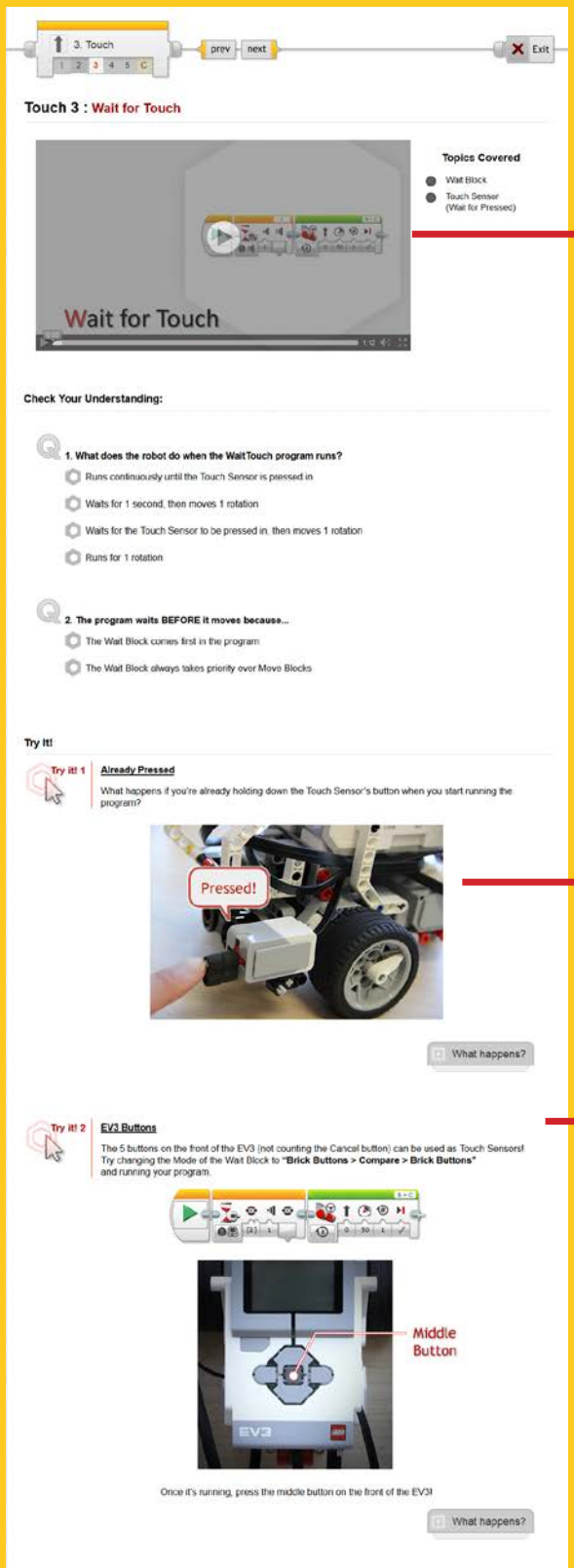
This chapter does not use a real-world robot. Instead, it focuses on the first use of sensors on the EV3 robot.



Touch 2: Robot Config

The robot is the driving base from the Movement Unit, with a Touch Sensor added.

Touch Sensor



Touch 3: Wait for Touch

This step introduces both the Touch Sensor and the Wait For (Sensor) Block.

The Touch Sensor physical mechanism is explained at the bottom of the page.

The Wait For (Sensor) Block "holds up" the program's flow until the sensor condition is met. When the condition is met, the program continues (with a Move Steering block in this case). This is the simplest way in which the sensor can be used to control a behavior, and is used throughout the Sensors Unit.

Try It!: Already Pressed

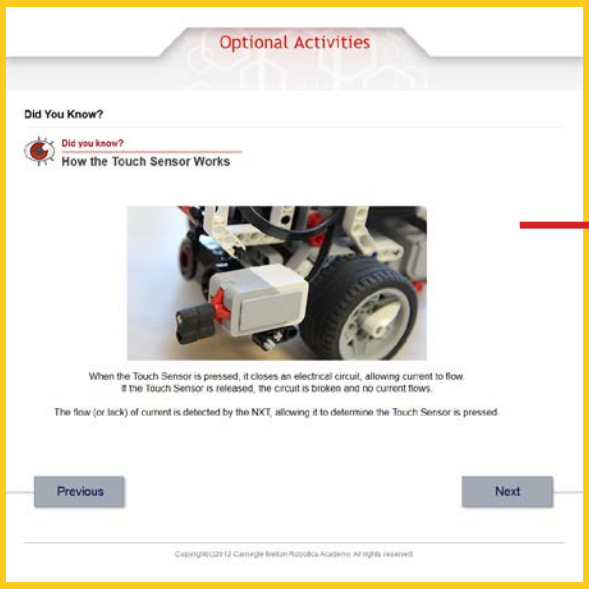
Since the Wait for Touch Block literally waits for the "Pressed" state, it can be triggered instantly if the sensor is already pressed in when the program starts.

This is a common source of error with all sensors: if the sensor is already in a "triggered" position, the "wait" is invisibly short. This is often mistaken for the program "ignoring" the sensor.

Try It!: EV3 Buttons

The buttons on the front of the EV3 are essentially touch sensors, and can be used as such.

Touch Sensor

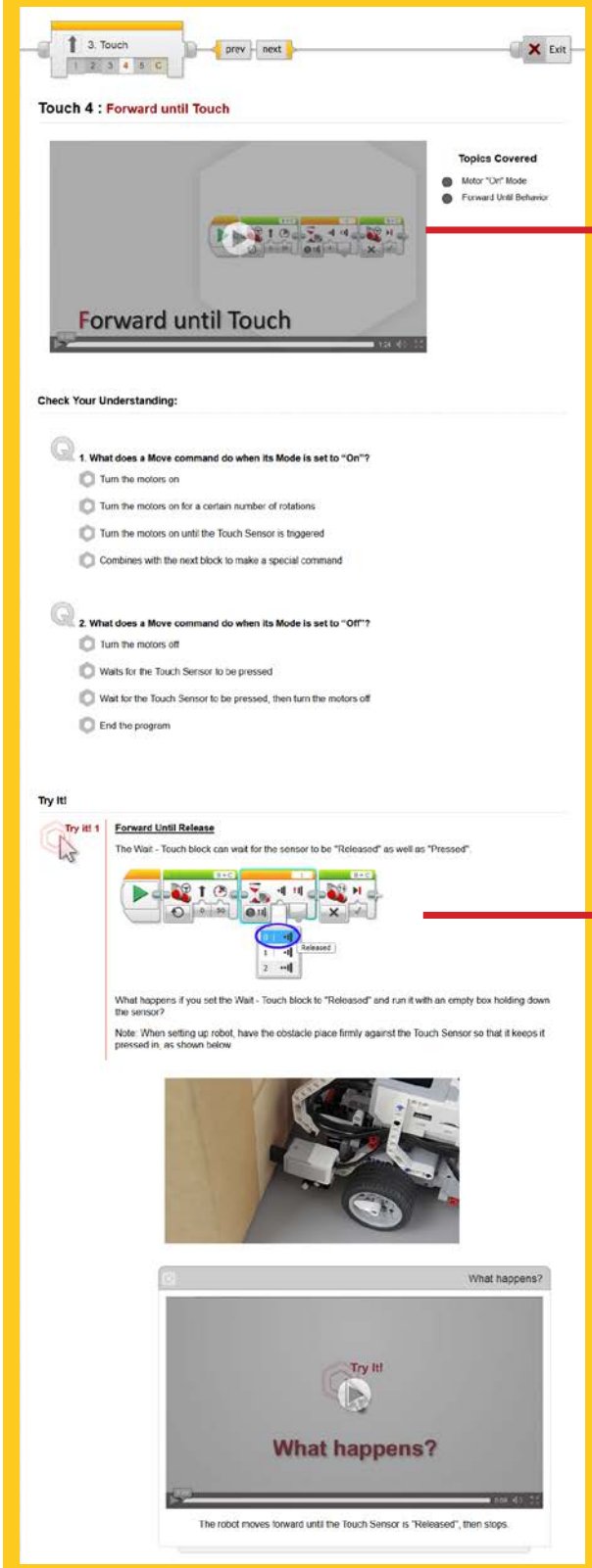


Touch 3 (continued)

[Optional] Did You Know?: How the Touch Sensor Works

An interactive animation showing how a Touch Sensor acts as an electrical switch to create a flow of electricity the EV3 detects.

Touch Sensor



Touch 4: Forward until Touch

This step introduces the Motor On and Motor Off modes of the Move Steering Block.

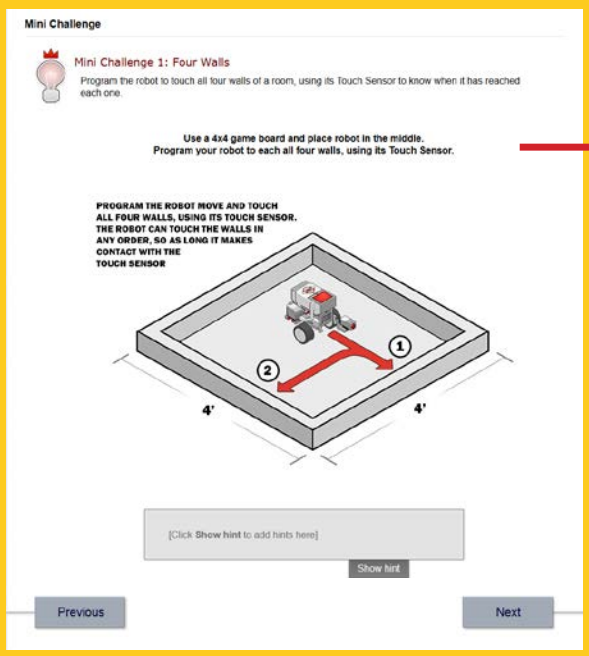
Motor On – Wait for Touch – Motor Off form a common pattern that makes the robot move forward until the Touch Sensor is pressed, then stop. This pattern is sometimes referred to as “Forward until”.

Try It!: Forward Until Release

Prompts students to try the “Released” setting for the Wait for Touch Block instead of “Pressed”. The robot will move until the Touch Sensor is NOT pressed.

Make sure the Touch Sensor starts pressed in, or the “Released” state will be detected immediately, and the robot will go nowhere (see “Already Pressed” on the previous page).

Touch Sensor



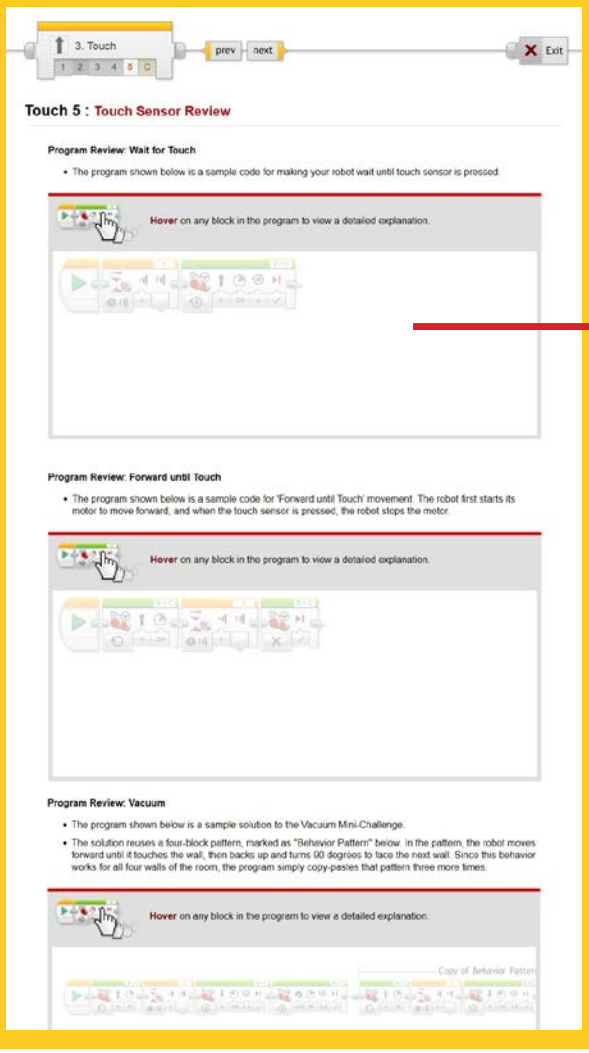
Touch 4 (continued)

Mini-Challenge: Four Walls

Challenges students to make the robot move to touch all four walls of an enclosed rectangular space.

The desired behavior can be thought of as “Forward until Touch (the wall), then turn” four times. Backing up prior to turning may help to avoid getting caught on the wall.

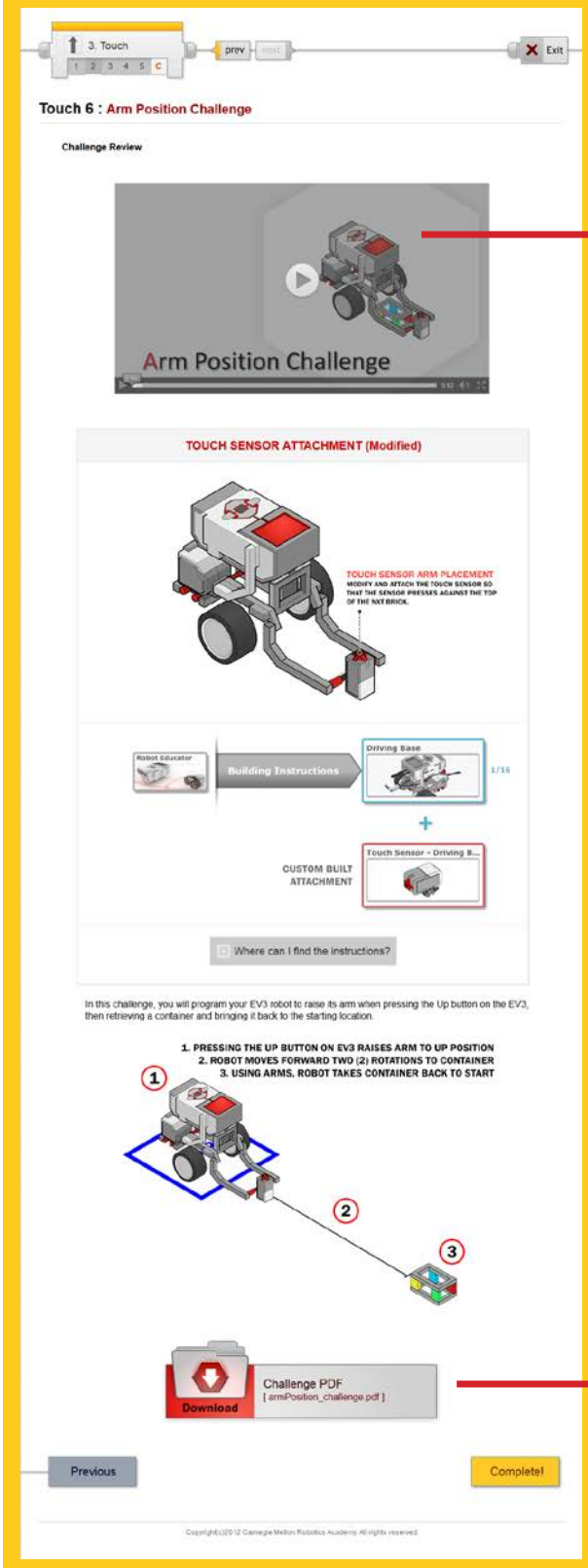
Students with prior programming experience may know that a Loop Block would be helpful here; it is up to you to decide whether it is allowed at this time.



Touch 5: Touch Sensor Review

Expanded explanations for both in-video programs and a sample solution for the mini-challenge can be found on this page.

Touch Sensor



Arm Position Challenge

This step lays out the details for the Arm Position Challenge.

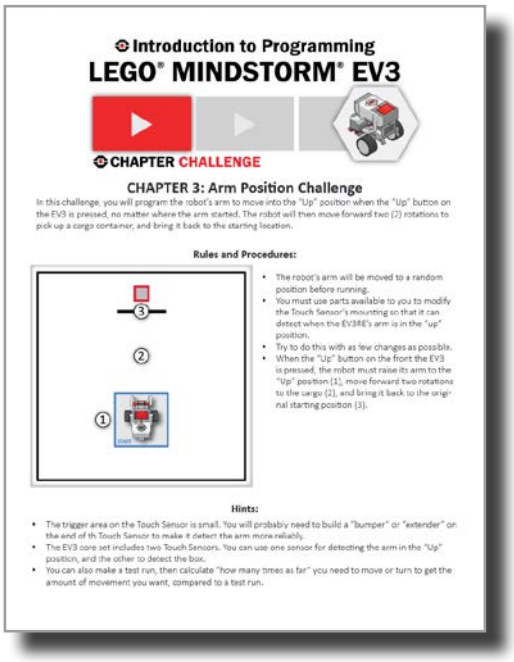
This challenge involves more physical construction than programming, as students will need to find a way to position the Touch Sensor so that it can detect the Arm reaching the top of its motion.

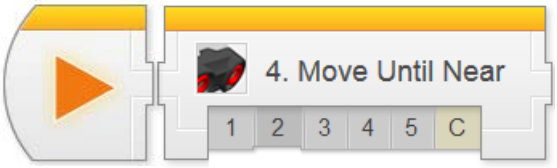
Students should be allowed limited freedom to modify the robot's arm or add extensions during this Challenge, but should not need to modify or disassemble the driving base.

A concept picture of one possible layout is shown on the page, but no specific building instructions are provided: students should work to complete a design on their own.

Arm Position Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.





Introduction to the Ultrasonic Sensor Unit

Sensors > Move Until Near Chapter

In Move Until Near, students program a robot to wait until its Ultrasonic Sensor detects an object within a certain “threshold” distance before proceeding with other commands. This is combined with Motors On and Motors Off to produce a Forward Until behavior parallel to the one constructed using Touch in the previous chapter.

Key Concepts: Ultrasonic Sensor, Threshold Value, Forward Until Pattern

- **Ultrasonic 1: Introduction to Sensors**
  Introduces the real-world robot (Hexarotor), and the challenge modeled after it (Maze Challenge)

- **Ultrasonic 2: Robot Config**
  Contains building and setup instructions for the rest of the chapter

- **Ultrasonic 3: Wait for Near**
  Uses the Wait for Near Block to make a robot wait for the Ultrasonic Sensor to detect an object closer than the threshold value before continuing

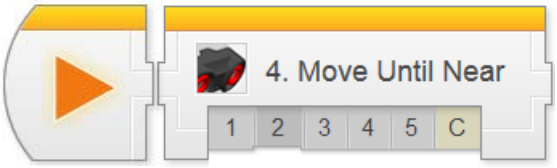
- **Ultrasonic 4: Forward until Near**
  Combines Motor On and Motor Off commands with Wait for Near to make the robot move forward until the Ultrasonic Sensor detects something nearby

- **Ultrasonic 5: Review**
  Explains sample solutions to mini-challenges from this chapter

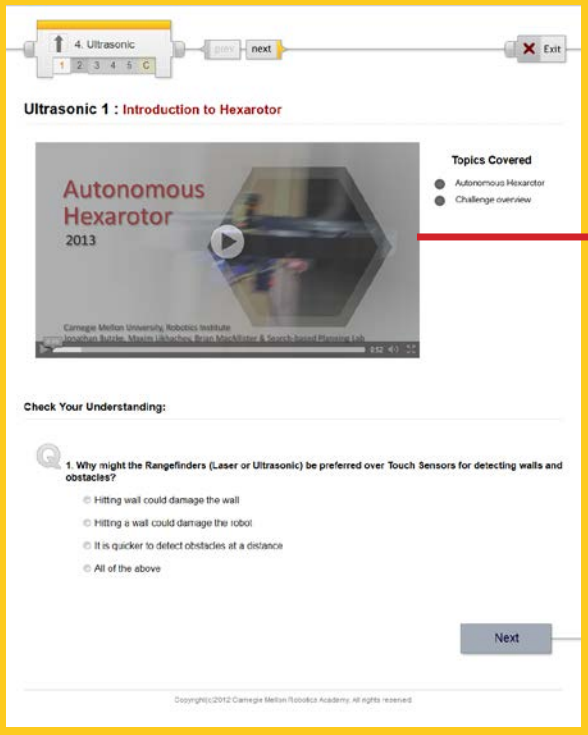
- **Maze Challenge**
  Requires students to program an Ultrasonic Sensor-based solution to a maze, detecting distances from key walls to known when to turn.

Hints:

- All of the chapters in the Sensors unit follow the general pattern laid out in this chapter: Introduction, Wait for (Sensor), Forward until (Sensor), Challenge.



Ultrasonic Sensor



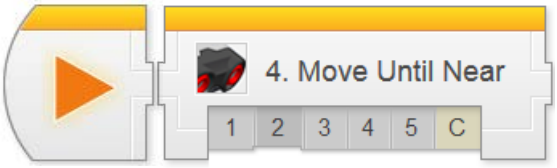
Ultrasonic 1: Introduction

Introduces the Autonomous Hexarotor and the Maze Challenge.

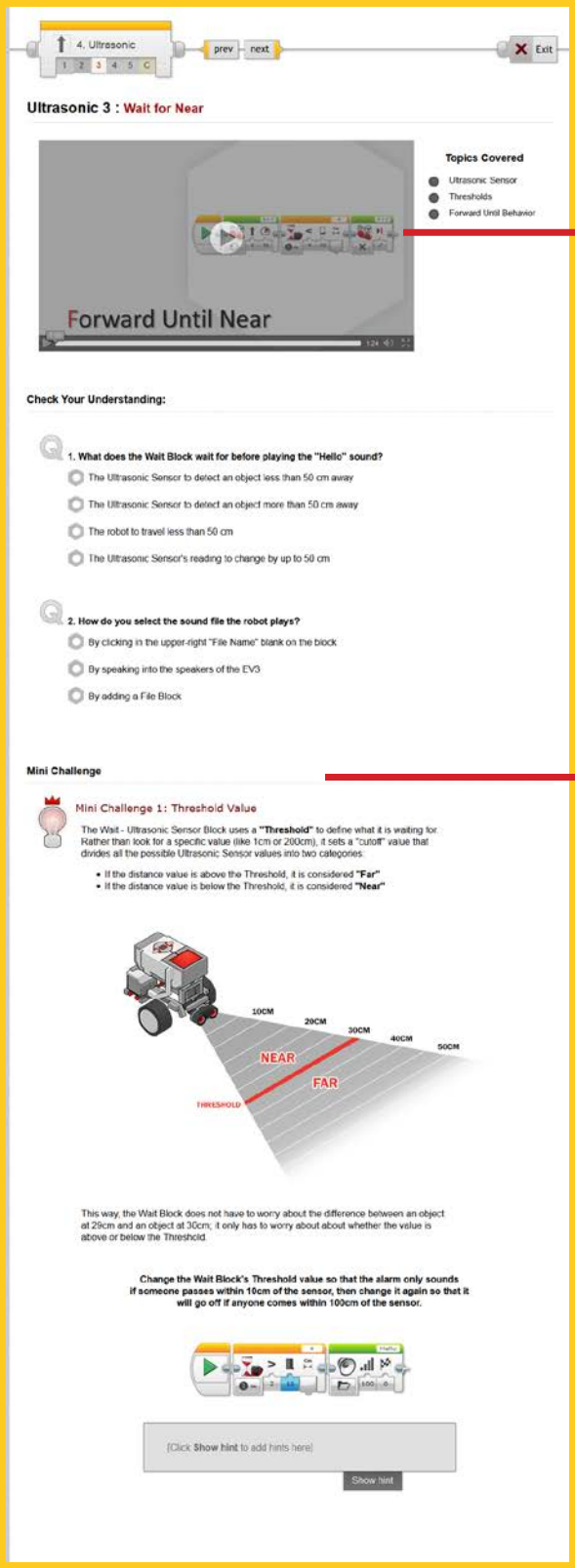
Ultrasonic 2: Robot Config

This chapter uses the driving base model, plus a forward-facing Ultrasonic Sensor.

Sensors from the previous chapter can be left on or removed as convenient, as long as they do not interfere with the Ultrasonic Sensor (i.e. are not within its “cone” of view).



Ultrasonic Sensor



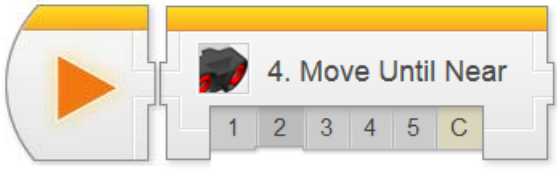
Ultrasonic 3: Turning in Place

This step introduces the Ultrasonic Sensor and Wait for Near Blocks. The Sound Block is used also, as a way of indicating when the sensor has been triggered.

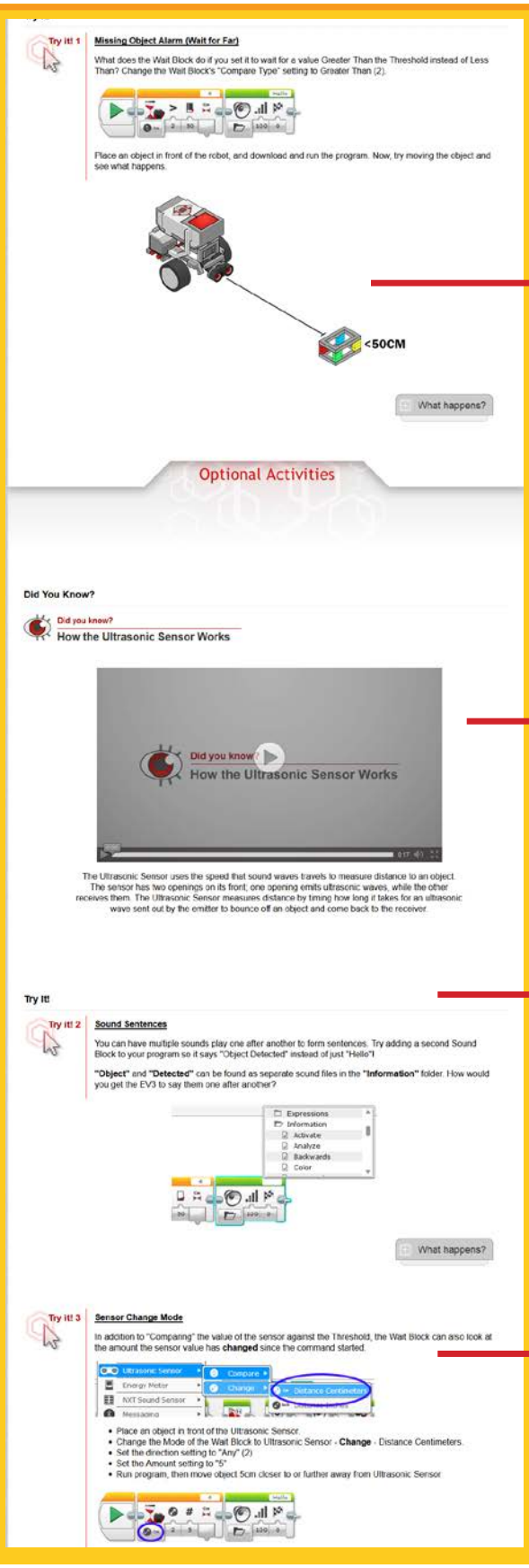
Mini-Challenge: Threshold Value

Challenges students to alter the Threshold value on their Wait for Near Block to trigger at 10 cm, and at 100 cm.

Thresholds are a key concept in robotics programming, because they allow programs to easily make decisions based on sensor readings that range over hundreds of possible values (1 cm, 2 cm, 3 cm...). Rather then write hundreds of different responses, the robot simply responds to the number being above or below the Threshold cutoff.



Ultrasonic Sensor



Ultrasonic 3 (continued)

Try It!: Missing Object Alarm

Prompts students to try using Greater Than Threshold instead of Less Than Threshold. This is analogous to Wait for Release instead of Wait for Pressed.

[Optional] Did You Know?: How the Ultrasonic Sensor Works

A video animation showing how an Ultrasonic Sensor uses sonar to calculate the distance to an object.

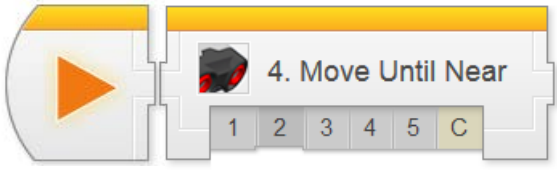
[Optional] Try It!: Sound Sentences

Adding sounds within your program provide excellent clues that alert you that a behavior has just completed.

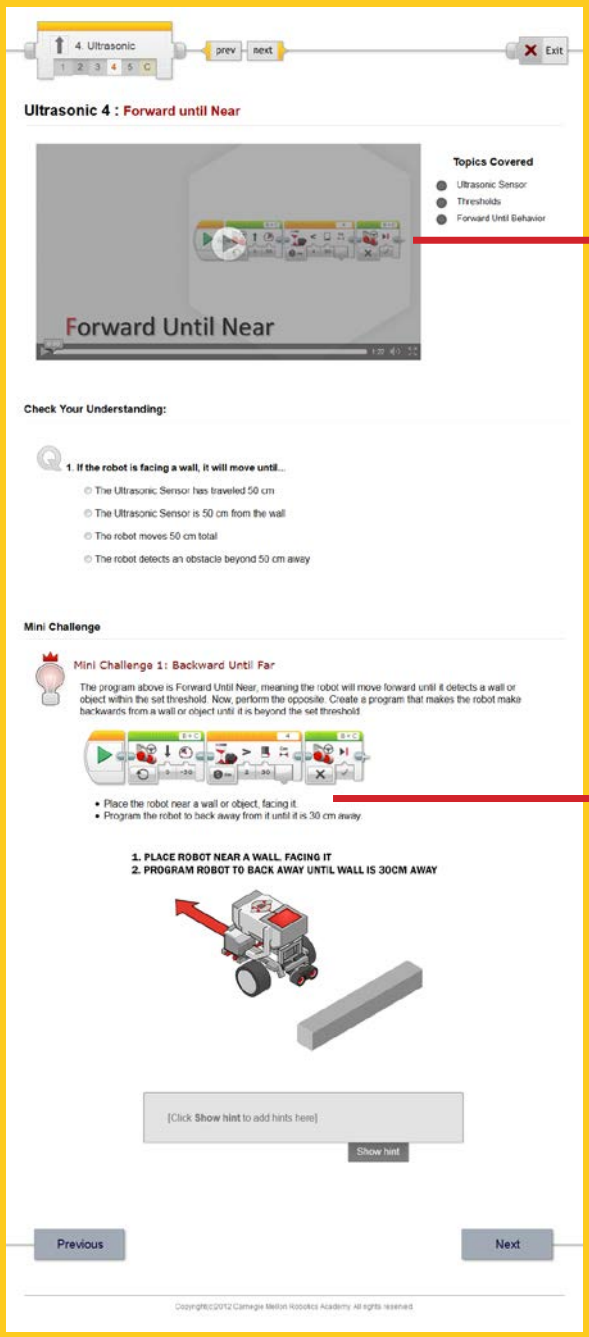
Focusing on the Sound Block, this Try It! prompts students to string together multiple blocks (saying different words) into a sentence.

[Optional] Try It!: Sensor Change Mode

Prompts students to try using the Change mode to wait for a change in Ultrasonic values, rather than a value above or below below a particular threshold (as it does in Compare mode).



Ultrasonic Sensor



Ultrasonic 4: Forward Until Near

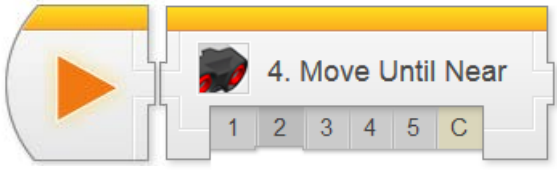
This step guides students through a Forward Until behavior that uses the Ultrasonic Sensor to stop when the robot gets close to a wall (Ultrasonic Sensor value is below a certain distance threshold).

This is analogous to Forward Until Pressed in the Touch Sensor unit.

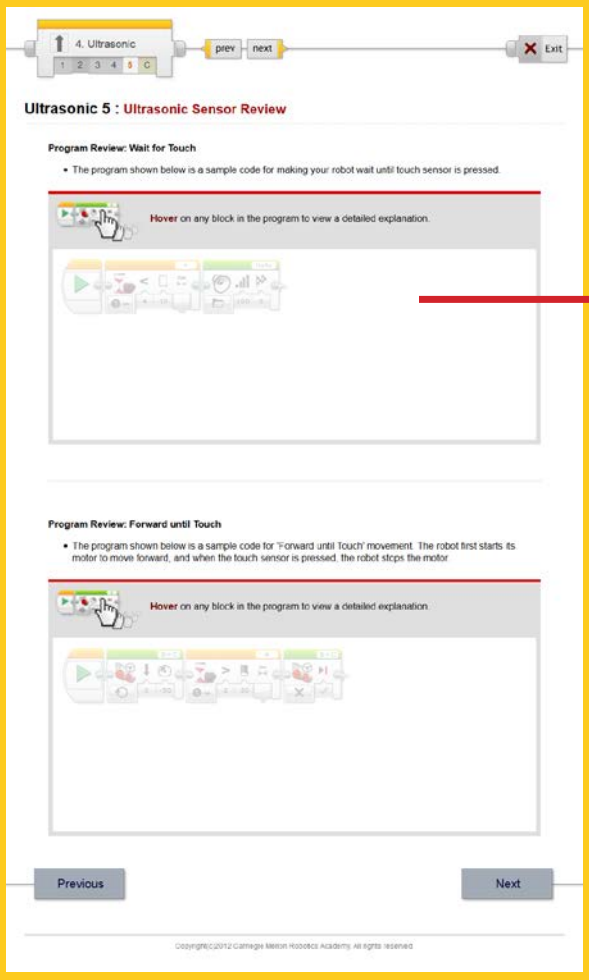
Mini-Challenge: Backward Until Far

Challenges students to adapt their behavior to move backwards until the robot is a certain distance away from an obstacle.

This activity is directly analogous to the “Forward Until Release” mini-challenge in the previous chapter, except that the robot needs to back up so that it gets farther from the wall (rather than continuing to get nearer).

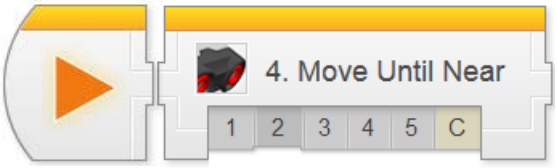


Ultrasonic Sensor

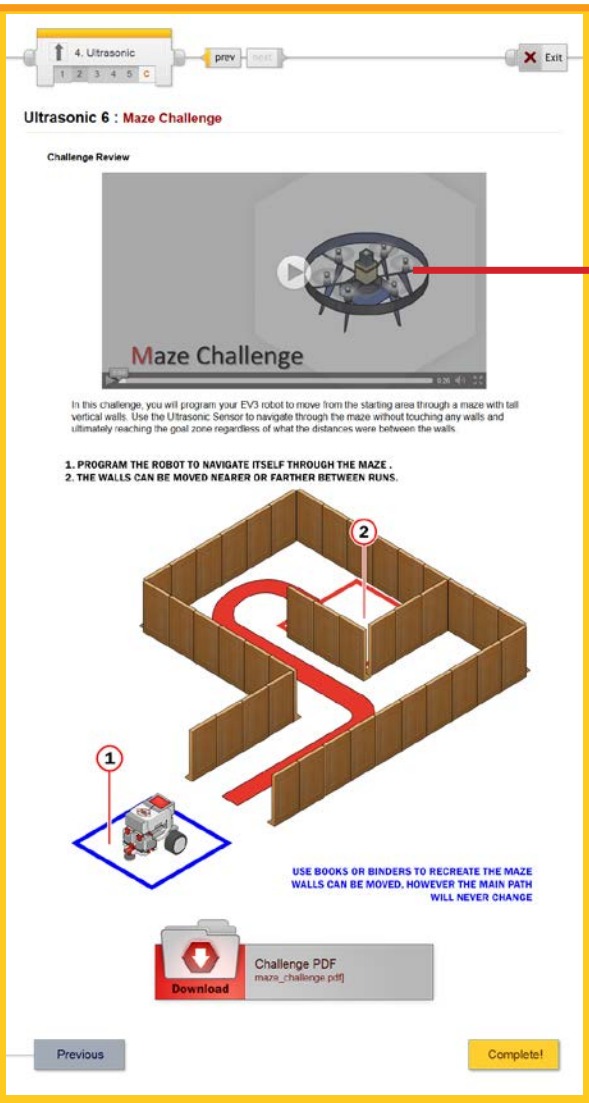


Ultrasonic 5: Ultrasonic Review

Expanded explanations for both in-video programs can be found on this page.



Ultrasonic Sensor

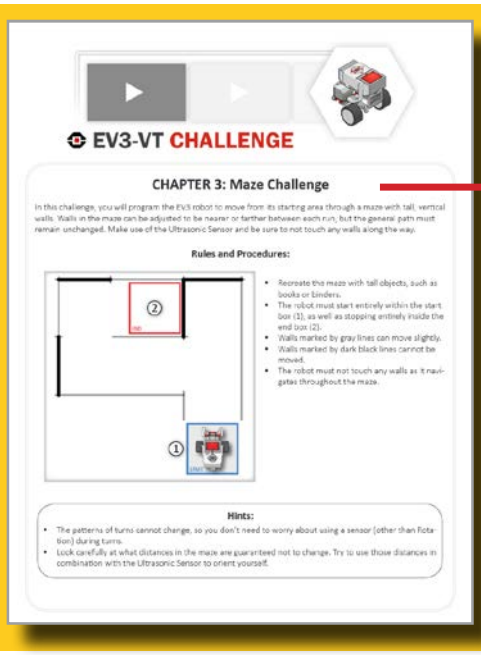


Maze Challenge

This step lays out the details for the Maze Challenge. Students should work in their teams to complete the challenge objectives.

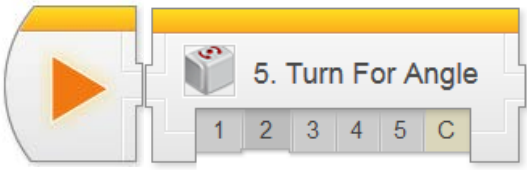
The route show in the picture is the only real route to the goal. However, certain walls are allowed to move, or even be removed (see PDF instructions).

The robot must use the “guaranteed” walls to find its way through the maze without touching any walls.



Maze Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Introduction to the Gyro Sensor Unit

Sensors > Turn for Angle Chapter

In Turn for Angle, students program a robot to turn until its Gyro Sensor detects a heading change greater than a certain “threshold”. This is the same pattern used with Forward Until Touch and Forward Until Near, but with turning.

Due to the nature of the Gyro Sensor, and of turning motion in general, a small amount of “overshoot” in the turn will occur. The programming in this lesson is broken into two steps to expilcitly address and accommodate this phenomenon.

Key Concepts: Gyro Sensor, Accommodating Sensor Error

- **Gyro 1: Introduction to Sensors**
  Introduces the real-world robot (Autonomous Golf Course Mower), and the challenge modeled after it (Mower Challenge)

- **Gyro 2: Robot Config**
  Contains building and setup instructions for the rest of the chapter

- **Gyro 3: Turn to Angle (Part 1)**
  Uses a variant of the Forward Until Pattern that turns instead of moving straight, and uses the Gyro Sensor to detect the change in heading. Program will work, but not be as accurate as desired.

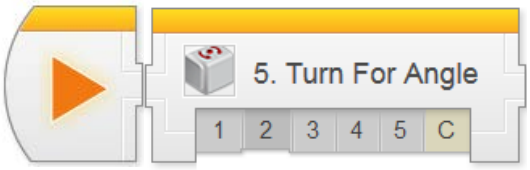
- **Gyro 4: Turn to Angle (Part 2)**
  Discusses physical factors that contribute to the inaccuracy of the original motion, and strategies to mitigate the issue.

- **Gyro 5: Review**
  Explains sample solutions to mini-challenges from this chapter

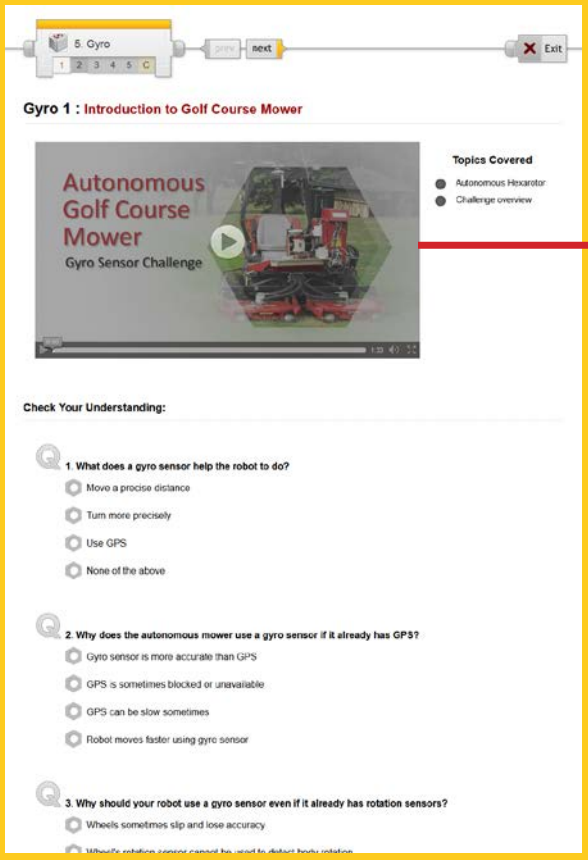
- **Mower Challenge**
  Requires students to program a Gyro Sensor-based behavior that will drive the robot over all parts of a rectangular surface, even if it loses traction partway through a turn.

Hints:

- The Gyro Sensor, like all real-world devices, is imperfect. This lesson uses that imperfection as a learning opportunity.



Gyro Sensor



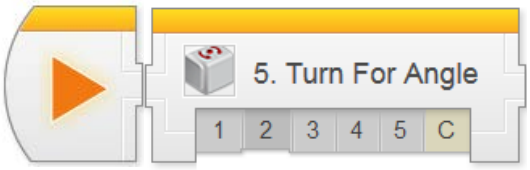
Gyro 1: Introduction

Introduces the Autonomous Golf Course Mower and Challenge

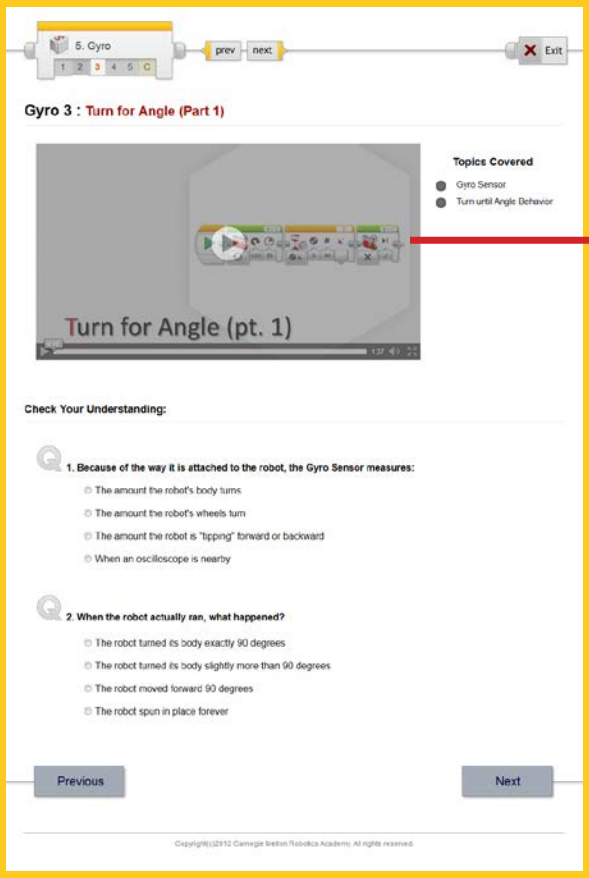
Gyro 2: Robot Config

This chapter uses the driving base model, plus a Gyro Sensor.

Sensors from the previous chapter can be left on or removed as convenient.



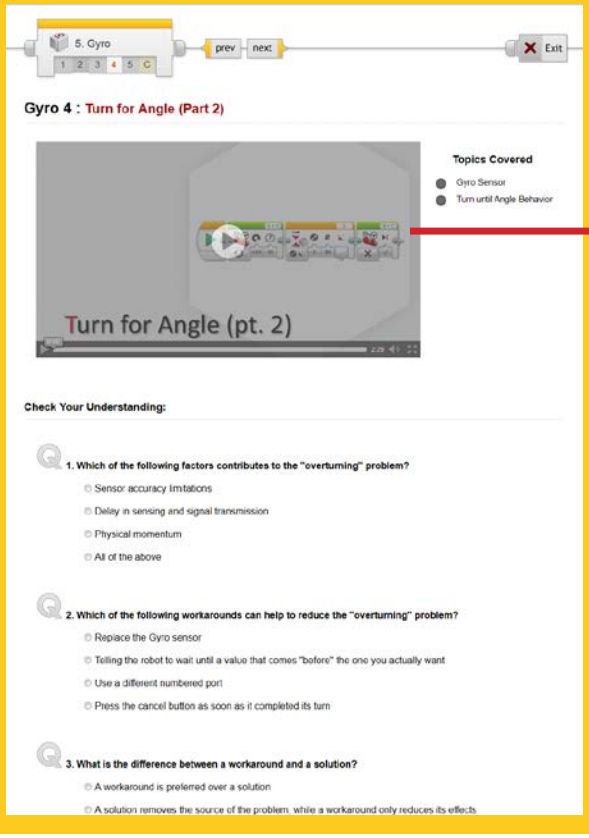
Gyro Sensor



Gyro 3: Turn for Angle (Part 1)

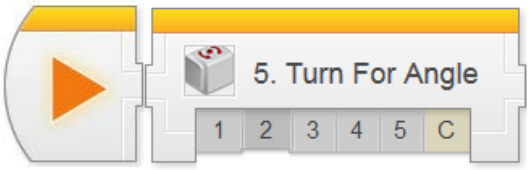
This step introduces Turn for Angle in the way that it would be expected to work, following the Forward Until pattern.

Due to a number of unavoidable physical factors, the robot will noticeably "overturn" the target angle. This phenomenon is addressed in the next step.

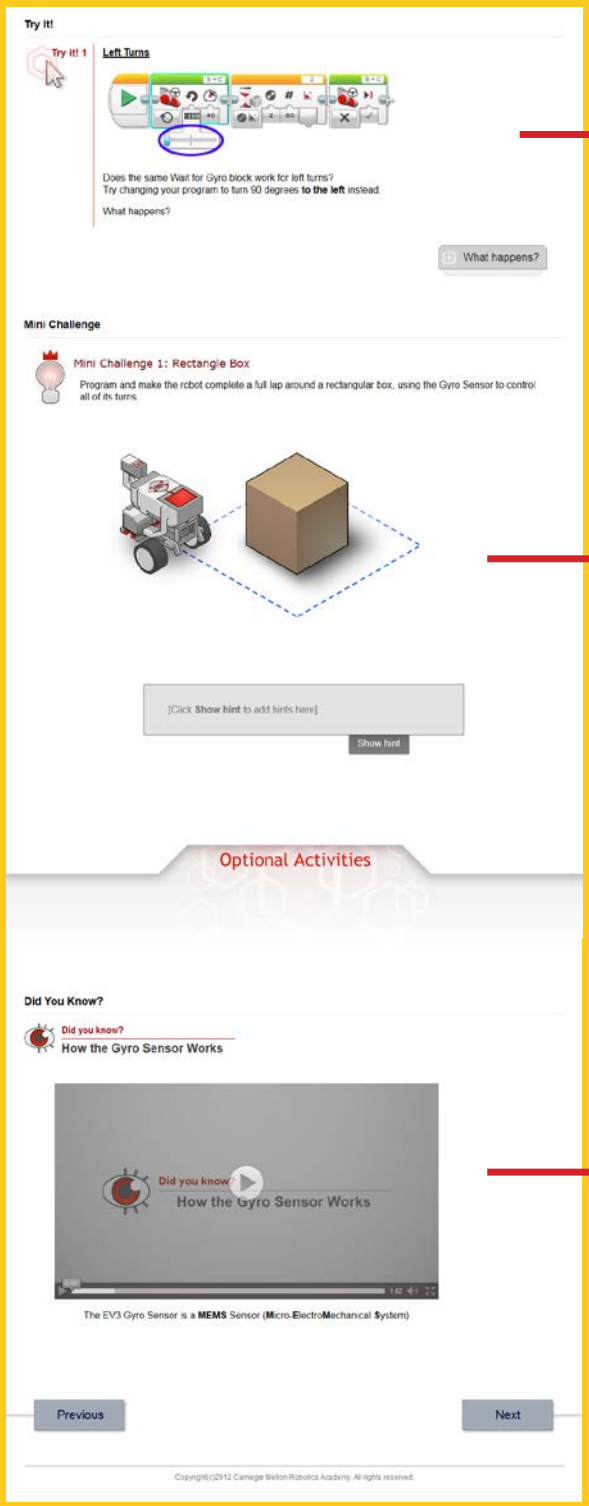


Gyro 4: Turn for Angle (Part 2)

This step discusses the reasons for the seemingly strange behavior of the Gyro Sensor in the previous step, and how this can lead to a workaround (and what a workaround is, compared to a solution).



Gyro Sensor



Gyro 4 (continued)

Try It: Left Turns

Prompts students to try using the Gyro Sensor to perform a left turn.

Since the Wait For Gyro Block is in Change mode, left and right turns both work – going 90 degrees in either direction is still a “change”. This is not true in Compare mode, however, as Compare mode uses compass headings that will go negative if the robot turns left (and thus reach -90, not 90).

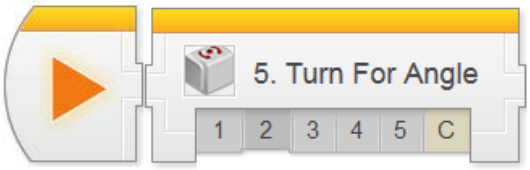
Mini-Challenge: Rectangle Box

Challenges students to make the robot run around a rectangular (or square) object, using the Gyro Sensor to make each turn.

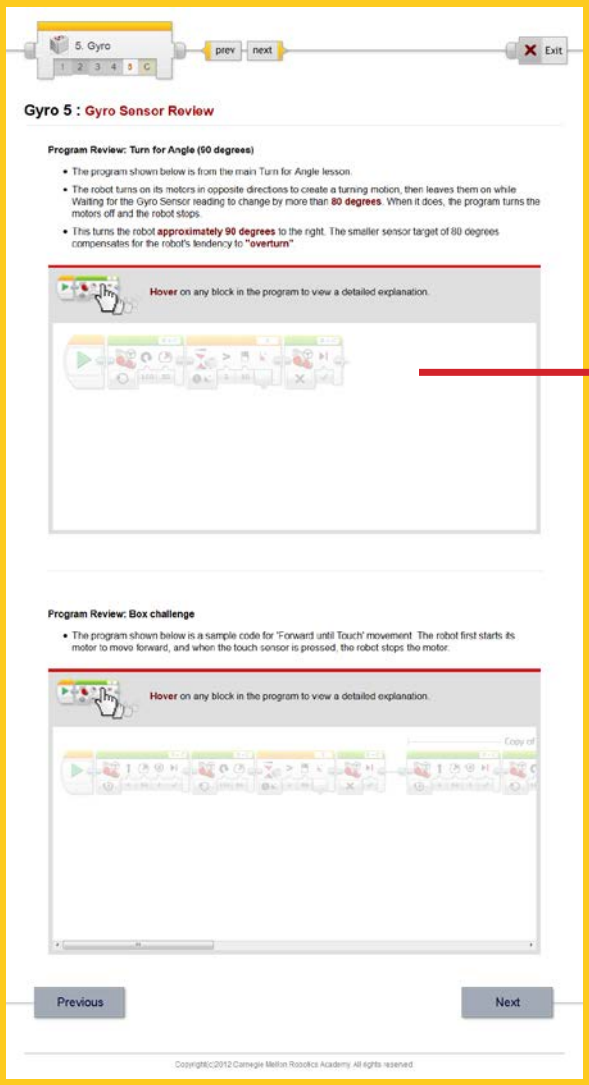
As with most mini-challenges, this task is very closely related to what students will be expected to do during the Challenge.

[Optional] How the Gyro Sensor Works

Explanation of the physical principle of operation of the Gyro Sensor.

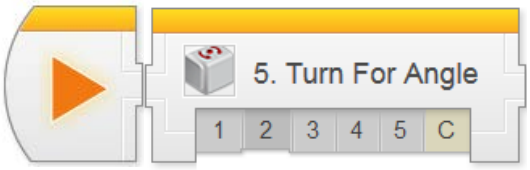


Gyro Sensor

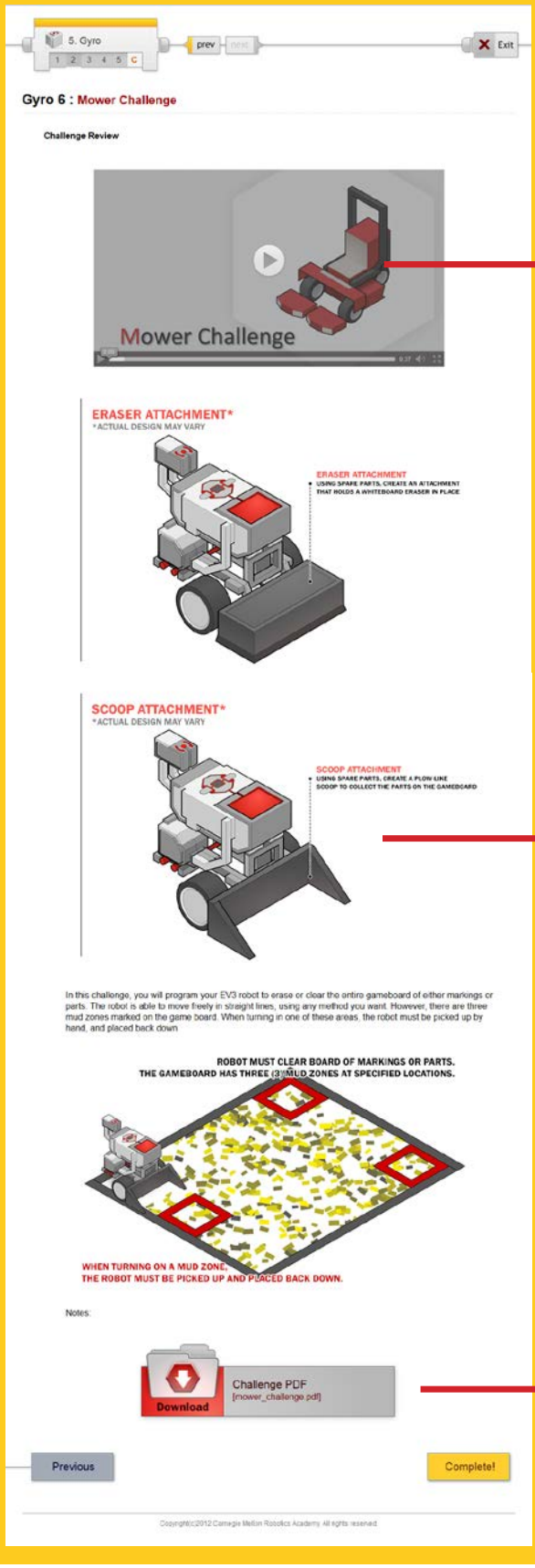


Gyro 5: Review

Sample solutions and explanations for both mini-challenges can be found on this page.



Gyro Sensor



Mower Challenge

This step lays out the details for the Mower Challenge. Students should work in their teams to complete the challenge objectives.

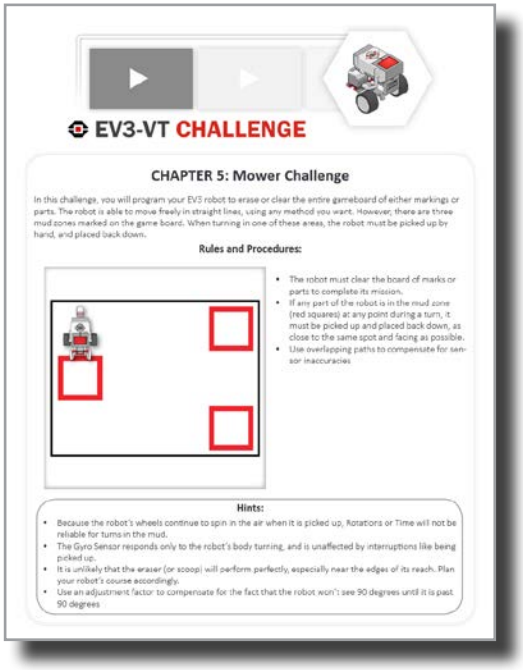
The “mud” zones (red squares) are designed to make Wheel Rotations-based solutions impossible. The robot should be picked up, held briefly in the air (with the wheels still spinning), then placed back down when the robot turns on top of a mud patch.

The mud zones are positioned so the robot will have to turn while on top of at least one.

If you have a game board surface that erases cleanly, the eraser version of the board may work better. If not, use the loose-parts version, but make allowances for a large number of parts rolling onto the floor.

Mower Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Introduction to the Color Sensor Unit

Sensors > Move Until Color Chapter

In Move Until Color, students program a robot to wait until its Color Sensor detects an object of a certain color before proceeding with other commands. This is combined with Motors On and Motors Off to produce a Forward Until behavior parallel to the ones using Touch and Ultrasonic Sonar in the previous chapter.

Key Concepts: Color Sensor, Forward Until Pattern

- **Color 1: Introduction to Sensors**
  Introduces the real-world robot (Autonomous Motor Vehicle), and the challenge modeled after it (Traffic Light Challenge)

- **Color 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter

- **Color 3: Wait for Green**
  Uses the Wait for Color Block to make a robot wait for the Color Sensor to detect a green object in front of it before moving

- **Color 4: Forward until Red**
  Combines Motor On and Motor Off commands with Wait for Color to make the robot move forward until the Color Sensor detects a red object

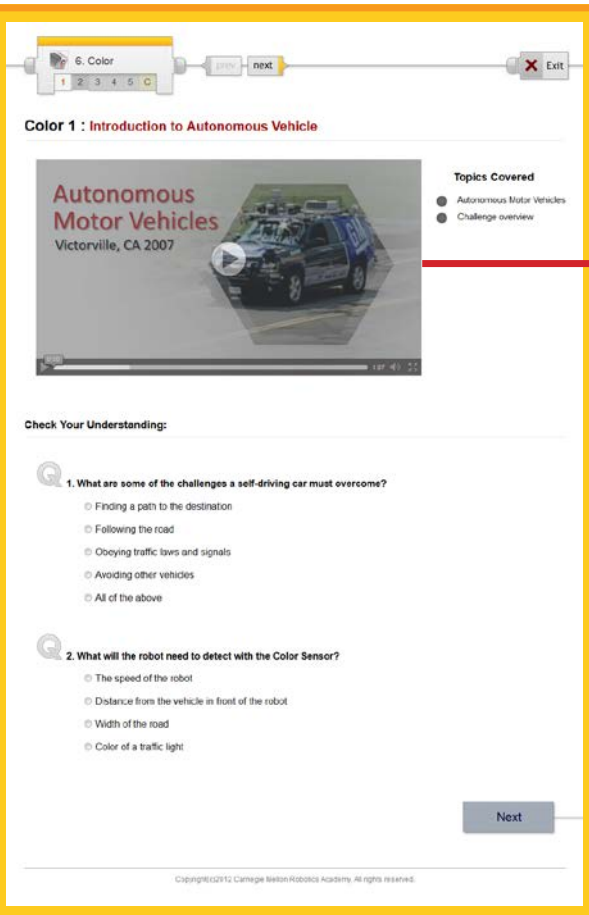
- **Color 5: Review**
  Explains sample solutions to mini-challenges from this chapter

- **Traffic Lights Challenge**
  Requires students to program a robot to move through three traffic signals, each of which may be red or green at random

Hints:

- The main programming pattern in this chapter is very similar to the previous chapters, but the logical complexity of the Challenge solution is higher. Students must continue improving their understanding of the.ways in which behaviors relate, to produce the best (and simplest) possible solution

Color Sensor



Color 1: Introduction

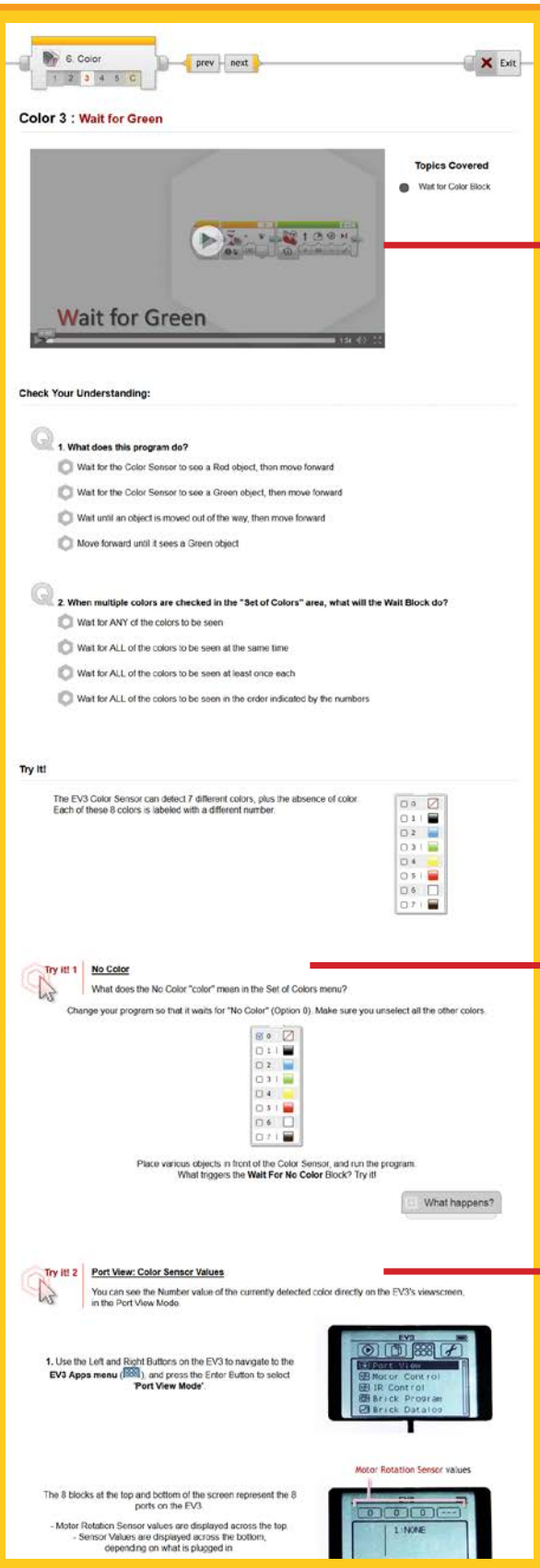
Introduces the Autonomous Motor Vehicle and the Traffic Light Challenge.

Color 2: Robot Config

For the video portion of this chapter, the Color Sensor will be mounted in the default location. It will need to be moved to the arm for the Challenge, as it will collide with the traffic signal otherwise.

If this causes an issue, you can change the rules of the Challenge to permit the student to move the traffic signal out of the way rather than moving the sensor to avoid it.

Color Sensor



Color 3: Wait for Green

This step introduces the Wait for Color Block. This step is structurally similar to the other Wait For behaviors – the Wait For Color Block will wait until ANY ONE of the selected colors is detected.

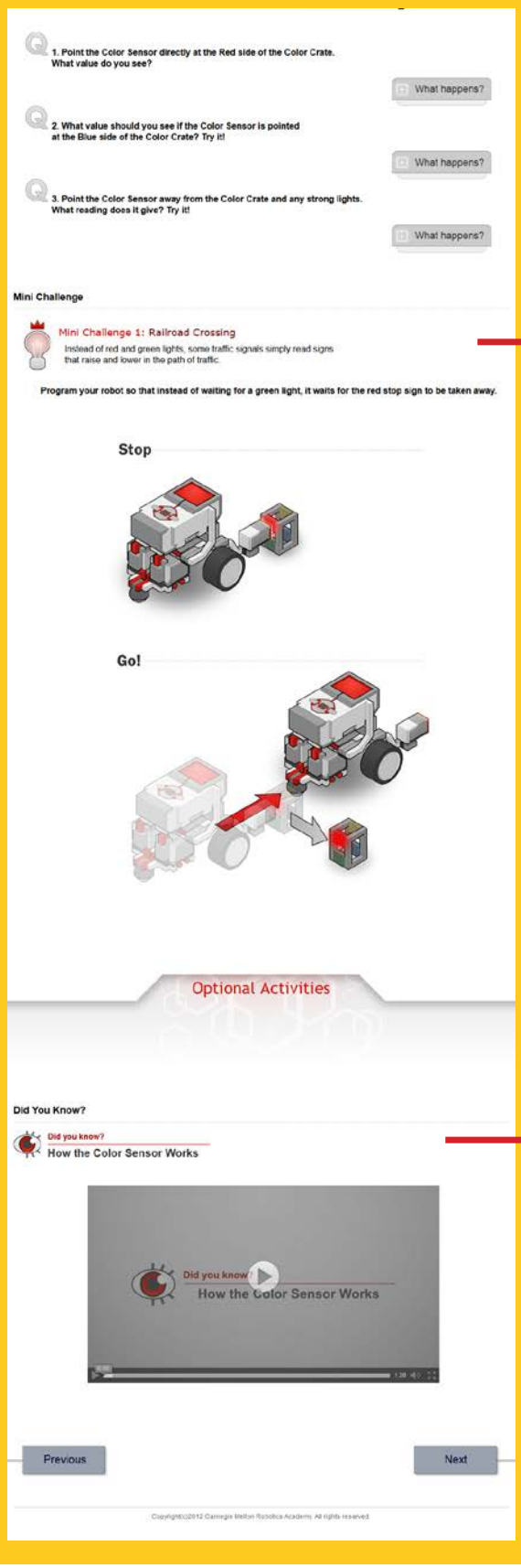
Try It! 1: No Color

The “No Color” option represents the state where the Color Sensor is not getting a reading from a surface in front of it.

Try It! 2: Port View Color Sensor Values

The Port View mode on the EV3 on-screen menus don’t call colors by name. Instead, they use the numeric codes shown next to the numbers in the checklist.

Color Sensor



Color 3 (continued)

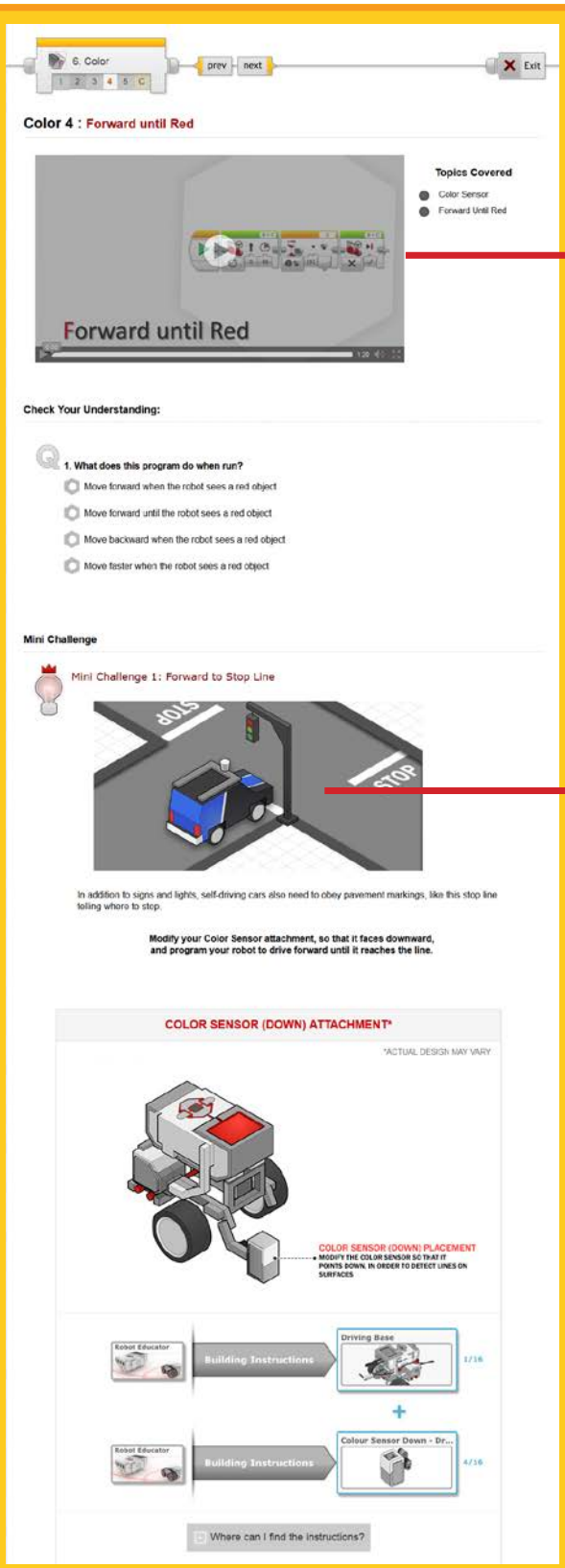
Mini-Challenge: Railroad Crossing

Instead of waiting for Green to go, Wait for "No Color".

[Optional] How the Color Sensor Works

The Color Sensor is actually three different sensors: a Red Sensor, a Blue Sensor, and a Green Sensor. By measuring the relative amounts of red, green, and blue light that a surface reflects, the sensor can tell the color of the surface.

Color Sensor



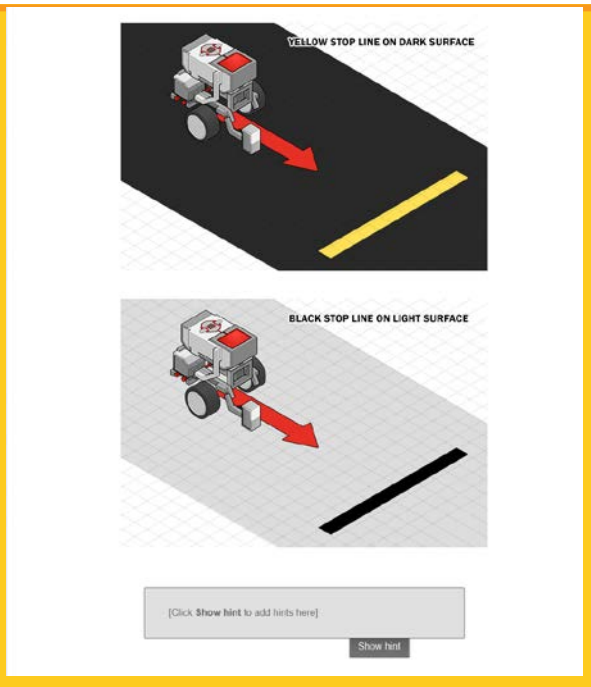
Color 4: Forward until Red

This step adds the Motor On and Motor Off commands to make a Forward Until behavior like the ones from previous chapters.

Mini-Challenge: Forward to Stop Line

Face the Light Sensor down at the ground to detect colored lines on the table surface. This is a common use of the Color Sensor in robotics competitions.

Color Sensor



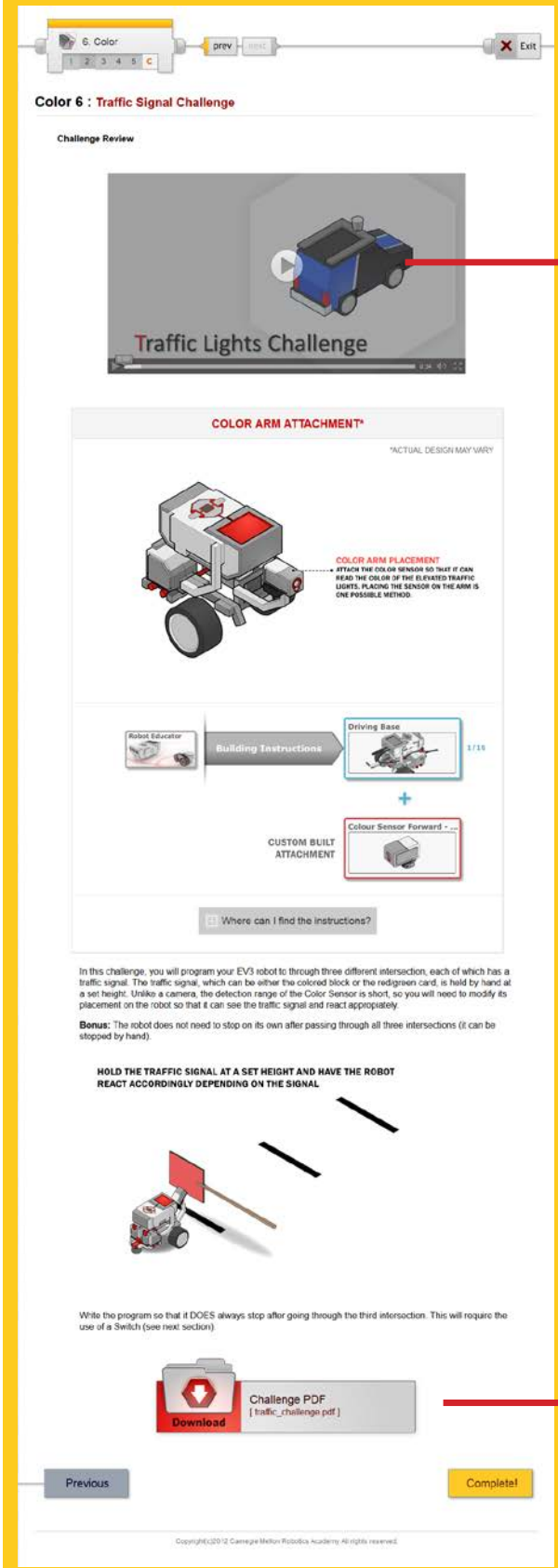
Color 4 (continued)

Now try the challenge on other surfaces with other colors!

Color 5: Color Sensor Review

Expanded explanations for the Wait for Green program and the Forward to Stop Line program can be found on this page.

Color Sensor



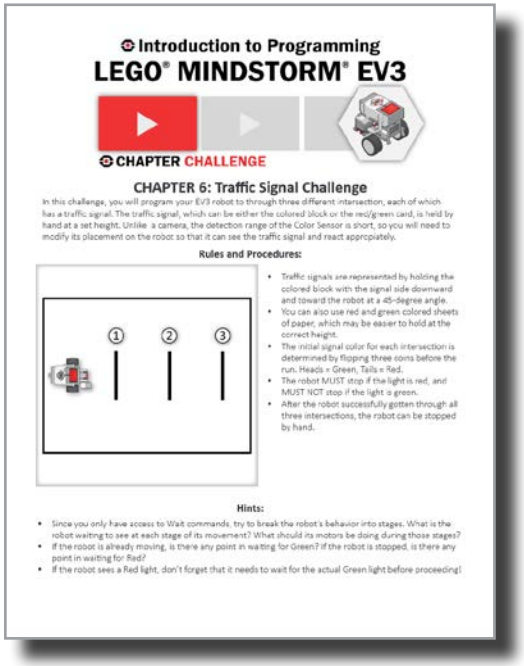
Traffic Signal Challenge

This step lays out the details for the Traffic Signal Challenge. Students should work in their teams to complete the challenge objectives.

Teams will need to reposition the Color Sensor to the robot's arm so that it can reach high enough to see the traffic signals, and also move the sensor out of the way afterward. If this is inconvenient, modify the challenge rules to allow the signal to be moved out of the way.

Traffic Signal Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Introduction to Robot Decisions - Loops

Decisions > Loops Chapter

In the Decisions Unit, students begin to work with Program Flow more directly. Loops give programmers the ability to repeat commands; many students already know this. However, the real power of Loops lies with the capability to decide whether to repeat or not.

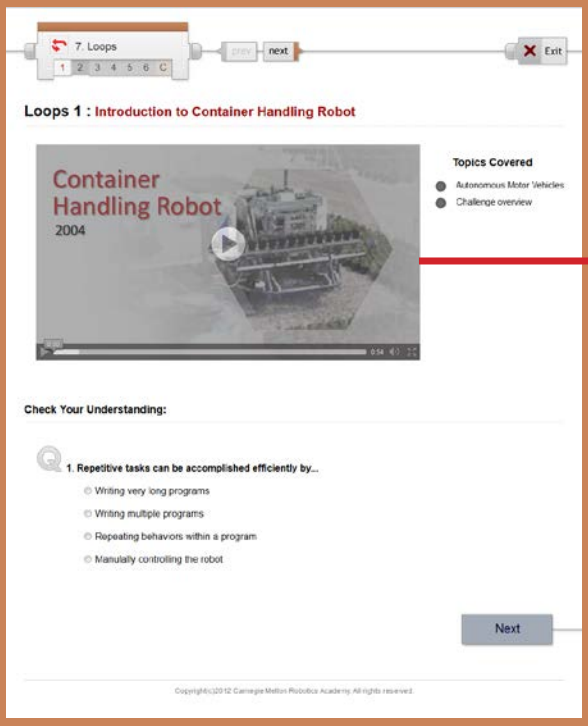
Key Concepts: Program Flow, Loops, Conditional Loops

- **Loops 1: Introduction to the Container Handling Robot**
  Introduces the real-world robot (Container Handling Robot), and the challenge modeled after it (Container Handling Challenge)
- **Loops 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter
- **Loops 3: Looped Movement**
  Uses a simple (infinte) loop to make the robot move back and forth repeatedly
- **Loops 4: Loop with Count Control**
  Sets the Loop to repeat only a set number of times
- **Loops 5: Loop with Count Control**
  Uses a Sensor to decide whether the Loop repeats or not at the end of each pass
- **Loops 6: Review**
  Explains sample solutions to mini-challenges from this chapter
- **Container Handling Challenge**
  Requires students to use loops and sensor control to program a robot to pick up a number of objects and move them back to a starting zone

Hints:

- The concept of repeating is simple, but it is important to begin building a broader mental model of Program Flow now so students can understand how Loops relate to Switches and Switch-Loops in the next chapters

Decisions - Loops



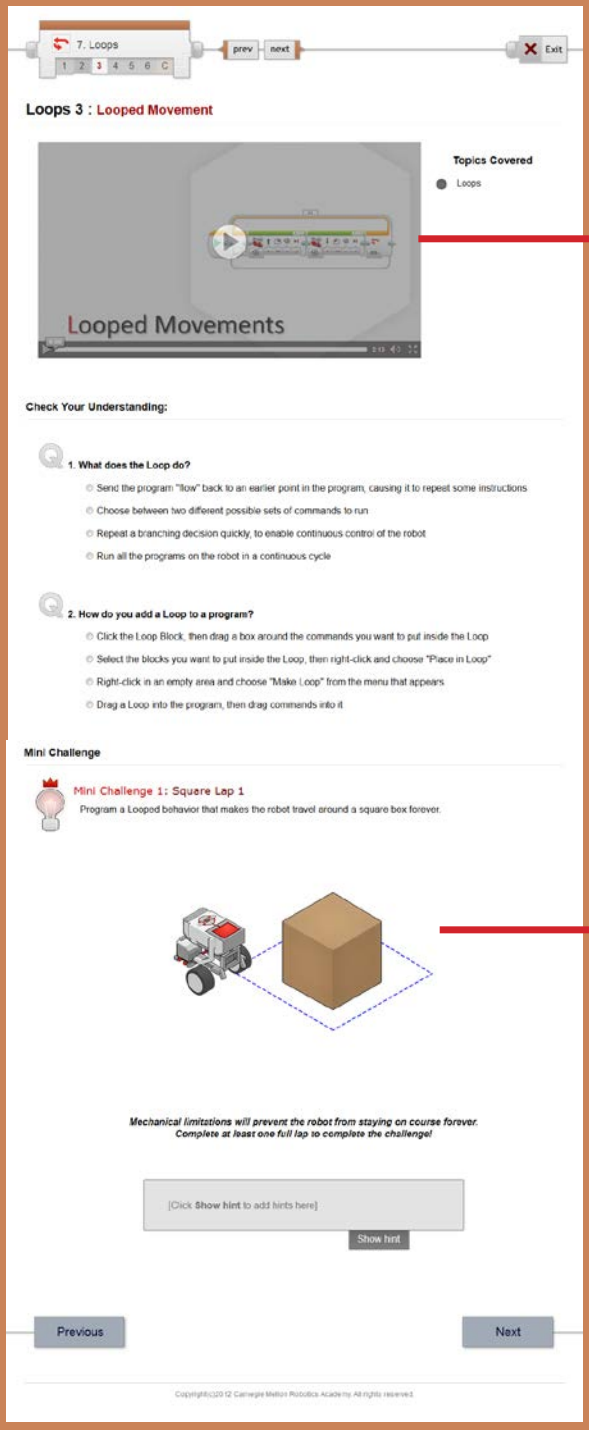
Loops 1: Introduction

Introduces the Container Handling Robot, the Container Handling Challenge, and Loops.

Loops 2: Robot Config

The robot for this chapter uses the Ultrasonic Sensor, and will eventually add the Color Sensor in the Challenge.

Decisions - Loops



Loops 3: Looped Movement

This step introduces Loops. The default loop sends Program Flow back to the beginning of the Loop every time it reaches the end (i.e. repeats infinitely).

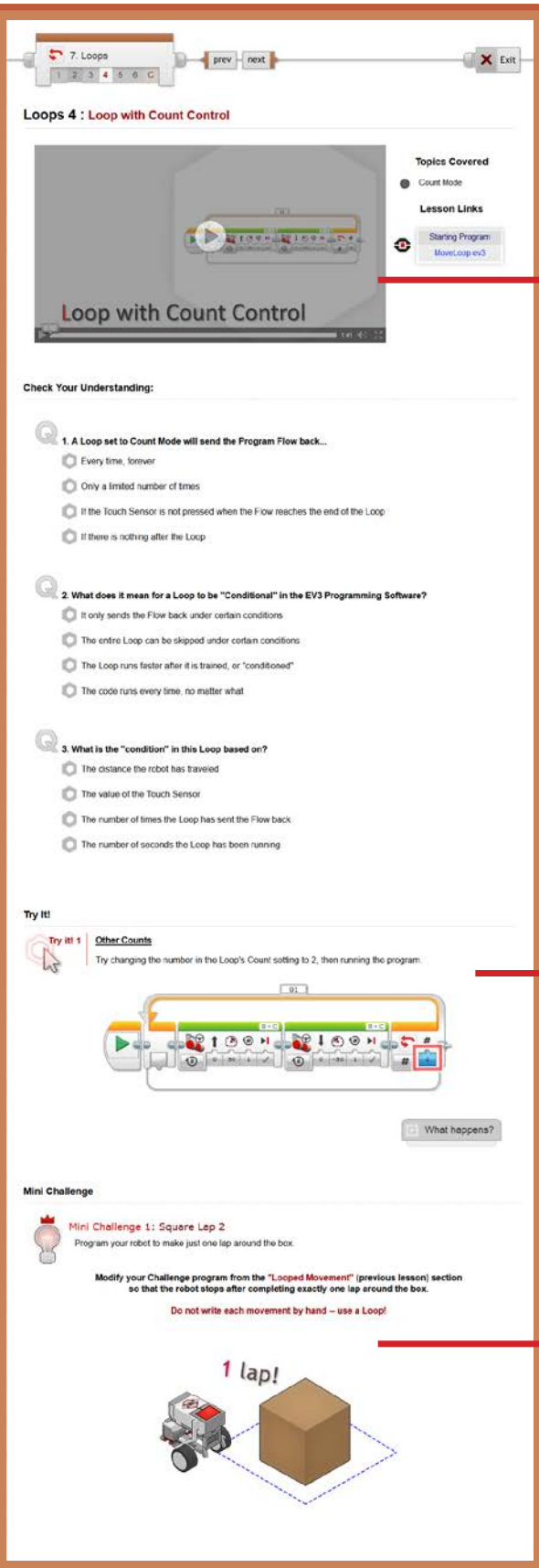
The Program Flow-based explanation is used because it explains the action of Loops (and later Switches) in a systematic way that avoids common misconceptions.

Mini-Challenge: Square Lap 1

Challenges students to modify the commands inside the loop so the robot makes its way around a square box.

The key to this challenge lies in the symmetry of the box: you can move the same distance for each side, and turn 90 degrees after each movement.

Decisions - Loops



Loop 4: Loop with Count Control

This step introduces the idea that Loops can end, by using loops that only repeat a certain number of times.

Loops that only repeat sometimes are called Conditional Loops. In this step, “sometimes” is based on the loop count; in the next step, a Sensor will make the decision.

This program builds on the program from the previous step. The “Starting Program” linked to the right of the video provides a working copy of the previous step’s program if needed.

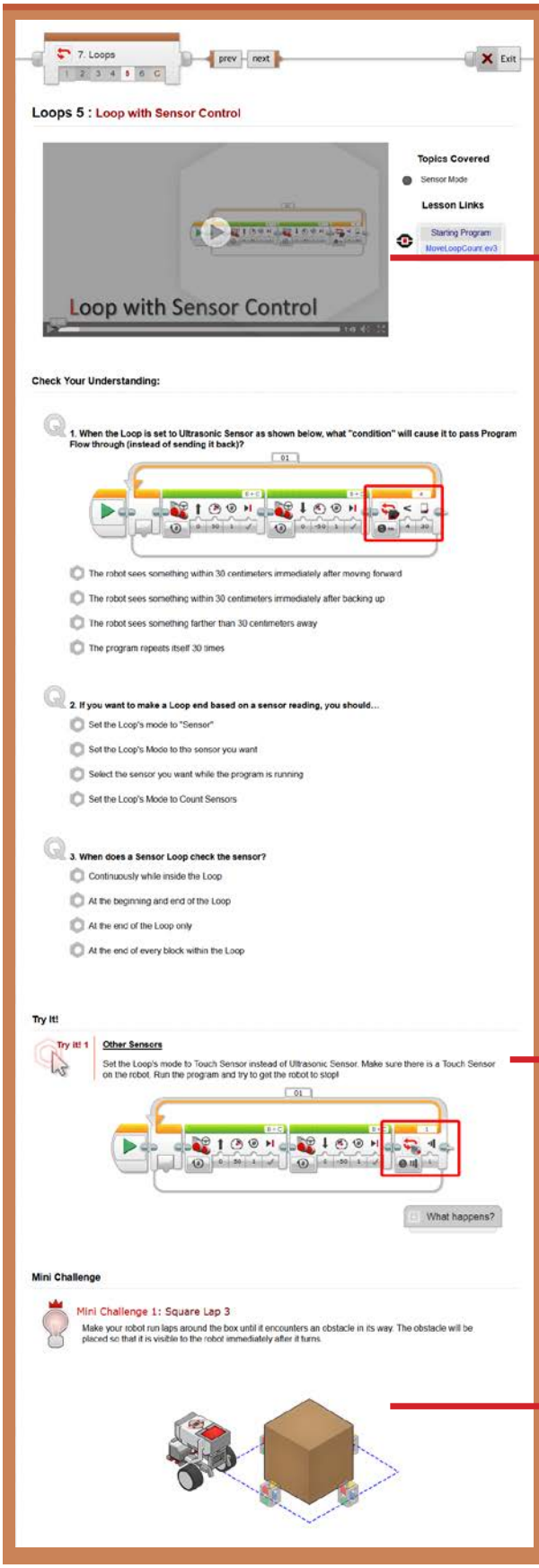
Try It!: Other Counts

Prompts students to use a different number of Counts in the Loop.

Mini-Challenge: Square Lap 2

Instead of looping forever, students are challenged to limit the lap-running behavior to a single full lap (4 sides of the box).

Decisions - Loops



Loops 5: Loop with Sensor Control

This step continues modifying the program from the previous steps by using a Sensor to decide whether to repeat or not.

There is a common misconception that a "Sensor-Controlled" Loop will continuously monitor the sensor and end the loop immediately when, for example, a threshold is reached.

However, that is not the case; the Sensor is only checked while the repeat-or-end decision is being made at the end of the Loop, not while the commands inside the Loop are running.

This program builds on the program from the previous step. The "Starting Program" linked to the right of the video provides a working copy of the previous step's program if needed.

Try It!: Other Sensors

Prompts students to try using the Touch Sensor to end the Loop instead of the Ultrasonic Sensor.

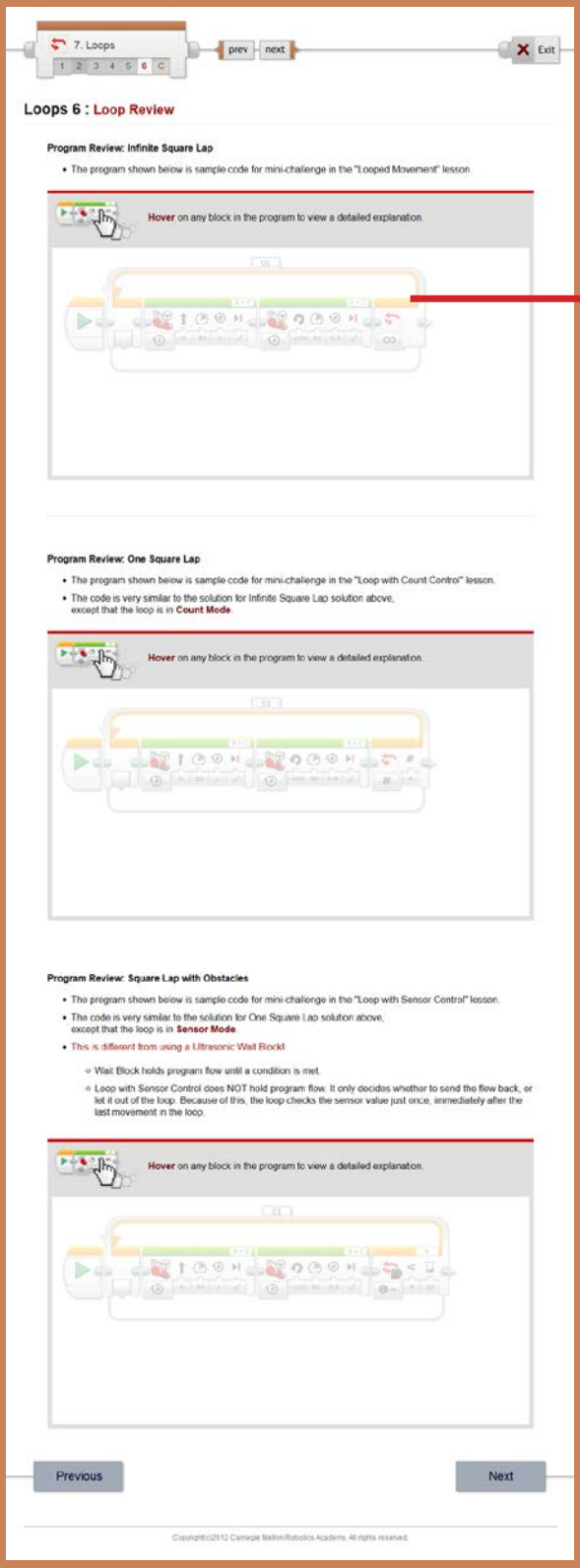
The same rules about the timing of sensor responsiveness still apply.

Mini-Challenge: Square Lap 3

Challenges students to adapt their Square Lap program to end based on an Ultrasonic Sensor value.

The program will only stop for obstacles that are visible to the robot when the Loop ends (typically just after turning).

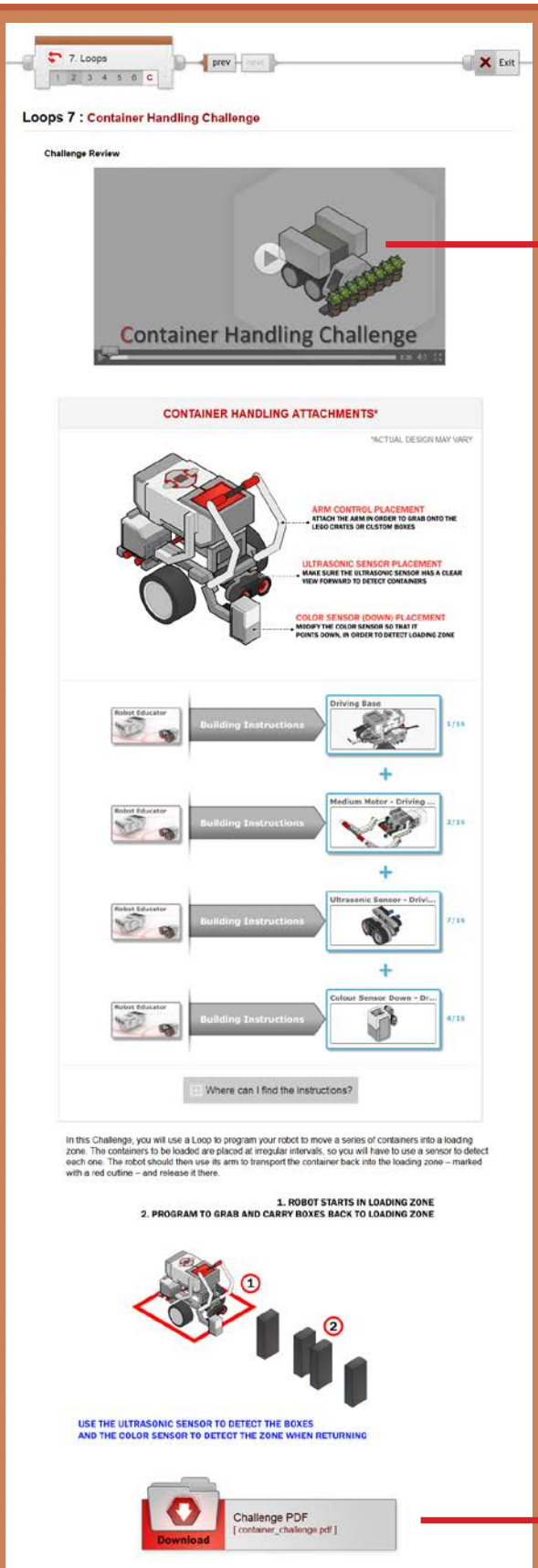
Decisions - Loops



Loops 6: Loop Review

Sample solutions and explanations for the mini-challenges in this chapter can be found on this page.

Decisions - Loops



Container Handling Challenge

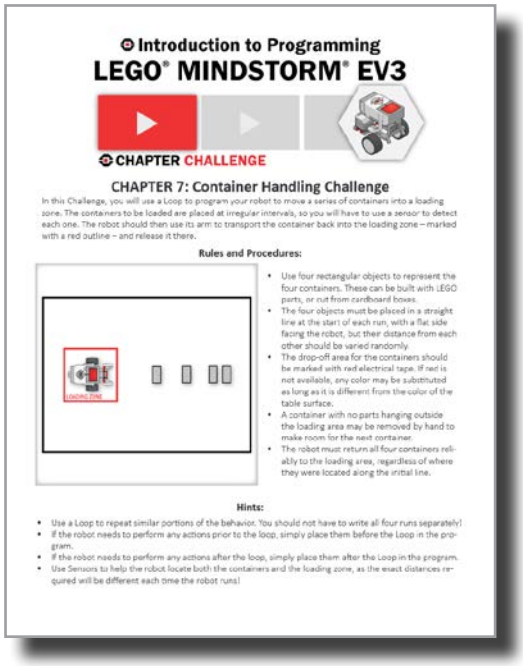
This step lays out the details for the Container Handling Challenge. Students should work in their teams to complete the challenge objectives.

As noted near the bottom of the page, the easiest method of solving the problem is to use Forward Until Near to get to the next object, Reverse Until Red to return to the starting area, and a Loop to repeat the behavior for all four containers.

Container objects should be large enough for the Ultrasonic Sensor to detect, but thin enough for the arm to close around. Erasers, toilet paper tubes, or cuttings from cardboard boxes or packing materials can all be good candidates. Be wary of sound-absorbing materials, however, which the Ultrasonic Sensor cannot detect.

Container Handling Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Introduction to Robot Decisions - Switches

Decisions > Switches Chapter

Switches and Loops have very different effects on Program Flow: whereas Loops could send Flow back to repeat commands, Switches force the robot to choose between alternative paths in the code. Like Conditional Loops, they typically make this decision based on Sensor feedback.

Switches are seldom seen alone in robotics programming, because robots very rarely make isolated, one-time decisions. It is far more common to put a Switch inside a Loop, to allow repeated decision-making.

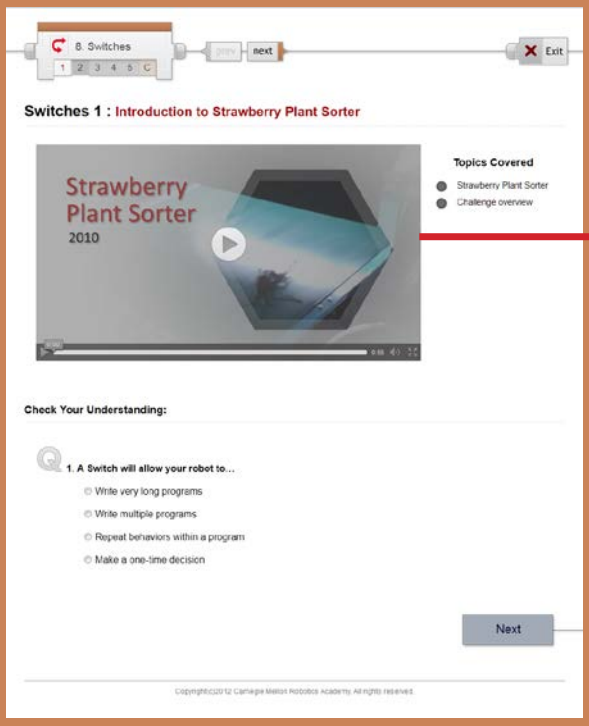
Key Concepts: Program Flow, Switches, Repeated Decisions (Switches in Loops)

- **Switches 1: Introduction to the Strawberry Plant Sorter**
  Introduces the real-world robot (Strawberry Plant Sorter), and the challenge modeled after it (Strawberry Plant Challenge)
- **Switches 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter
- **Switches 3: Move If Clear**
  Uses a single Ultrasonic Switch to make a decision: move forward if there is no object nearby, or turn to the side if there is
- **Switches 4: Looped Decision**
  Use a Loop to repeat the Switch-based behavior, allowing the robot to solve certain simple mazes
- **Switches 5: Review**
  Explains sample solutions to mini-challenges from this chapter
- **Strawberry Plant Challenge**
  Requires students to use repeated decisions and sensors to program a robot to sort a number of colored objects and move them back to a starting zone

Hints:

- Switches do not repeat unless a Loop makes them repeat (the same way a Loop makes any block repeat)

Decisions - Switches



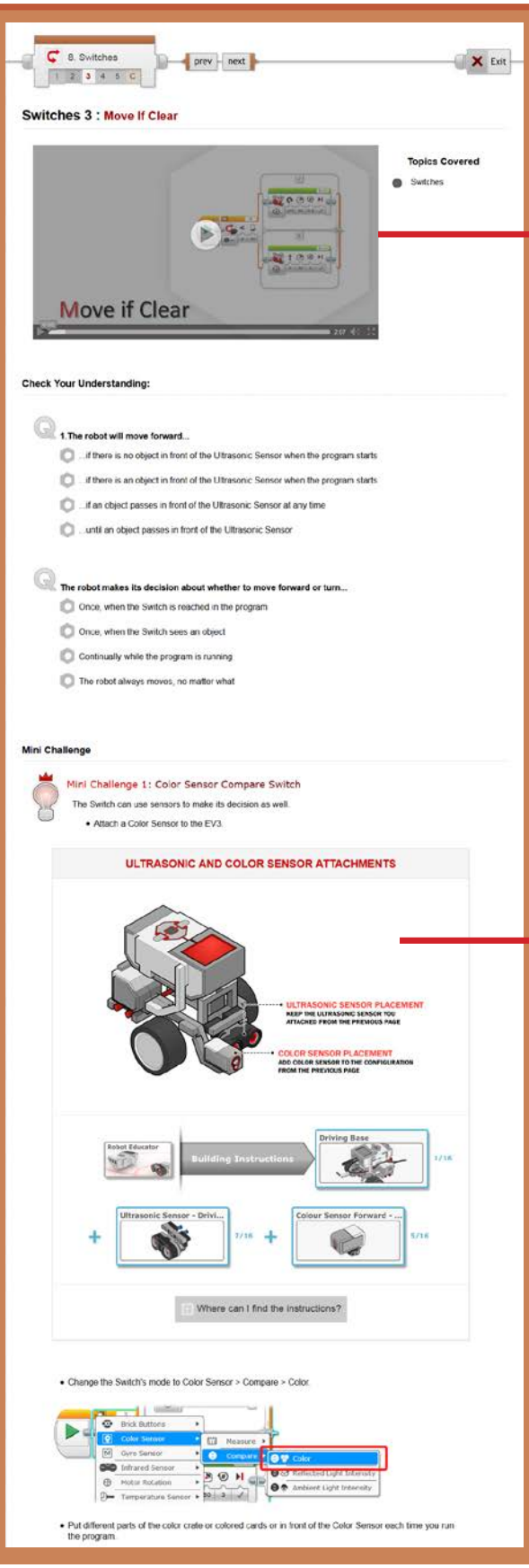
Switches 1: Introduction

Introduces the Strawberry Plant Sorter, the Strawberry Sorter Challenge, and Switches.

Switches 2: Robot Config

The robot for this chapter uses the Ultrasonic Sensor, and will eventually add the Color Sensor in the Challenge.

Decisions - Switches



Switches 3: Move If Clear

This step introduces Switches, using the Ultrasonic Sensor to choose between moving straight (if no object is in the way), or turning once (if an object is in the way).

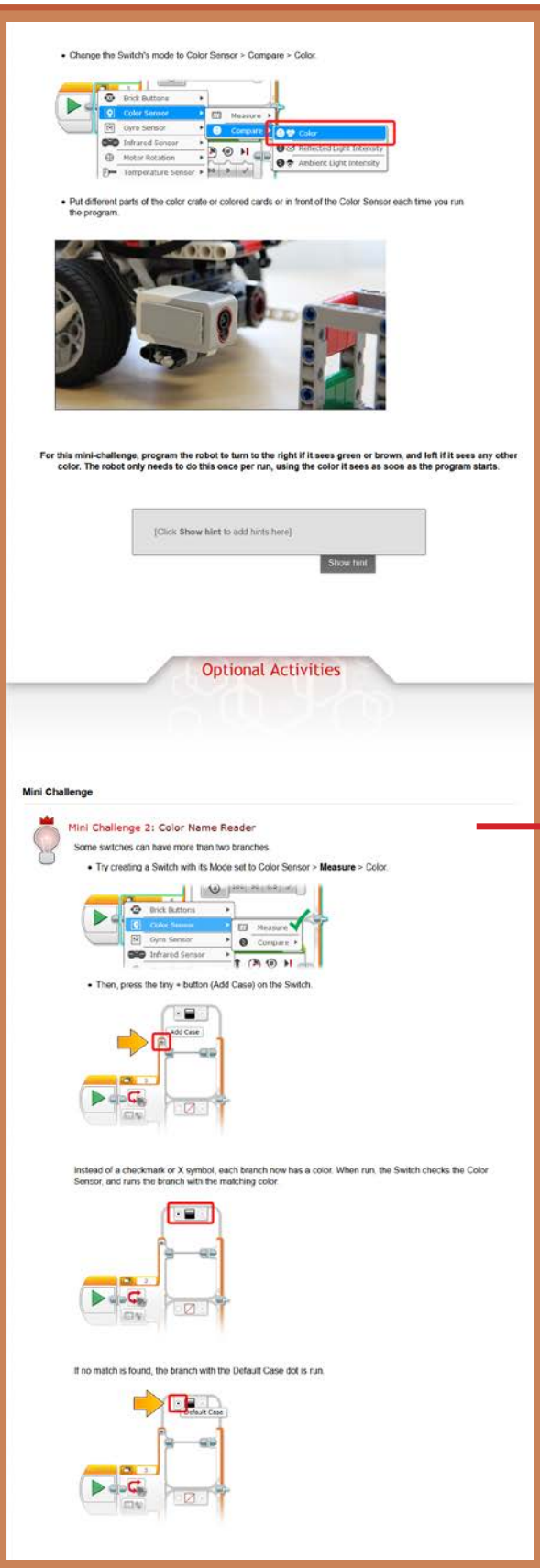
The Program Flow-based explanation is used because it explains the action of Switches in a systematic way that avoids common misconceptions, that also explains their relation to Loops.

Mini-Challenge: Color Sensor Compare Switch

Challenges students to use a Color Sensor to decide whether to turn left or right.

This behavior is directly reusable in the sorting task in the Chapter Challenge.

Decisions - Switches

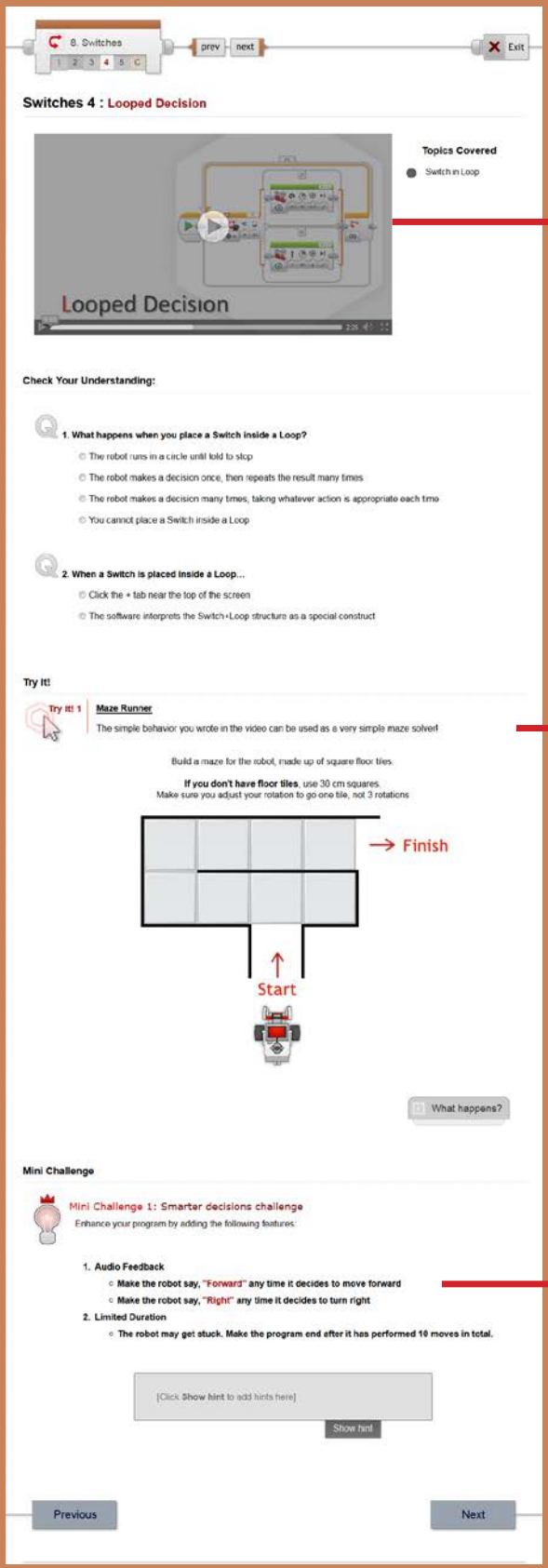


Switches 3 (continued)

[Optional] Mini-Challenge: Color Name Reader

Challenges students to investigate the Measure mode of the Color Sensor Switch, which supports multiple branches so the robot can act on several different colors differently, rather than having only two choices.

Decisions - Switches



Switches 4: Looped Decision

This step places the Switch in a more natural context: inside a Loop.

A single decision often occurs too quickly to be useful (or even noticeable). Repeating the decision gives the robot has the opportunity to perform more meaningful behaviors.

Most robot decision-making takes place in a structure resembling this one.

Try It!: Maze Runner

Prompts students to try running their straight-or-turn looped decision behavior in a maze. The robot will go straight whenever it can, and turn when there is a wall in front of it.

Students will need to adjust the distances traveled in the program to match the “tiles” in the maze.

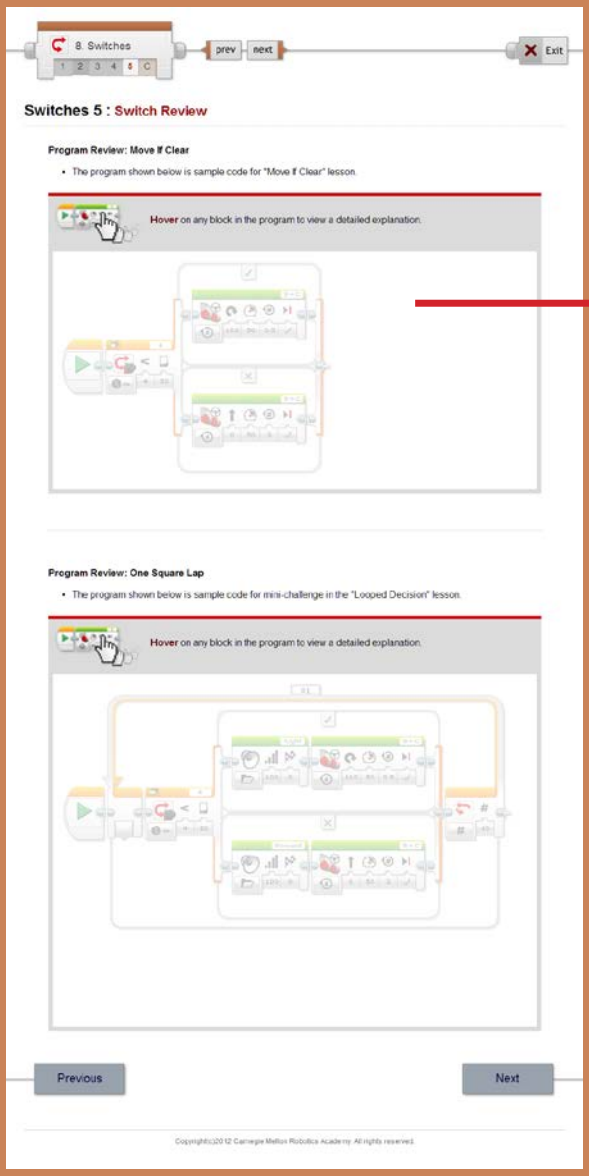
The walls in this maze should be raised walls (as opposed to marked on the ground). Use textbooks or other free-standing obstacles if possible. If “thin” walls are not available, you can use boxes and push the “top” row back one tile to create a “C”-shaped maze.

Mini-Challenge: Smarter Decisions

Challenges students to add features to different parts of their program.

Students must think about where to add each command, which focuses attention on the role that each part of the program plays.

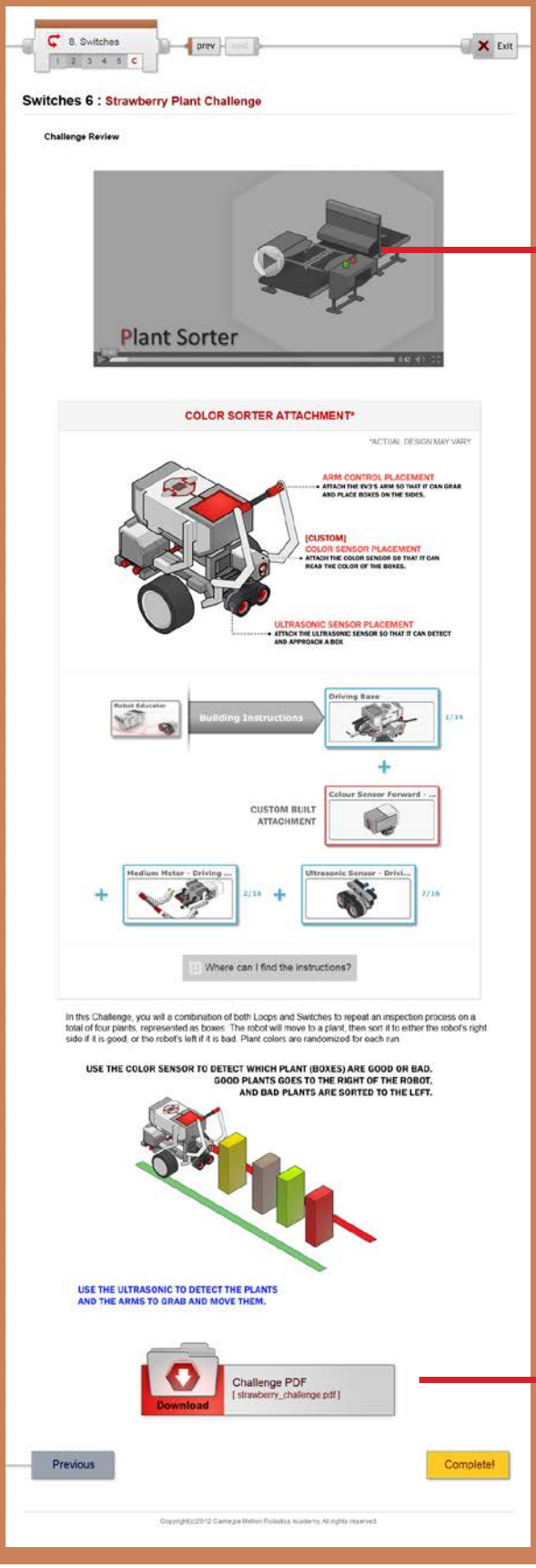
Decisions - Switches



Switches 6: Switches Review

Sample solutions and explanations for the mini-challenges in this chapter can be found on this page.

Decisions - Switches



Strawberry Plant Challenge

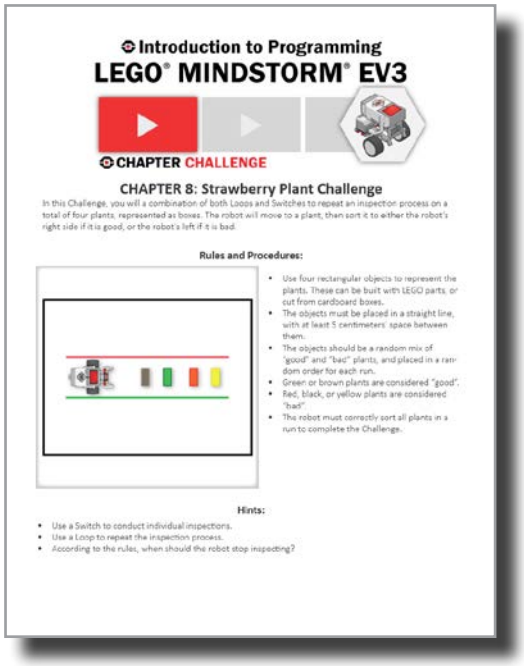
This step lays out the details for the Strawberry Sorter Challenge. Students should work in their teams to complete the challenge objectives.

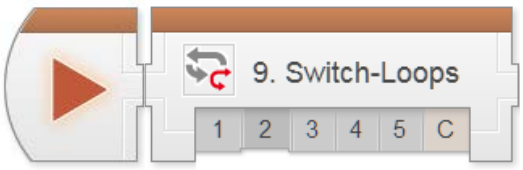
The robot must sort four plants to the correct side based on each plant's color. The good-or-bad decision should immediately suggest a Switch-based decision, and the fact that there are four objects should suggest a Repeated Decision (Switch in a Loop).

The same objects used in the Loops Chapter's Container Handling Challenge can be used for this Challenge. Add colored paper around or on the sides of each object.

Strawberry Plant Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.





Introduction to Robot Decisions - Switch-Loops

Decisions > Switch-Loops Chapter

Switch-Loops are actually just Switches inside Loops, the same pattern we called Repeated Decisions in the last chapter. However, if a decision-response cycle is repeated quickly enough, it approaches a “continuous” level of responsiveness.

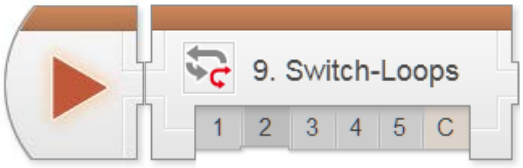
By analogy, a movie looks like it’s moving smoothly – “continuously” – even though it’s really made of still images, because many frames go by very quickly (24 per second). If a robot updates its motor powers very quickly in response to sensor feedback, the robot looks like it’s responding “continuously”.

Key Concepts: Program Flow, Rapidly Repeated Decisions = “Continuous” Control

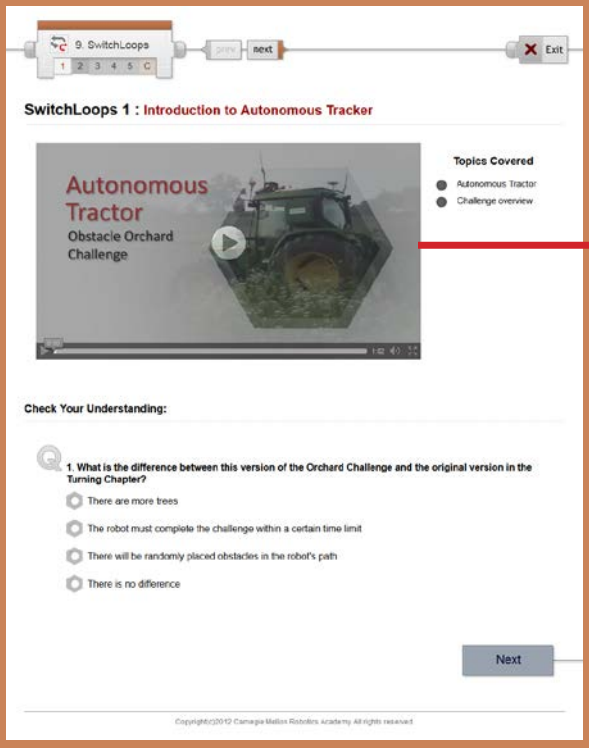
- **Switch-Loops 1: Introduction to the Autonomous Tractor**
  Re-introduces the real-world robot (Autonomous Tractor), from the Turning Chapter, and the new challenge modeled after it (Obstacle Orchard Challenge)
- **Switch-Loops 2: Robot Configuration**
  Contains building and setup instructions for the rest of the chapter
- **Switch-Loops 3: Obstacle Detection Failures**
  Shows two “intuitive” attempts to add obstacle detection using existing techniques, both of which fail
- **Switch-Loops 4: Obstacle Detection**
  Uses rapid Repeated Decisions to create a working Obstacle Detection program
- **Switch-Loops 5: Review**
  Explains sample solutions to mini-challenges from this chapter
- **Obstacle Orchard Challenge**
  Requires students to use Obstacle Detection to complete the Orchard Challenge with the added element of obstacles

Hints:

- Switches inside Loops were already used in the last chapter (as “Repeated Decisions”). The important distinction in this chapter is that “Continuous” behaviors require a rapidly-repeating loop, which the “Discrete” movement responses in the previous chapter did not maintain.



Decisions - Switch-Loops

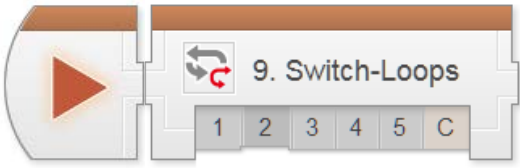


Switch-Loops 1: Introduction

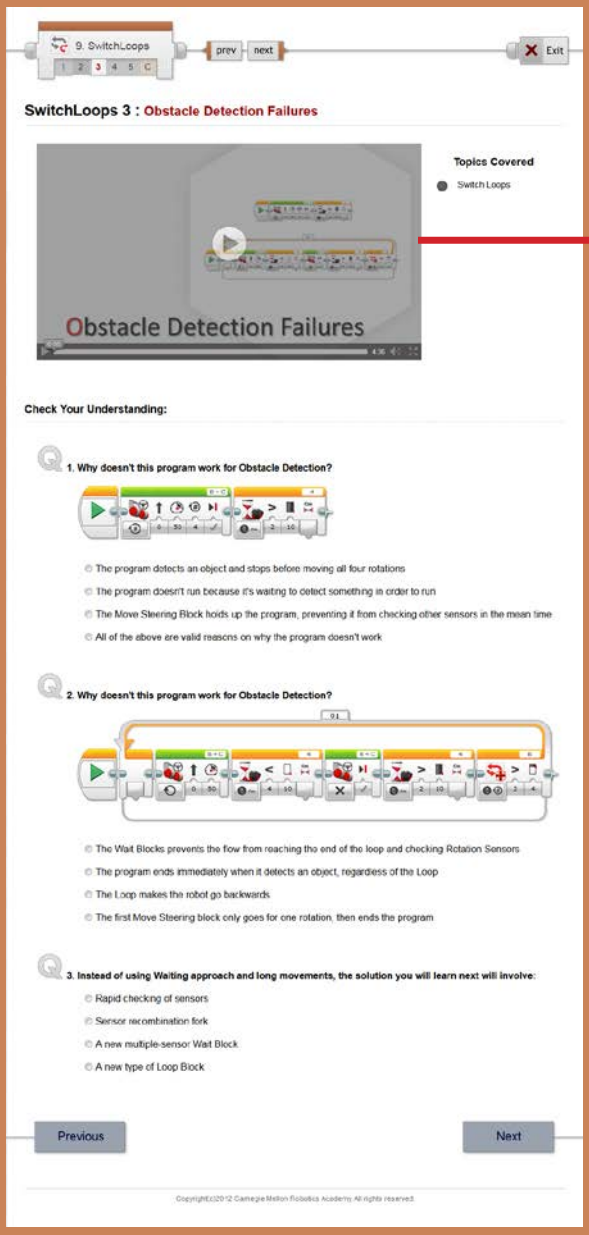
Re-introduces the Autonomous Tractor, and introduces the Obstacle Orchard Challenge, and Switch-Loops.

Switch-Loops 2: Robot Config

The robot for this chapter uses the Ultrasonic Sensor.



Decisions - Switch-Loops

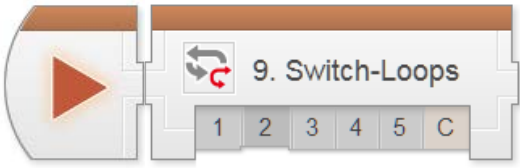


Switch-Loops 3: Failures

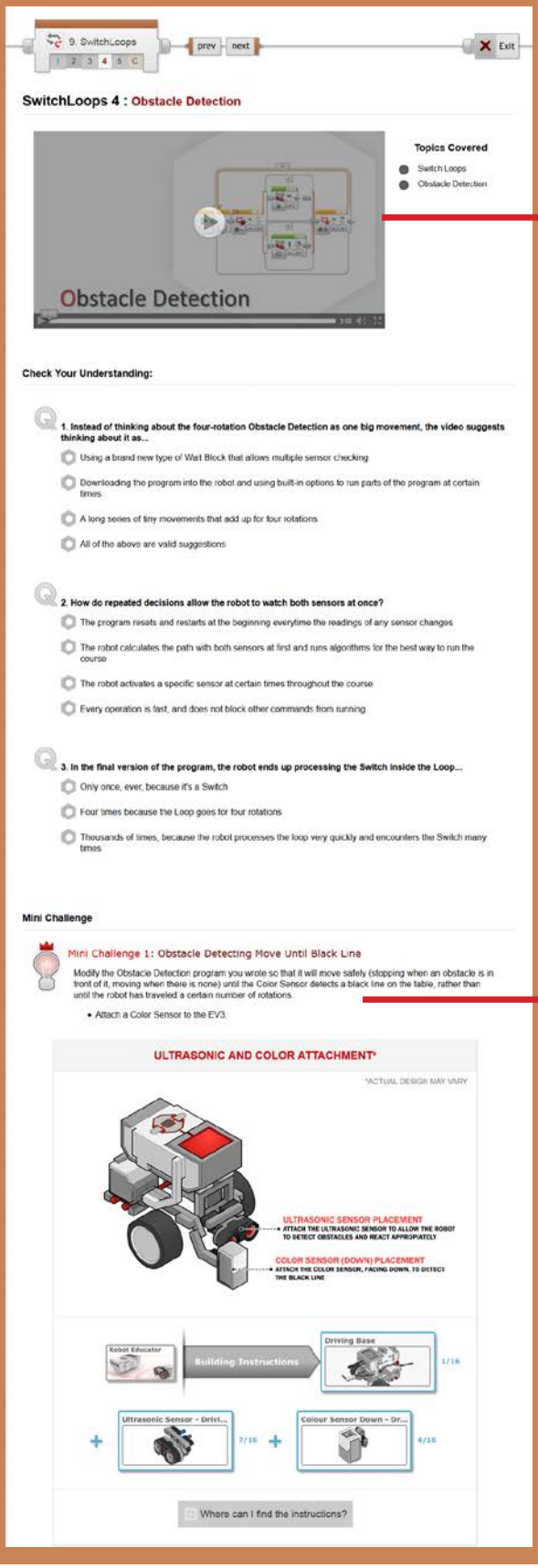
This step deliberately walks through two programs that do NOT work as a set up for the program that DOES (in the next step).

Students often have strong preconceptions that the methods shown in this video should work with the right tweaks, when in fact, both methods are fundamentally unworkable.

This video attempts to move students toward greater acceptance of that fact, and openness toward the new approach.



Decisions - Switch-Loops



Switch-Loop 4: Obstacle Detection

This step introduces the idea that large behaviors can be built up from repeated small behaviors, and that a Switch inside a Loop can create this effect in code.

The rapid repetition of the Switch and Loop decisions allows multiple sensors to be checked, as neither one “blocks” the other by holding up the program flow.

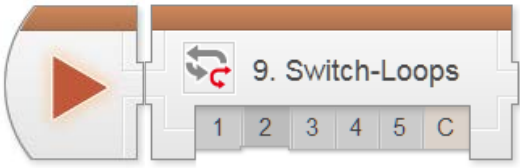
Since the behavior relies on the Loop to continue running, exiting the Loop ends the behavior. Consequently, the sensor condition on the Loop (Motor Rotations > 4 in this case) determines when the behavior ends. The sensor in the Switch determines what the robot does in each given instant until then.

This, of course, only works so long as the program is able to loop rapidly; it would not be able to check the Loop end condition if another block were holding up program flow!

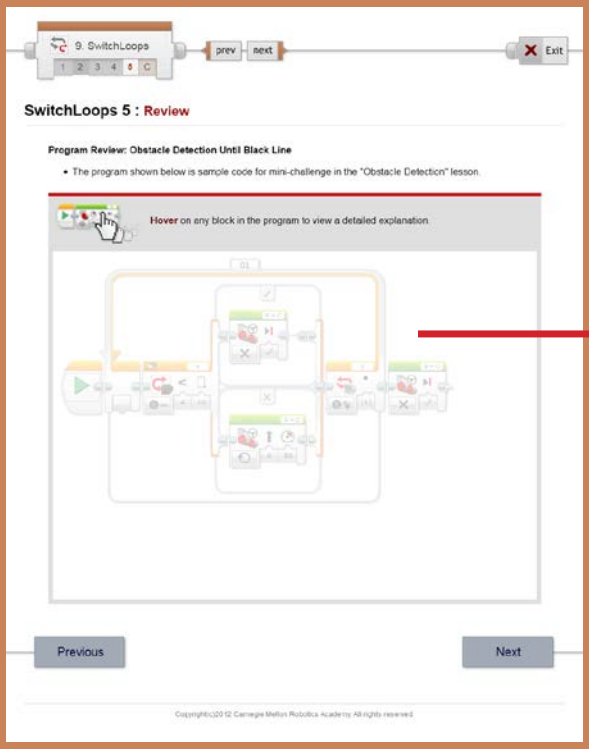
Mini-Challenge: Obstacle Detecting Move Until Black Line

Challenges students to add a Color Sensor to the EV3 and modify the program so that it ends when the robot reaches a black line.

Since the sensor on the Loop determines when the behavior ends, setting the Loop condition to Color Sensor > Color > Black means it will end when the robot reaches the black line.

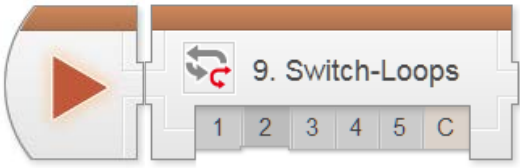


Decisions - Switch-Loops

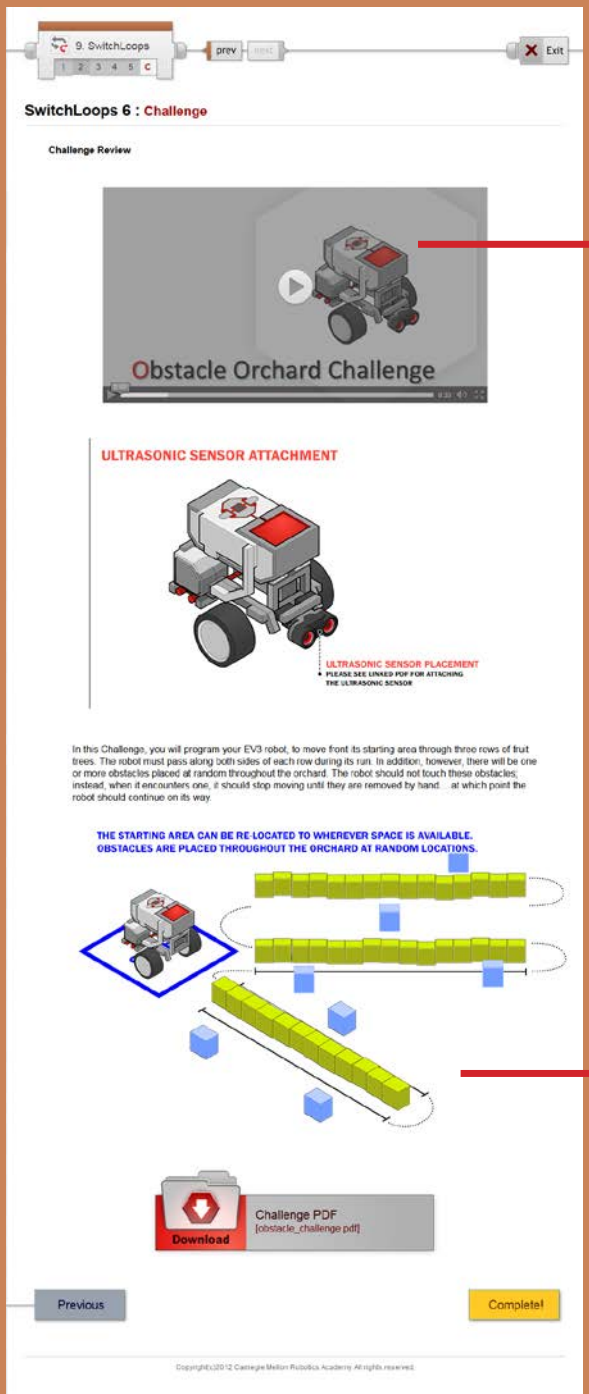


Switch-Loop 5: Review

A sample solution and explanation for the mini-challenge in this chapter can be found on this page.



Decisions - Switch-Loops



Obstacle Orchard Challenge

This step lays out the details for the Obstacle Orchard Challenge. Students should work in their teams to complete the challenge objectives.

This Challenge board is set up identically to the Orchard Challenge from the Turning chapter, but contains obstacles that can be randomly placed. The obstacles can be the same as the ones used in the Container Handling or Strawberry Sorter Challenges.

Obstacle Orchard Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.

Introduction to Robot Decisions - Line Follower

Decisions > Line Follower Mini-Chapter

Note: The terms "Line Following" and "Line Tracking" are used interchangeably in this chapter.

Line Following is actually just another application of the rapid repeated decisions pattern introduced in Switch-Loops. Consequently, the Line Follower chapter actually contains no new blocks or concepts – it is a new application of an existing idea.

As it is more practice and less new material, the Line Follower chapter is condensed into two pages and two videos.

Key Concepts: Applying "Continuous Control" in a new situation, Line Tracking

- **Line Tracking 1: Introduction to the AMTS**
  Introduces the real-world robot (Automated Material Transport System [AMTS]) and the new challenge modeled after it (Line Tracking Challenge). Also contains the building and setup instructions for this chapter.

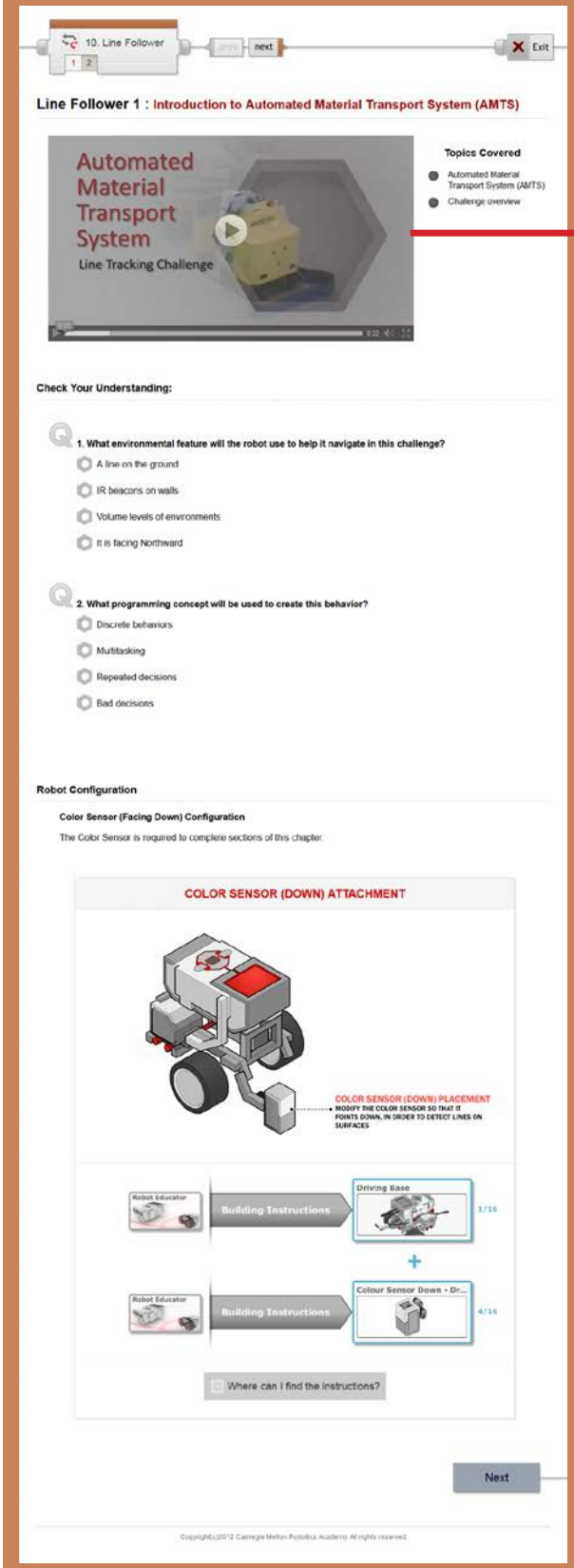
- **Line Tracking 2: Line Tracking**
  Explains Line Tracking as a use of Repeated Decisions and walks through a basic program that performs Line Tracking. Also lays out the Line Tracking Challenge, which requires students to move a crate along a curved path.

Hints:

- Line Following is a useful option any time there are suitable floor markings, including many robot competitions boards.

- Just as with Obstacle Detection, the Line Following behavior relies on the Loop's condition to know when to stop, and the Switch's condition to decide what motor commands to issue in any given instant.

Decisions - Line Follower

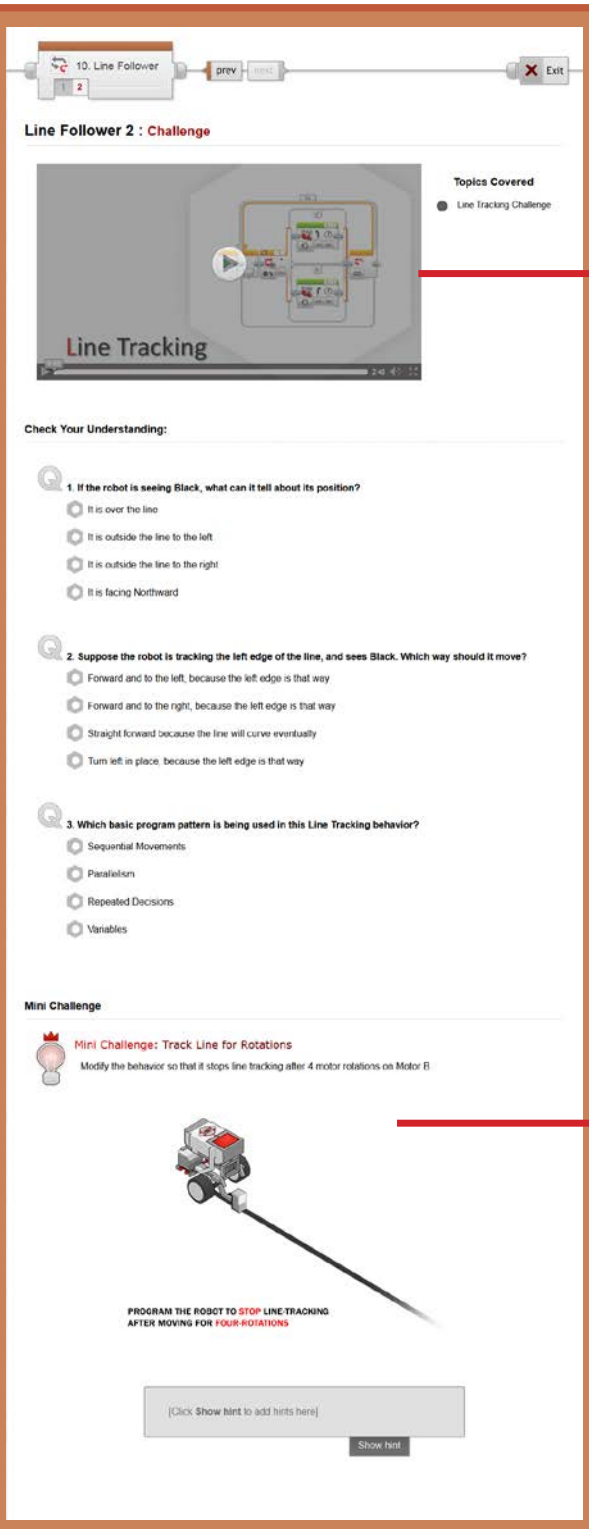


Line Tracking 1: Introduction & Config

Introduces the Automated Material Transport System (AMTS), the Line Tracking Challenge, and the Line Following/Tracking behavior.

This page also includes the building instructions for this chapter.

Decisions - Line Follower



Line Tracking 2: Challenge

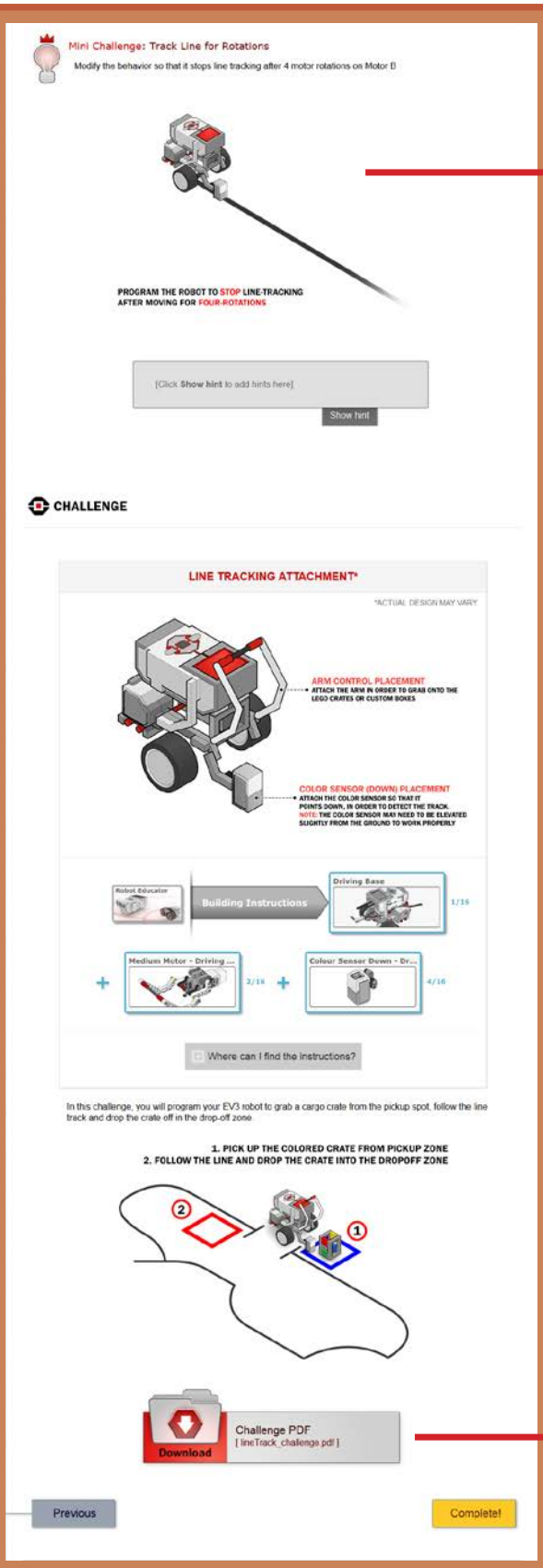
This step explains Line Tracking, which uses the same Rapidly Repeated Decisions logic used in Obstacle Detection.

The Challenge for this chapter is found farther down this page.

Mini-Challenge: Line Track for Rotations

Challenges students to make the Line Tracking behavior end after 4 rotations. The same logic applies here that was used to make Obstacle Detection end after 4 rotations.

Decisions - Line Follower



Line Follower 3 (continued)

Challenge: Line Tracking Challenge

Challenges students to have the robot pick up a crate and follow a complex line using a series of line-tracking behaviors.

Students can greatly improve the performance of the robot by modifying motor power levels.

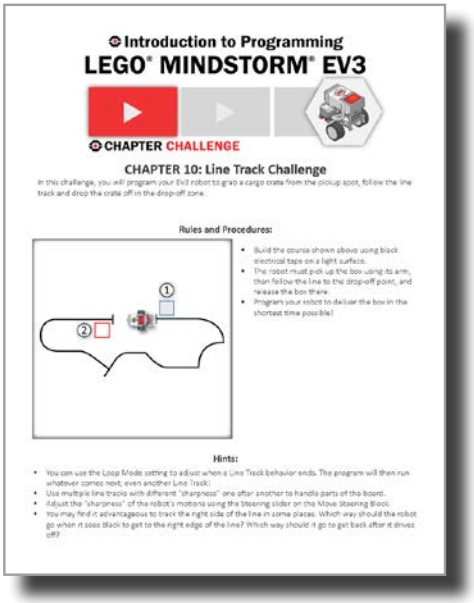
The ratio of the left and right motor powers determines the “sharpness” of the robot’s motion (e.g. 75/25 follows the same course as 30/10).

High motor powers will make the robot move quickly to save time, while lower ones will make it move more slowly (but stay on the line better).

Best results are achieved by using multiple line tracking behaviors back-to-back, with each one having a different combination of motor powers. Each can run for a set distance or length of time, then end, allowing the next to run.

Line Tracking Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Final Challenge Resources

Resources 1 : Flowcharts

The Flowcharts video .explains how a robot makes decisions. This video is designed to introduce students to flowcharts.

Key Concepts: Problem Solving: Breaking Down large problems

Resource 2 : Iterative Design

The Iterative Design video gives students a process that they can use to solve their programming problems.

Key Concepts: Building Up a solution with Iterative Design

Oftentimes, students' first inclination when solving a problem that involves programming is to simply sit down and start coding. This is generally counterproductive if the solution is not immediately obvious – students are more likely to get lost than succeed if they do not "get their bearings" and pick a sensible direction first. [NGSS: MS-ETS1, HS-ETS1-2]

Resources 3 : Project Planning

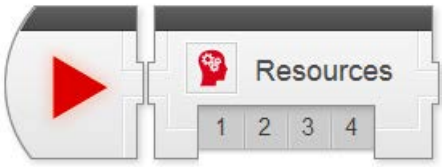
The Project Planning video .explains how important planning is when working in teams.

Key Concepts: Problem Solving: Planning, Breaking Down large problems

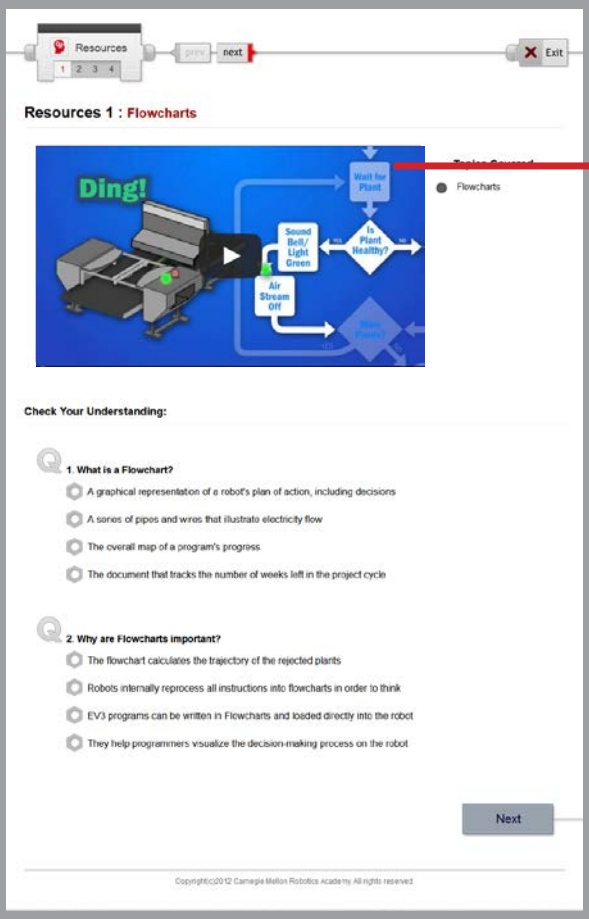
Resources 4 : Engineering Process

The Engineering Process video .describes a logical and systematic way to solve engineering projects.

Key Concepts: Problem Solving: Planning, Breaking Down large problems



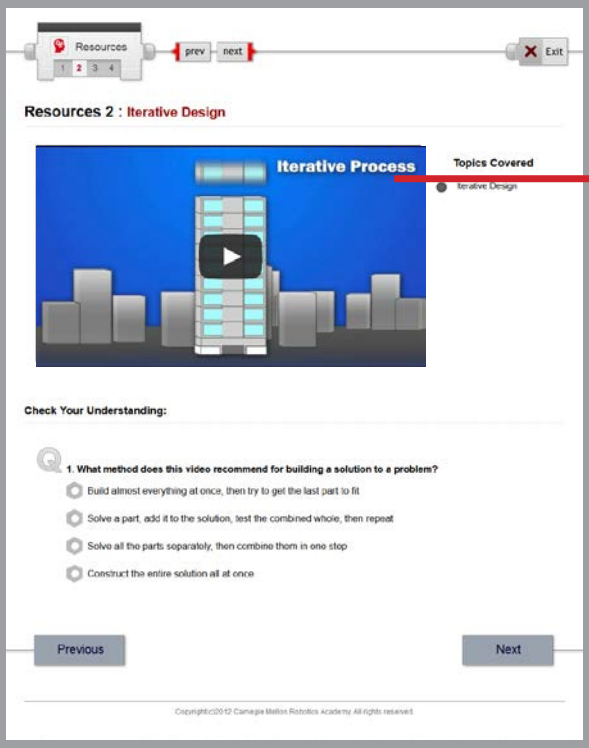
Final Challenge Resources



Final Challenge Resources 1

Flowcharts Video

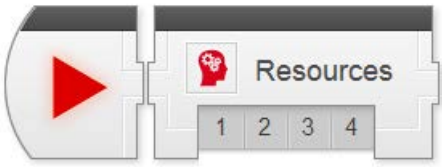
The Flowcharts video .explains how a robot makes decisions. This video is designed to introduce students to flowcharts



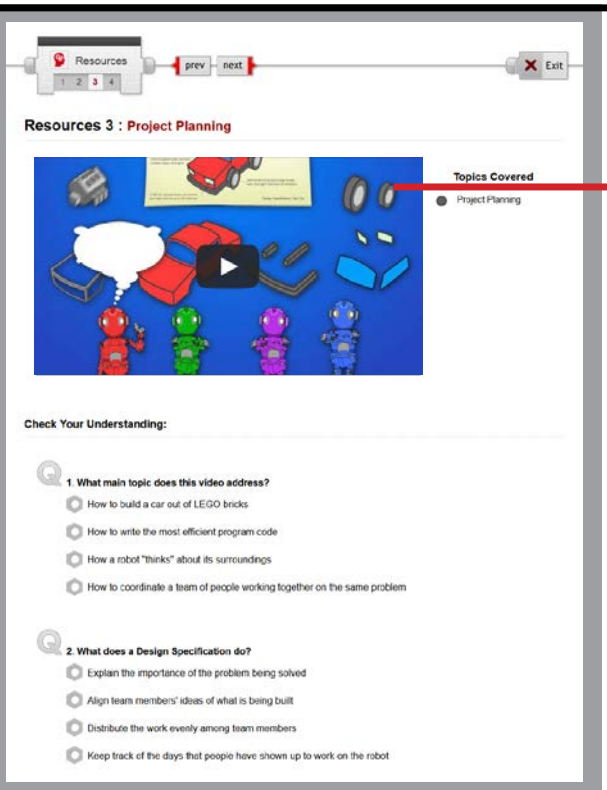
Final Challenge Resources 2

Iterative Design Video

The Iterative Design video gives students a process that they can use to solve their programming problems.



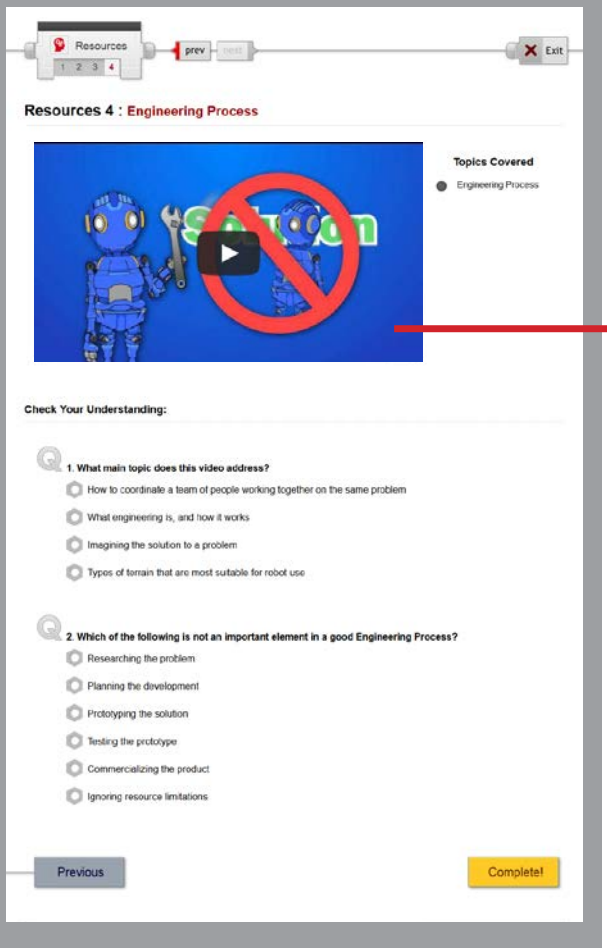
Final Challenge Resources



Final Challenge Resources 3

Project Planning Video

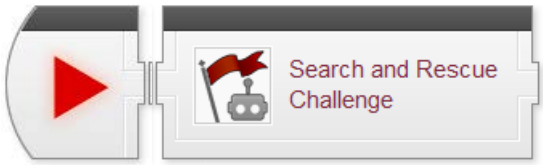
The Project Planning video .explains how important planning is; especially when working in teams.



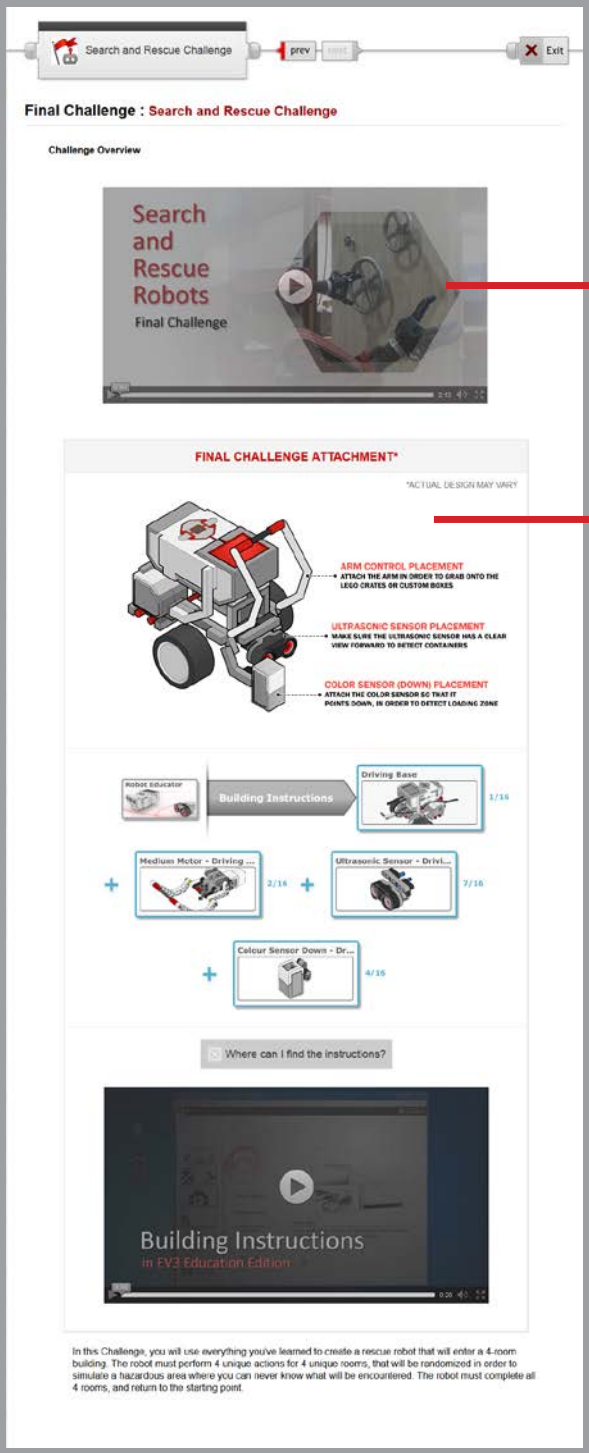
Final Challenge Resources 4

Engineering Process Video

The Engineering Process video .describes a logical and systematic way to solve engineering projects.



Search and Rescue Challenge



Search & Rescue Challenge

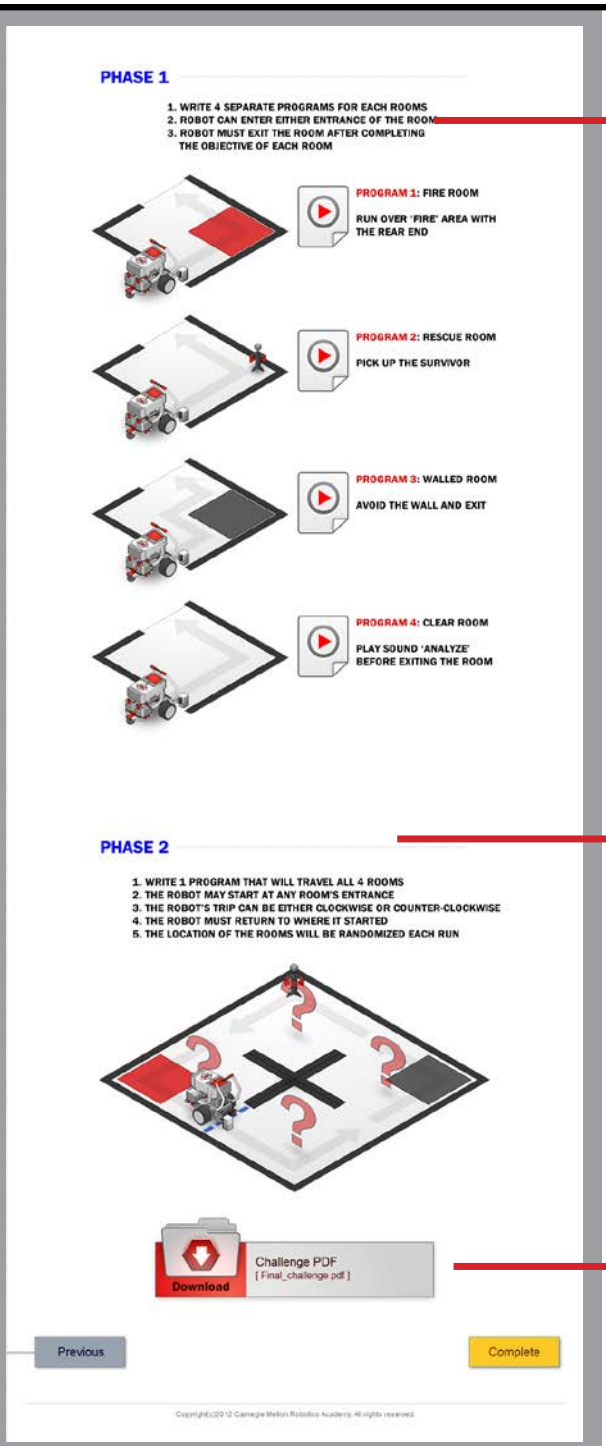
This step lays out the details for the final Search and Rescue Challenge. Students should work in their teams to complete the challenge objectives.

This challenge unfolds in two stages, to help students focus on breaking down the problem and building up the solution.

Building Instructions

Students should be allowed to make minor modifications to their robots during this Challenge, although they should not be necessary; all tasks can be completed with the standard attachments as shown.

Search and Rescue Challenge



Search and Rescue Challenge (cont'd)

Phase 1

In Phase 1, students should focus on completing the tasks found in each room *separately*, using a separate program for each room.

In Phase 2, these individual behaviors will be combined with additional logic that makes the correct behavior run at the correct time, and repeats the process to cover four rooms.

In the "iterative" model, this is the first step – the foundation upon which the next steps will be built.

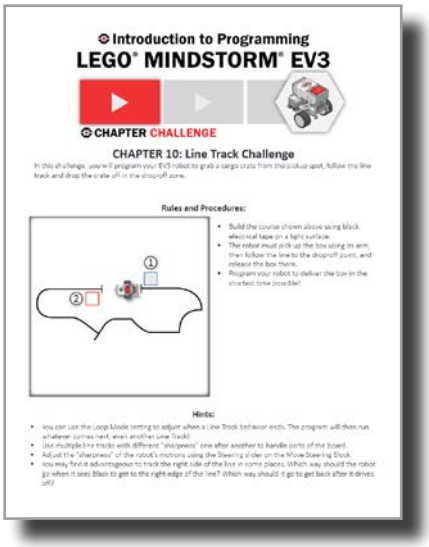
Phase 2

In Phase 2, students work on the logic that decides which of the four room-specific behaviors should run, and at what times. It will then rely on the existing, tested behaviors from Phase 1 (with small modifications as necessary) to complete the room task.

In the "iterative" model, this step builds upon the first step's behaviors, and instead focuses on choosing the right one at the right time.

Search and Rescue Challenge PDF

Detailed measurements for the board layout, as well as instructions for setting it up, rule details, and hints for solving the challenge can be found in this printable document.



Reproducibles

Table of Contents

1 Unit Worksheets

93 Movement Straight Question and Answer Key
95 Movement Turning Question and Answer Key
97 Sensors Touch Question and Answer Key
99 Ultrasonic Sensor Question and Answer Key
101 Gyro Sensor Question and Answer Key
103 Color Sensor Question and Answer Key
105 Decisions Loops Question and Answer Key
107 Decisions Switches Question and Answer Key
109 Decisions Switch Loops Question and Answer Key
113 Decisions Line Follower Question and Answer Key
115 Robot Engineering Question and Answer Key

117 Robot Programming Worksheets

117 What are Behaviors?
118 What are Flowcharts?
119 What is Pseudocode?
120 What is a Robot?

121 Engineering Handouts

121 Engineering Process Handout
122 Engineering Process Steps
123 Using Gantt Charts
124 Using PERT Charts
125 Introduction to the Engineering Journal
126 Using the Engineering Journal

128 Rubrics

128 Student Work Habit Evaluation Rubric
129 Example Writing Rubric
130 Student Presentation Rubric
131 Design Review Rubric
132 Proposal Writing Rubric

133 Addendum: Bonus Materials

133 Data Logging Investigation
138 Data Wires and Logic