INTRODUCTION TO ROBOTICS LESSON PLAN

USING THE EV3 PROGRAMMING APP

LEGOeducation.com/MINDSTORMS

LEGO mindstorms education EV3

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Introduction to Robotics Lesson Plan

This Lesson Plan provides educators with step-by-step instructions for how to use the LEGO® MINDSTORMS® Education EV3 Programming App with classroom-based lessons. Each lesson and challenge will give teachers the help they need to prepare, run and assess the class. It is up to the teacher to select which, as well as how many of the provided extra tasks and challenges will be used in the Robotics course.

Within the program, teachers have the option to start the course by either focusing on some of the Design Brief Challenges or by having students complete the tasks after a more structured start by using the tutorials provided.

Who Is It For?

This Lesson Plan is a valuable tool for anyone who wishes to learn how to use LEGO MINDSTORMS Education EV3.

What Is It For?

The coursework for the LEGO MINDSTORMS Education EV3 Programming App focuses primarily on engineering, technology, and computer science. However, it also provides an opportunity to integrate cross-curricular activities, such as science and mathematics, when the students complete the challenges.

The engaging and motivating nature of the EV3 Programming App enables the students to construct and program, and provides them with the scope to experiment, without prior knowledge or experience around programming or building.

The featured Lesson Plans enable educators to take a step-by-step approach to the course or, if required, to use a more open-ended approach.

The Lesson Plans are invaluable for equipping teachers with what they need to teach their students how to use LEGO MINDSTORMS Education EV3 within a classroom setting. They also serve as a learning guide for the EV3 programming language and the hardware included within the set. The intuitive programming interface, combined with the supporting material, will the enable students to make a quick and easy transition into robotics within a STEM context. Teachers who are already familiar with the EV3 Programming App will find fresh inspiration within the educational package to further the building and programming skills of their students.

What Is in the Lesson Plan PDF?

- Step-by-step help for using six of the Robot Educator tutorials
- A range of ideas for lesson-specific challenges
- Two Master Challenges that provide solid opportunities for the students to use EV3 in a STEM context
- Four open-ended Design Brief Challenges
- References to relevant learning areas
- Suggestions for how to assess the students' learning
- A class assessment record

The LEGO® MINDSTORMS® Education EV3 Software, Programming App, Lessons, and Challenges are designed for use with the 45544 LEGO MINDSTORMS Education EV3 Core Set.

Classroom Management Tips

How Much Time Do I Need?
The time taken to complete each of the tutorials and the suggested activities in the Lesson Plan depends on a number of factors, including the level of complexity, the age of the students, and the students' experience with LEGO® MINDSTORMS® and the concepts covered in the relevant lesson. The following estimates are therefore based on the time it would take an average student with no prior experience with LEGO MINDSTORMS to complete the following tasks:

Category	Estimated Completion Time Including Building (in minutes)
Tutorial	45-90
Tutorial and Lesson Challenge	90-135
Master Challenge 1	90-180
Master Challenge 2	90-270
Design Brief Challenge	90-270

Based on the estimates listed above, it should be possible for your students to complete the first tutorial within a 45-minute lesson.

Additional Materials
To complete the Lesson Plan, the following additional materials will be required: different-coloured sticky tape or paper (at least black, blue, grey and one other colour), large sheets of paper, objects of different shapes and sizes, protractors, measuring tapes (minimum length 1 meter) and markers.

Challenge-Based Assessment

The LEGO® MINDSTORMS® Education EV3 concept includes several ways of assessing the students' work. The hands-on Challenge approach, which provides a simple method of observing a robot's ability or failure to complete a task is an effective way of challenging a student's problem-solving skills and integrating the student and teacher assessment tools. When the students have difficulty completing a Challenge using their robot, they are motivated to improve their design or program in order to see something that they have built themselves succeed; this is a self-reinforcing process.

In the 'Test It' phase of the tutorials, the students are asked to describe the behaviour of their robot by writing their description in a Comment Box they add to the Canvas. This process encourages students to reflect on the connection between the programming blocks and robot behaviour.

The 'Modify It' tasks included in the tutorials help to consolidate learning by asking the students to make changes in the sample program to fulfill a given task.

The Lesson Challenges provided for teachers in the Lesson Plan enable the students to show that they can apply the skills gained through the tutorials. Each Lesson Plan includes a discussion section which gives guidance on what kinds of questions to ask the students, along with model answers. In the Design Brief Challenges, you can choose an approach that, compared to the step-by-step tutorials, is more open-ended. This allows you to assess the students' innovation and collaborative skills.

By using the Challenge-based assessment approach, the students can apply their STEM learning in an authentic context and show what they have learned.

Where Can I Find the Assessment Materials?

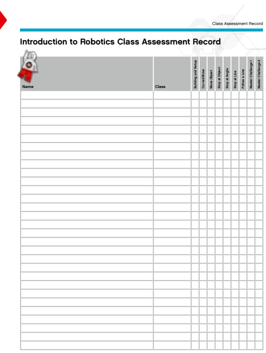
Assessment materials are provided for all seven lessons and for the two Master Challenges.

You can find the Introduction to Robotics class assessment record on page 38. The Introduction to Robotics rubrics are provided as a separate PDF in the Teacher Support section.

What Learning Goals Are Assessed?

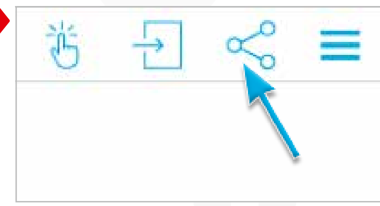
On the Introduction to Robotics rubrics PDF, the students can evaluate their project work according to the learning goals. Each rubric includes four levels: Bronze, Silver, Gold and Platinum. The intention is to help the students to reflect on what they have done well in relation to the learning goals and what they might do better. The students should mark an X to indicate the appropriate rubric level. You can also use the rubrics for your own evaluation of the students' work, marking your own X in the appropriate column and adding optional comments in the Notes column.

If a more formative assessment approach is required, you can record grades on the class assessment record provided on page 38. Your students can retain the Introduction to Robotics rubrics as a record of their progress.



Student Documentation
When documenting, the students will reflect on and consolidate what they have just learned. They will also consider how to use appropriate language to communicate this. You can ask the students to:

- Write full descriptions of their working processes
- Add images and videos of their robot in action
- Take screenshots from the EV3 Programming App
- Share their unique project with other students



Guide the students in which app(s) to use when documenting what they have learned after each lesson; the EV3 Programming App does not include a documentation tool. If the students are using shared Chromebooks, make sure they know how and where to save their programs.

Before Starting the First Lesson

If you have never worked with LEGO® MINDSTORMS® Education EV3 before, you should ensure the following:

1. Each Chromebook has a preinstalled version of the LEGO MINDSTORMS Education EV3 Programming App.

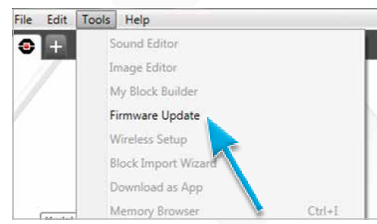
2. Each EV3 Brick has the latest firmware and is fully charged. To install the firmware, you will need a desktop version of the EV3 Software. For further instructions, please refer to the User Guide, which can be accessed from the Menu.

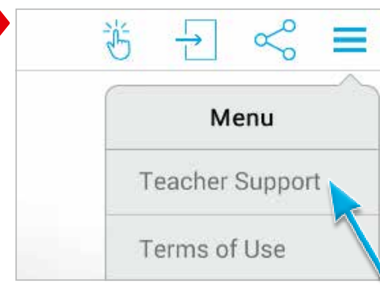
3. Before connecting computers and EV3 Bricks via Bluetooth in the classroom, we recommend renaming each EV3 Brick. This can be done in two ways:
    a. Update the name via the desktop EV3 Software using a USB cable.
    b. Update to firmware V1.07E or later and change the name via the EV3 Brick Settings Area (please refer to the User Guide for more help).

4. Watch the Quick Start Video, which can be accessed from the Menu.

You may want the students to understand the names and functions of the different elements in the brick set. Discuss the naming and basic functionality of the key hardware components and establish a set of brick management rules. Please refer to the User Guide for the Core Set Elements List.

Firmware Update



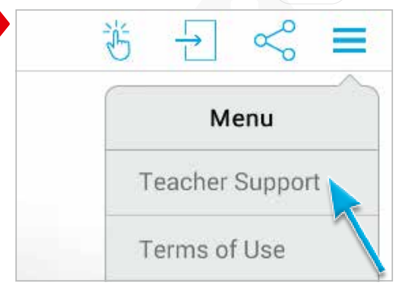


Lesson 1 – Building and Setup

Objective
After completing this lesson, the students will be able to build the Driving Base, connect the Chromebook to the EV3 Brick and download and run programs that control the robot's behaviour.

Duration
2 to 3 x 45 mins.

Preparation
You should understand the process of connecting a Chromebook to the EV3 Brick, watch the Quick Start Video for guidance. Distribute one EV3 Core Set and one Chromebook with the EV3 Programming App installed for every two to three students. Optional materials: cardboard, textiles and other materials for personalising the robots.



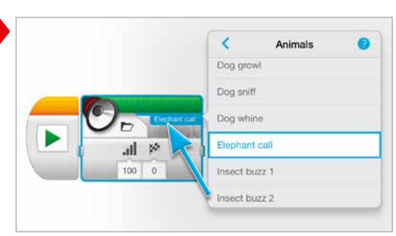
Procedure
1. The students will build the Robot Educator Driving Base using the Building Instructions booklet (included with the 45544 Core Set) or the Building Instructions available via the links in step two of each tutorial.

   Note: *Ensure that all of the students have the opportunity to build part of the model during the activity.*

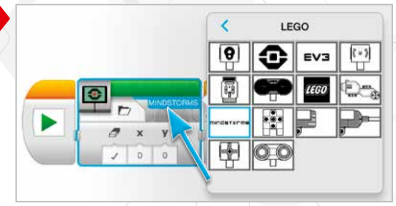
   Optional: An effective way of allowing the students to take ownership of their robot is to have them personalise it using additional LEGO® elements and other materials. By doing this, they can turn their robot into a puppy, an elephant or even a fantasy creature.

2. As a class, go through the process of connecting the Chromebook to the EV3 Brick and running the first program, *or* direct the students to the Quick Start Video, which will help them to connect the devices for themselves.

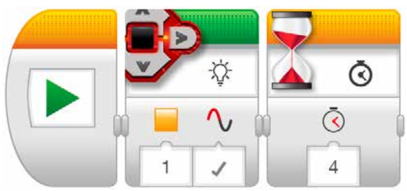
3. The students will use the Programming App to make simple programs that:
   a. Make their robot play a sound that is appropriate to their creature



b. Make their robot display an image or their own text in the EV3 Brick Display



c. Make their robot flash the Brick Status Light



Discussion Questions

Robot Behaviour: What problems did you encounter when constructing the Driving Base?

- *They might have used the wrong components in a step and had to go back and change the model, or had difficulty finding parts, especially the smaller ones.*

Program Flow: What did you have to do to change either the Sound or Brick Display image?

- *Click the top right hand corner of the programming block and select a file.*

Discovery: What did you find out when you connected the EV3 Brick to the Chromebook and downloaded your first program?

- *There are two ways to download and run a program. You can use the blue arrow facing right or the green arrow in the first programming block on the Canvas.*

Assessment

During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Lesson 2 – Curved Move

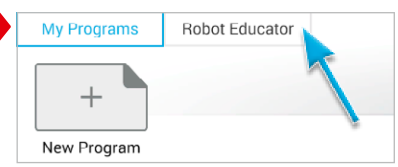
Objective
After completing this lesson, the students will be able to navigate their robot through an obstacle course. By selecting the correct programming blocks and setting their parameters, the students will know how and when to use point turns, single-motor turns and curved turns.

Duration
2 to 3 x 45 mins.

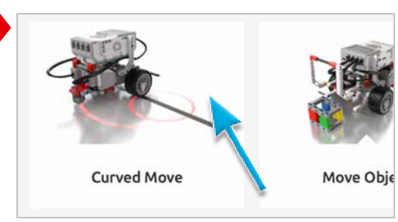
Preparation
For task 5b, you will need elastic bands to allow the students to attach a pen to their robot. For task 5c, you will need to prepare an obstacle course on the floor. You can use a large sheet of paper and markers, or place sticky tape on the floor (please refer to the illustration below).

Procedure

1. Introduce the students to the Lobby of the EV3 Programming App. The students need to know where to find the Robot Educator tutorials and how to open them. Demonstrate the flow of one tutorial to ensure that the students know their way around the tutorials in combination with the Programming Canvas and Hardware Page (please also refer to the Quick Start Video).



2. The students will complete and test the **Curved Move** tutorial, which introduces the Move Steering Block.



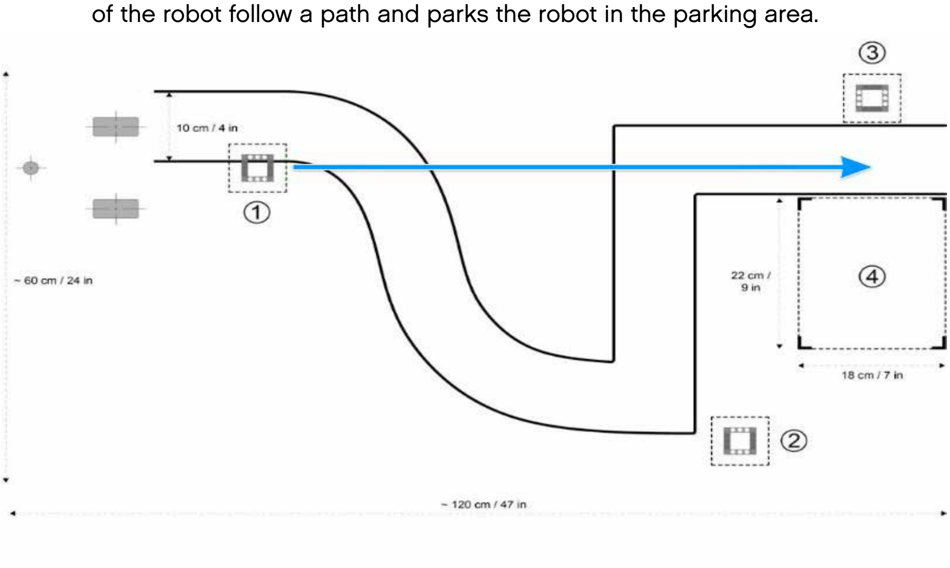
3. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The students can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

   The following sample program is provided for the students:

   Example of a robot behaviour description:
   The robot performs a point turn, then a single-motor turn and lastly, a curved turn. Each action is separated by a pause, which allows the robot to settle before executing the next action.

4. The students will solve the 'Modify It' task, which challenges them to add three Move Steering Blocks to their program in order to make the robot drive backwards, following the same path back to the starting position.

5. Lesson Challenge Ideas:
    a. Program the robot to trace out a figure eight, the first letter of your name or another letter or number.
    b. Attach a pen to the robot and program it to draw a cloverleaf, heart, flower or another shape.
    c. To ensure that the students know when to use the different kinds of turns (point turn, single-motor turn or curved turn), make an obstacle course that requires different turning methods (please refer to the illustration below and/or Appendix A). The students must write a program that makes the left wheel of the robot follow a path and parks the robot in the parking area.



For this path, use curved turns for the first section, followed by single-motor turns for the 90-degree turns and finally, a point turn before reversing the robot into the parking area.

The obstacle course can be simplified for some of the students by allowing them not to drive through the curve. This will allow the robot to drive in a straight line and then park.

Discussion Questions

Robot Behaviour: What did you discover when using the different turn methods?
- *The Steering Parameter Value was set to 50 to perform a single-motor turn and the Steering Parameter Value was set to 100 or -100 to perform a point turn.*

Program Flow: What is the purpose of the Wait Block?
- *The Wait Block makes your program wait for something before continuing to the next block in the sequence. You can wait for a certain amount of time for a sensor to reach a certain value or for a sensor value to change.*

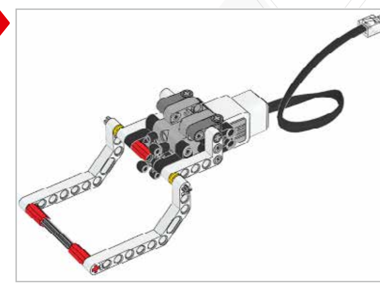
Discovery: Which method of turning worked the best for the curved line?
- *Move Tank or Move Steering Blocks work best because they keep both motors running in the same direction, with one motor running slightly slower.*

Assessment
During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Lesson 3 – Move Object

Objective
After completing this lesson, the students will be able to program their robot to move and release objects of different shapes and sizes.

Duration
2 to 3 x 45 mins.



Preparation
Find several objects of different shapes and sizes that may or may not fit in the frame of the Medium Motor Module. For this Lesson Challenge, you will need to prepare an obstacle course on the floor. You can use sticky tape on the floor or markers on a large sheet of paper (please refer to the illustration below).

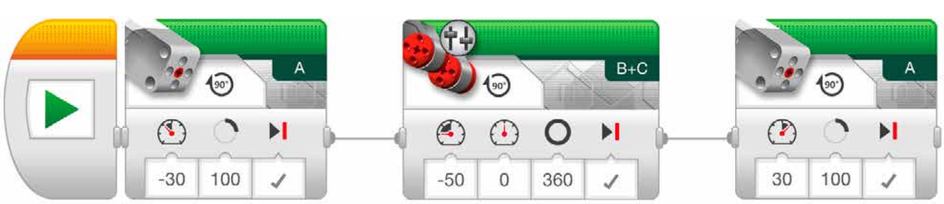
Procedure
1. The students will build and attach the Medium Motor Module to the Driving Base.

2. The students will build the Cuboid.

3. The students will complete the **Move Object** tutorial to understand how they can use the Medium Motor Module to grab the Cuboid.

4. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The tudents can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

   The following sample program is provided for the students:

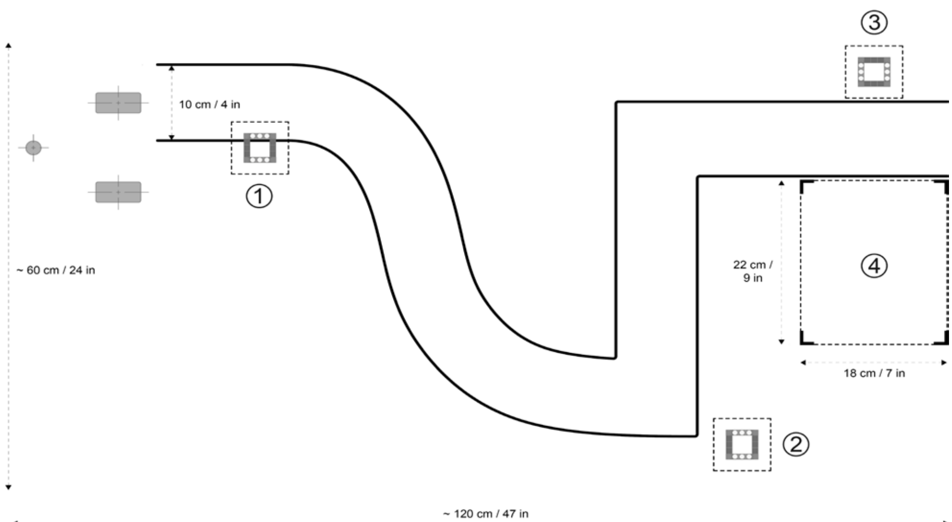


   Example of a robot behaviour description:
   Using the Medium Motor Module, the robot lowers the frame and grabs the Cuboid. It then reverses before raising the frame to release the Cuboid.

5. The students will complete the 'Modify It' task. The shape and size of different objects challenges the students to modify their program or make changes to the Medium Motor Module to enable the robot to grab the different objects. When modifying the program, the students will have to change the number of degrees the Medium Motor turns in order to accommodate the varying dimensions of the objects.

   Note: *Before modifying the Medium Motor Module, please be aware that it is also required in Lesson 4 and Master Challenge 2.*

6. Lesson Challenge:
   Combine the optional challenge of Lesson 2 with moving the Cuboid (or another object) from predetermined start and end positions (please refer to the illustration below and/or Appendix A). For an additional challenge, the students can also use the Ultrasonic Sensor to help detect the Cuboid (please refer to Lesson 4 for further details).



Discussion Questions

Robot Behaviour: How did you overcome the problem of moving larger sized objects?
- *Modified the Medium Motor Module frame to fit the larger objects.*

Program Flow: What did you have to change in order to move different sized objects?
- *The number of degrees of the Medium Motor Block had to be changed.*

Discovery: What did you discover when using the Medium Motor Module?
- *In order for the robot to lower the Medium Motor Module, the Medium Motor Block Power setting must be set to a negative (-) value.*

Assessment

During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Lesson 4 – Stop at Object

Objective
After completing this lesson, the students will understand the difference between the Change and Compare Modes of the various EV3 sensors. This particular lesson features the Ultrasonic Sensor.

Duration
2 to 3 x 45 mins.

Preparation
You should understand the difference between Change and Compare Modes. When using Compare Mode, the program waits for a certain distance to be read by the sensor. When using the Change Mode, the program reads the distance and then waits for a certain increase or decrease in distance. For this Lesson Challenge, you will need to prepare an obstacle course on the floor. You can use sticky tape on the floor or markers on a large sheet of paper (please refer to the illustration below).

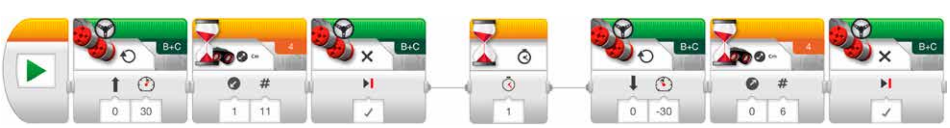
Procedure

1. The students will build the Ultrasonic Sensor Module and attach it to the Driving Base.

2. The students will complete the **Stop at Object** tutorial, during which they will learn that the Ultrasonic Sensor measures the distance to objects. Understanding this allows the students to program the robot to react to a detected object.

3. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The students can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

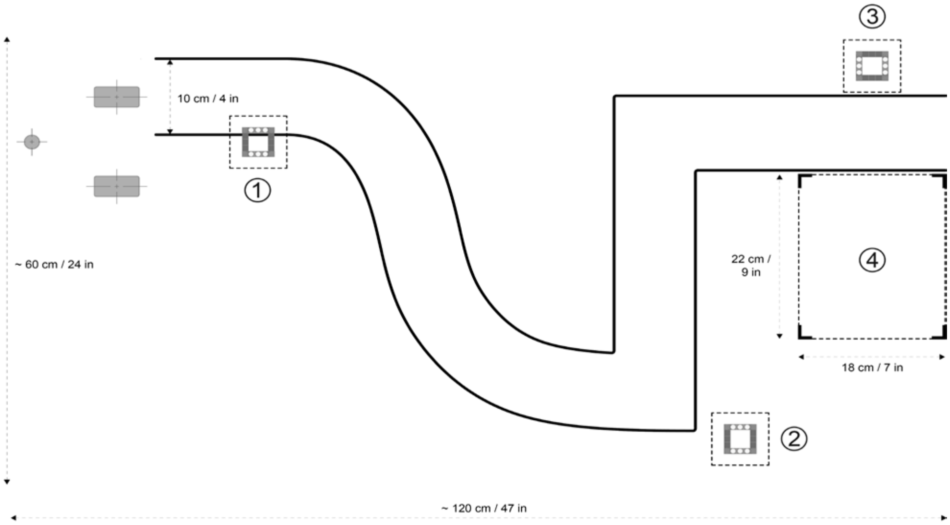
   The following sample program is provided for the students:



   Example of a robot behaviour description:
   Measuring distance using the Ultrasonic Sensor, the robot moves forwards until it detects a decrease of 11 cm from the Cuboid and stops. The robot then reverses until it detects an increase of 6 cm from the Cuboid.

4. The students will also complete the 'Modify It' task. They should realise that the robot will always move forwards 11 cm and then backwards 6 cm, regardless of the start distance to the Cuboid; this is the essence of the Ultrasonic Sensor's Change Mode.

5. Lesson Challenge Ideas:
   Have the students attach the Medium Motor Module and grab the Cuboid (please refer to the illustration below and/or Appendix A). Remind the students to use the Wait Block's Ultrasonic Sensor in Compare Mode so that the robot moves close enough to the Cuboid. The following scenarios can be used:
   a. Cuboid in position 1 → robot in start position → make the robot move the Cuboid to position 2 and return to the start position
   b. Cuboid in position 1 → robot in start position → make the robot move the Cuboid to position 3 and then park in position 4
   c. Cuboid in position 3 → robot starts in position 4 → make the robot move the Cuboid to position 1 following the path



Discussion Questions

Robot Behaviour: What happens if the speed of the Medium Motor Module is set too high?
- *The Medium Motor Module knocks over or pushes aside the Cuboid before it can take hold of it.*

Program Flow: What is the difference between the Change and Compare Modes when using the Ultrasonic Sensor?
- *Change Mode reads the distance and then waits for an increase or decrease. Compare Mode waits for a certain predefined distance.*

Discovery: What happens to the robot when it drives towards a round object?
- *The Ultrasonic Sensor does not always recognise the shape, as it is unable to receive a signal back.*

Assessment
During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Change Mode:

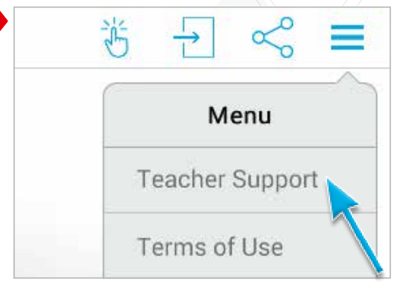
Compare Mode:

Lesson 5 – Stop at Angle

Objective
After completing this lesson, the students will be able to turn their robot based on input from the Gyro Sensor.

Duration
2 to 3 x 45 mins.

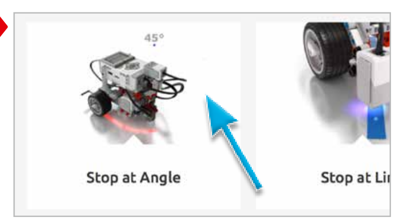
Preparation
You should familiarise yourself with the Gyro Sensor to ensure that you can detect when it is drifting and how to correct it. The Gyro Sensor chapter in the User Guide will help to familiarise you with the Sensor. This topic is also covered in Step 4 of the procedure below. Using sticky tape and protractors, the students can create different angles on the floor to validate the turning angle of their robot. For tasks 6a and 6b, you will need to provide elastic bands to allow the students to attach a pen to their robot. For task 6c, you will need to prepare a maze on the floor. You can use sticky tape on the floor or markers on a large sheet of paper. Any objects can be used as obstacles (please refer to the illustration below).



Procedure

1. The students will build the Gyro Sensor Module and attach it to the Driving Base.

2. The students will complete the **Stop at Angle** tutorial to make the robot turn 45 degrees based on Gyro Sensor angle readings.



3. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The students can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

   The following sample program is provided for the students:

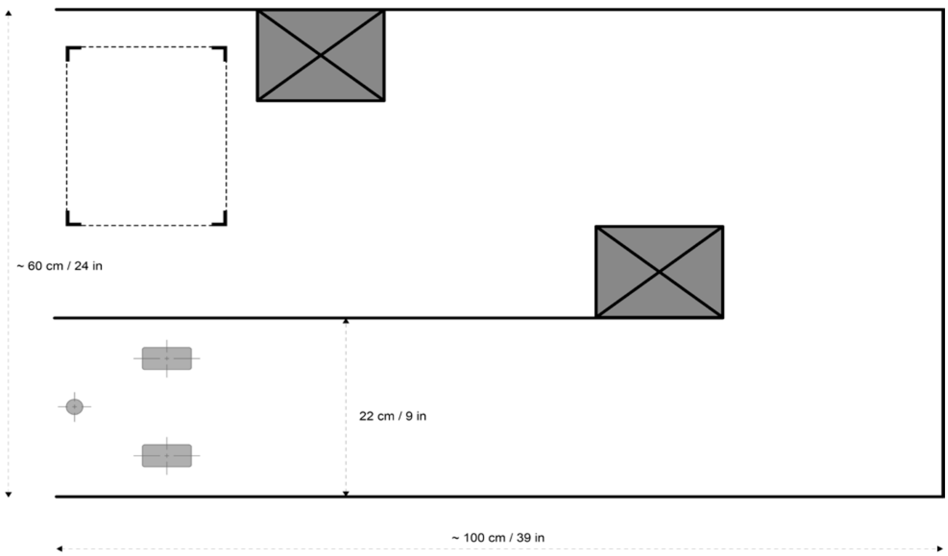
   Example of a robot behaviour description:
   Measuring rotational angle using the Gyro Sensor, the robot point turns until it detects an angle increase of 45 degrees. The robot then drives forwards for one rotation and stops.

4. Troubleshooting: The troubleshooting notes included in the tutorial will help the students to understand how to avoid Gyro Sensor drift. Introduce the EV3 Brick Port View App as a method of checking the Sensor reading. As the Gyro Sensor has a tolerance of +/- 3 degrees, you should therefore expect to compensate for that in the programs (e.g., to make a 90-degree turn, you may have to set the Amount parameter of the Wait Block's Gyro Sensor – Change – Angle Mode to 87 degrees).

5. In the 'Modify It' task, you might wish to introduce the students to the Loop Block as a way of decreasing the number of blocks needed to drive in a square. However, you should allow the students sufficient time to work it out for themselves.

   Suggested program:

6. Lesson Challenge Ideas:
   a. Attach a pen to the robot and then use a Gyro Sensor to program your robot to draw the letter ‘Z’.
   b. Attach a pen to the robot and then use a Gyro Sensor to program your robot to draw a star shape (consisting of five identical angles). Next, try increasing or decreasing the angle. How does the shape change?
   c. Challenge the students to make their robot navigate through a maze using the Gyro Sensor (please refer to the illustration below and/or Appendix B).



Discussion Questions

Robot Behaviour: What did you have to do in order to make your robot turn 90 degrees?
- *Slow down the rotation speed of the robot and potentially set the angle to a value of less than 90 degrees.*

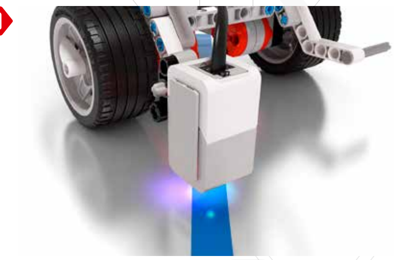
Program Flow: Why is it important to know how to set the Threshold Value?
- *This can make the difference between whether or not the robot reacts to the input of the sensor. It is also a way in which the robot can be ‘fine-tuned’ to make it more accurate.*

Discovery: What did you find was the difference between the Change and Compare Modes?
- *Change Mode - Wait for the selected value to change*
- *Compare Mode - Wait to reach a selected value*

Assessment
During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Lesson 6 – Stop at Line

Objective
After completing this lesson, the students will be able to use the Colour Sensor to stop the robot when a line is detected. The students will also be able to set a Threshold Value for a sensor.



Duration
2 to 3 x 45 mins.

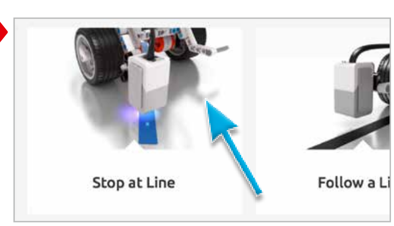
Preparation
Provide the students with different-coloured paper or sticky tape and a sheet of white paper with a thick black line printed across it. Follow these steps to test whether the Colour Sensor can read the selected colour materials correctly:

1. Turn on the EV3 Brick and connect a Colour Sensor to Port 3.
2. Navigate to the Port View App and open it.

3. Use the Right Button to navigate to Port 3.
4. The value shown is the Reflected Light Intensity (COL-REFLECT). Press the Centre Button to change the mode.
5. Scroll down the displayed list, select Colour Mode (COL-COLOR) and then point the Sensor at the coloured material. The value displayed equates to the following colours: 0, No Colour; 1, Black; 2, Blue; 3, Green; 4, Yellow; 5, Red; 6, White; and 7, Brown.
6. If the value does not match the colour of your material, you will need to use another material.

   ***Note:** For best accuracy when in Colour Mode or Reflected Light Intensity Mode, the Sensor must be held perpendicular and close to, but not touching the surface being detected.*

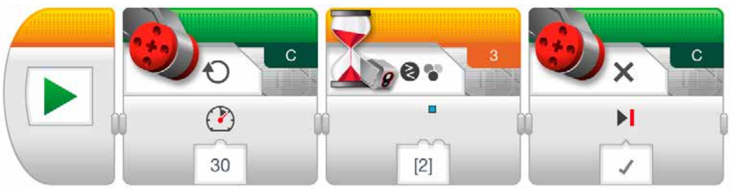
Procedure
1. The students will build the Colour Sensor Down Module and attach it to the Driving Base.
2. The students will complete the **Stop at Line** tutorial to detect a blue line using the Colour Sensor.



3. The students will complete the ‘Modify It’ task, in which they will practice detecting lines of a different colour.

4. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The students can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

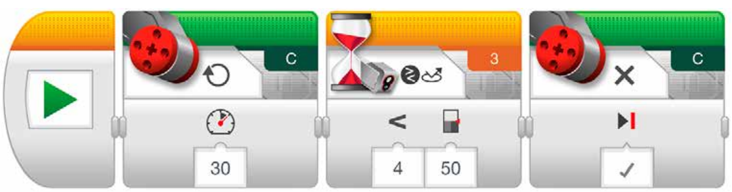
   The following sample program is provided for the students:

   Example of a robot behaviour description:
   Measuring colour using the Colour Sensor, the robot turns until it detects the colour blue and then stops.

5. Lesson Challenge:
   Ask the students to change the mode of the Colour Sensor to Reflected Light Intensity Mode and see if they can get the robot to stop on a black line.

   Suggested program:

   Example of a robot behaviour description:
   Measuring the Reflected Light-Intensity using the Colour Sensor, the robot turns until it detects the black line and then stops.

   Ask the students to find out what the No Colour parameter does (it causes the robot to react when the Colour Sensor fails to detect a colour that matches any of the predefined colours).

Discussion Questions

Robot Behaviour: Which colour or shade reflects the most light?
- *White reflects the most and black reflects the least.*

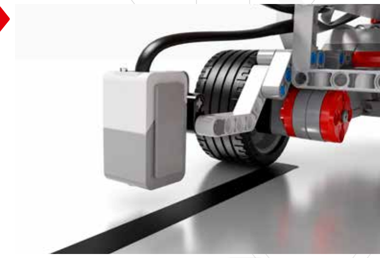
Program Flow: Was it easier to set up the Wait Block to measure Colour or Reflected Light Intensity?
- *When detecting a colour, the colour is just selected. When reacting to reflected light, a good Threshold Value must be found in order for the robot to behave as expected. Colour is easier if the Colour Sensor recognises the colour.*

Discovery: What would you do if the robot were to detect a grey colour?
- *Use the Wait Block set to read the Colour Sensor in Reflected Light Intensity Mode.*

Assessment

During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Lesson 7 – Follow a Line

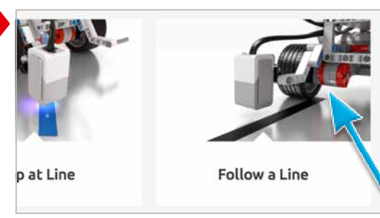


Objective
After completing this lesson, the students will be able to use the Switch Block to make dynamic sensor-based decisions in order to make their robot follow a line.

Duration
2 to 3 x 45 mins.

Preparation
Provide the students with black- and grey-coloured sticky tape that they can use to make a path for the robot to follow.

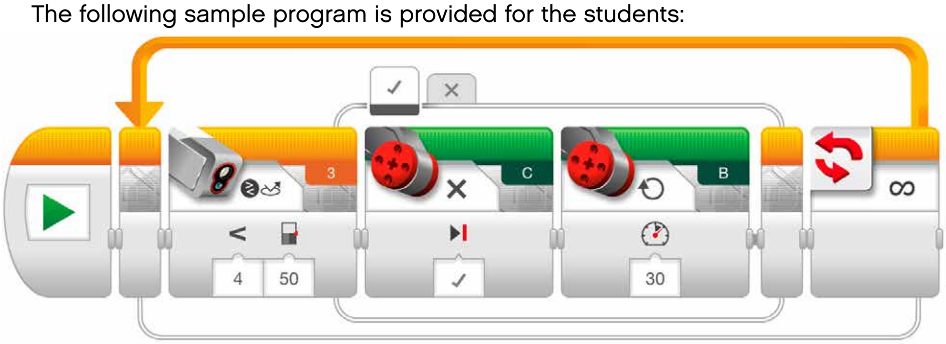
Procedure
1. If it is not already built, the students will build the Colour Sensor Down Module and attach it to the Driving Base, pointing down.



2. The students will complete the **Follow a Line** tutorial. Even though the Wait Block can be used to make a robot follow a line, this tutorial uses the Switch Block in order to introduce the abstract concept of if/then statements to the students.

3. In the 'Test It' phase, the students will see a sample program to copy. Ensure that each group takes the time to describe the robot's behaviour in their own words, while running the program. This encourages the students to reflect on what they see and how it relates to the programming blocks. The students can record notes on the Canvas by adding a Comment Box from the purple Comment Palette.

   The following sample program is provided for the students:



   Example of a robot behaviour description:
   While moving forwards along a line, the robot uses the Colour Sensor to alternately switch each motor on and off when it detects changes in the brightness that is reflected by the dark line and bright surface. This is why the robot 'wiggles' forwards.

4. The students will complete the 'Modify It' task, which allows them to test their program with a lighter-coloured line. This will challenge them to experiment with the Switch Block's Threshold Value parameter.

5. Lesson Challenge Ideas:
    a. Ask the students to test how fast they can make their robot follow a line.
    b. Make a line-follower program that uses Move Steering Blocks to perform curved turns rather than the sharp single-motor turns used in the tutorial.
    c. The tutorial sample program uses a Switch Block to create a line follower. Can the students produce the same result without using a Switch Block?

Discussion Questions

Robot Behaviour: What did you have to do in order to make the robot follow the line more smoothly?
- *Keep both motors running, one at a lower speed than the other, or use the Move Steering Blocks.*

Program Flow: What is a threshold value?
- *The threshold value is the average number reading between light and dark. This is the number that you add to the Switch Block.*

Discovery: What did you have to do in order for the robot to follow a grey line?
- *Work out the average threshold value between white and grey.*

Assessment
During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

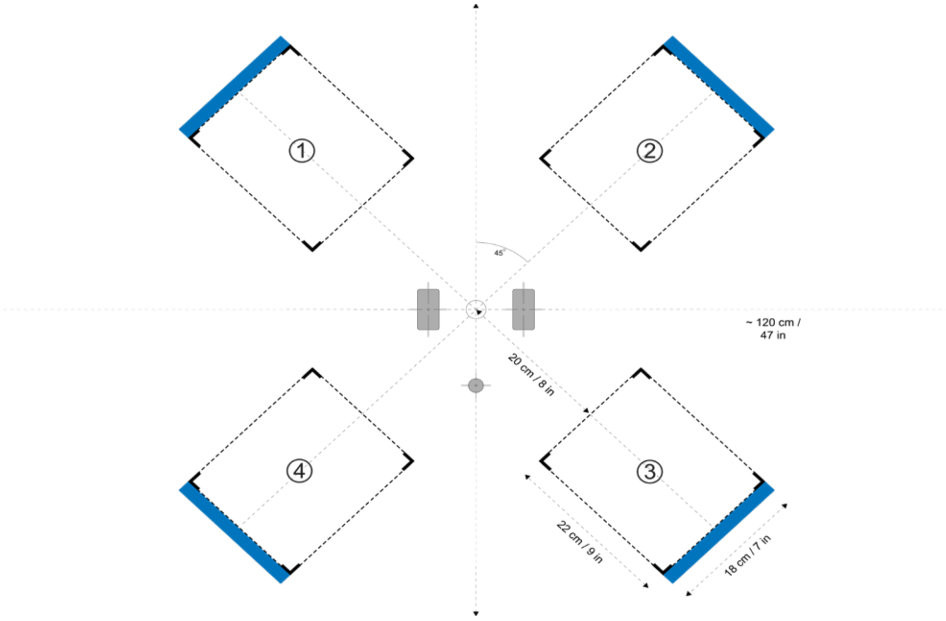
Master Challenge 1 – The Turntable Challenge

Objective
The objective of this Master Challenge is for the students to navigate their robot around a four-bay, turntable-style parking area using a combination of point turns and sensors. After completing this Challenge, the students will be able to use angles to predict the final position of their robot and compensate for factors that may affect the accuracy of the Gyro and Colour Sensors.

Prerequisites
At a minimum, the students must be familiar with the Colour Sensor and Gyro Sensor, as featured in the **Stop at Line** and **Stop at Angle** Lessons.

Duration
2 to 4 x 45 mins.

Preparation
To create the Challenge mat illustrated below and/or in Appendix C, the students will need protractors, long rulers, pencils, markers and blue sticky tape or blue paper.



Tasks

1. Using two sensors, the students will move the robot from the centre to final positions 1, 2, 3 and 4. If they are using the suggested angles for the Wait Block's Gyro Sensor Mode, the students should create their own copy of the chart below and try to predict which of the parking bays their robot will drive into:

Programmed Angle	Predicted Parking Bay	Actual Parking Bay
45 degrees clockwise		
135 degrees anti-clockwise		
405 degrees anti-clockwise		
		3

Note: *There may be several correct answers because the robot can be rotated both clockwise and anti-clockwise.*

2. Create a program that uses a Switch Block to enable the students to navigate the robot into one of the four parking bays by pressing one of the EV3 Brick Buttons.

   Suggested program:

Assessment

Observe and/or ask questions to determine if the students:

- Use both the Colour and Gyro Sensors
- Correctly predict the angle required to park the robot in each of the parking bays
- Use the blue line to stop forward movement
- Can compensate for the factors that may affect the stopping precision when using the Gyro Sensor (sensor tolerance, motor slack, and rotational momentum)
- Work cooperatively to solve the tasks

During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Master Challenge 2 – The LEGO® Factory Robot Challenge

Objective
The purpose of this Master Challenge is to create a simplified representation of one of the real-life robots used in LEGO® factories around the world to automate various tasks. After completing this Challenge, the students will be able to combine what they have learned in the previous lessons to master the basics of robotics.

Prerequisites
It is recommended that the students complete all seven lessons before beginning this Master Challenge. However, if you prefer a more project-based, explorative method, you can start out with this Challenge and allow students to find help on their own by referring to the lessons.

Duration
2 to 6 x 45 mins.

Preparation
To create the path illustrated below and/or in Appendix D, the students will need sticky tape, markers, a measuring tape, the Cuboid, and a large object to be placed at the end of the black line. The students might also need a large protractor for measuring the angle in step three below.

Tasks
1. Detect and grab the Cuboid using the Medium Motor and Ultrasonic Sensor Modules.

2. Drive the robot forwards exactly 84 cm.

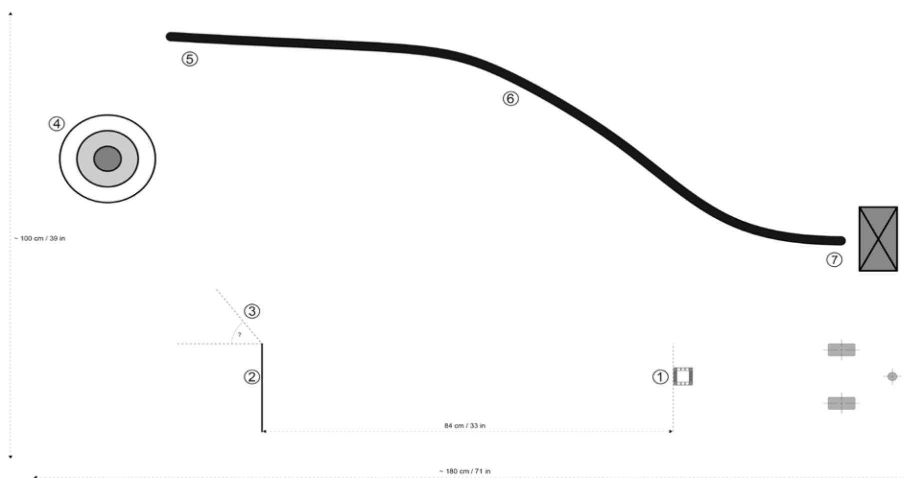
3. Determine and turn x degrees clockwise using the Gyro Sensor to point the robot towards the target circle.

4. Drive as close as possible to the centre of the target and release the Cuboid.

5. Locate the line using the Colour Sensor. To challenge the students, use sticky tape of a different colour to what was used in the **Stop at Line** and **Follow a Line** Lessons.

6. Have the robot follow the line towards the large object.

7. Stop right in front of the object. Here, the main challenge for the students is to define for how long the robot should follow the line before stopping. The large object at the end of the line gives the students a chance to escape the line-follower loop using the Ultrasonic Sensor, which can also be used to solve the Challenge.



Assessment
Observe and/or ask questions to determine if the students can use their experience from the seven lessons to solve this seven step Challenge by:

- Understanding the difference between Change and Compare Modes; the students should use the Wait Block's Ultrasonic Sensor in Compare Mode to achieve the best results in this Challenge
- Calculating distance based on wheel circumference or using trial and error to arrive at the required 84 cm
- Estimating the turn angle by using a protractor and the Gyro Sensor
- Measuring the distance and then calculating the number of motor rotations needed to get close to the centre of the target
- Programming the robot to stop at the line
- Following the line back
- Stopping in front of the large object
- Working cooperatively to solve the tasks

During the lesson, the students can interact with the Introduction to Robotics rubrics by using peer or self-assessment and can record their progress by marking the box that best reflects their level of work. Help your students to improve by writing a comment for each of them in the Notes column during the lesson.

Design Brief Challenges

Not all robots are Driving Bases. These Design Brief Challenges test the students' ability to build and program their own creations based on a brief that allows for a diversity of solutions. The students have a chance to choose an approach that, compared to the step-by-step tutorials, is more open-ended. Design Brief Challenges also allow you to assess a student's creative and collaborative skills.

Four design briefs are listed below. For each Challenge, you should consider in advance how many lessons the students will be given in order to complete the task. If the students are told in advance that they will have four 45-minute lessons and must then be ready to present their unique solution, they will have a better chance of successfully managing their time and can adjust their ambitions accordingly.

These Design Brief Challenges can be used as a starting point for your lessons; the students can use the tutorials and help text as a reference.

Alarm System
Build and program an alarm system using one or more sensors.

Dancing Robot
Build and program a robot that moves to your favourite music.

Greeting Robot
Build and program a robot that greets you positively when meeting it.

Robotic Sweeper
Build and program a robot that sweeps objects out of its path.

Relevant Learning Areas

The seven lessons, two Master Challenges, and Design Brief Challenges provide a full introduction to robotics and are great examples of how to use robotics within Computing and within a STEM context.

Using the LEGO® MINDSTORMS® Education EV3 concept in the classroom presents a range of valuable learning outcomes. Skills such as teamwork, creativity and problem solving are an inherent part of the experience, and the students' natural mastery of digital technologies will help them to learn the language of programming more rapidly.

Below is a selected overview of relevant learning areas that could be **addressed or partially addressed** when using LEGO MINDSTORMS Education EV3. This list will grow steadily as you expand the use of EV3 in your classroom.

Technologies

Overarching idea
• Creating preferred futures

Project management

Thinking in Technologies
• Systems thinking
• Design thinking
• Computational thinking

Digital Technologies
• Knowledge and understanding
  • Digital systems
    - Examine the main components of common digital systems and how they may connect together to form networks to transmit data (ACTDIK014).
    - Investigate how data is transmitted and secured in wired, wireless and mobile networks, and how the specifications affect performance (ACTDIK023)
    - Investigate the role of hardware and software in managing, controlling and securing the movement of and access to data in networked digital systems (ACTDIK034)

- Processes and production skills
    - Creating digital solutions by:
        - Investigating and defining
            - Define problems in terms of data and functional requirements drawing on previously solved problems (ACTDIP017)
            - Define and decompose real-world problems taking into account functional requirements and economic, environmental, social, technical and usability constraints (ACTDIP027)
            - Define and decompose real-world problems precisely, taking into account functional and non-functional requirements and including interviewing stakeholders to identify needs (ACTDIP038)
        - Generating and designing
            - Design, modify and follow simple algorithms involving sequences of steps, branching, and iteration (repetition) (ACTDIP019)
            - Design algorithms represented diagrammatically and in English, and trace algorithms to predict output for a given input and to identify errors (ACTDIP029
            - Design algorithms represented diagrammatically and in structured English and validate algorithms and programs through tracing and test cases (ACTDIP040)
        - Producing and implementing
            - Implement digital solutions as simple visual programs involving branching, iteration (repetition), and user input (ACTDIP020)
            - Implement and modify programs with user interfaces involving branching, iteration and functions in a general-purpose programming language (ACTDIP030)
            - Implement modular programs, applying selected algorithms and data structures including using an object-oriented programming language (ACTDIP041)
        - Evaluating
            - Explain how student solutions and existing information systems are sustainable and meet current and future local community needs (ACTDIP021)
            - Evaluate how student solutions and existing information systems meet needs, are innovative, and take account of future risks and sustainability (ACTDIP031)
            - Evaluate critically how student solutions and existing information systems and policies, take account of future risks and sustainability and provide opportunities for innovation and enterprise (ACTDIP042)
        - Collaborating and managing

Design and Technologies

- Knowledge and understanding
  - Technologies and society
    - Examine how people in design and technologies occupations address competing considerations, including sustainability in the design of products, services, and environments for current and future use (ACTDEK019)
    - Investigate the ways in which products, services and environments evolve locally, regionally and globally and how competing factors including social, ethical and sustainability considerations are prioritised in the development of technologies and designed solutions for preferred futures (ACTDEK029)
    - Critically analyse factors, including social, ethical and sustainability considerations, that impact on designed solutions for global preferred futures and the complex design and production processes involved (ACTDEK040)
    - Explain how products, services and environments evolve with consideration of preferred futures and the impact of emerging technologies on design decisions (ACTDEK041)
  - Technologies contexts
    - Engineering principles and systems
      - Investigate how electrical energy can control movement, sound or light in a designed product or system (ACTDEK020)
      - Analyse how motion, force and energy are used to manipulate and control electromechanical systems when designing simple, engineered solutions (ACTDEK031)
      - Investigate and make judgments on how the characteristics and properties of materials are combined with force, motion and energy to create engineered solutions (ACTDEK043)
    - Materials and technologies specialisations
      - Investigate characteristics and properties of a range of materials, systems, components, tools and equipment and evaluate the impact of their use (ACTDEK023)
      - Analyse ways to produce designed solutions through selecting and combining characteristics and properties of materials, systems, components, tools and equipment (ACTDEK034)
      - Investigate and make judgments on how the characteristics and properties of materials, systems, components, tools and equipment can be combined to create designed solutions (ACTDEK046)
      - Investigate and make judgments, within a range of technologies specialisations, on how technologies can be combined to create designed solutions (ACTDEK047)

- Processes and production skills
    - Creating designed solutions by:
        - Investigating and defining
            - Critique needs or opportunities for designing, and investigate materials, components, tools, equipment and processes to achieve intended designed solutions (ACTDEP024)
            - Critique needs or opportunities for designing and investigate, analyse and select from a range of materials, components, tools, equipment and processes to develop design ideas (ACTDEP035)
            - Critique needs or opportunities to develop design briefs and investigate and select an increasingly sophisticated range of materials, systems, components, tools and equipment to develop design ideas (ACTDEP048)
        - Generating and designing
            - Generate, develop and communicate design ideas and processes for audiences using appropriate technical terms and graphical representation techniques (ACTDEP025)
            - Generate, develop, test and communicate design ideas, plans and processes for various audiences using appropriate technical terms and technologies including graphical representation techniques (ACTDEP036)
            - Develop, modify and communicate design ideas by applying design thinking, creativity, innovation and enterprise skills of increasing sophistication (ACTDEP049)
        - Producing and implementing
            - Select appropriate materials, components, tools, equipment and techniques and apply safe procedures to make designed solutions (ACTDEP026)
            - Select and justify choices of materials, components, tools, equipment and techniques to effectively and safely make designed solutions (ACTDEP037)
            - Work flexibly to effectively and safely test, select, justify and use appropriate technologies and processes to make designed solutions (ACTDEP050)
        - Evaluating
            - Negotiate criteria for success that include sustainability to evaluate design ideas, processes and solutions (ACTDEP027)
            - Independently develop criteria for success to evaluate design ideas, processes and solutions and their sustainability (ACTDEP038)
            - Evaluate design ideas, processes and solutions against comprehensive criteria for success recognising the need for sustainability (ACTDEP051)
        - Collaborating and managing
            - Develop project plans that include consideration of resources when making designed solutions individually and collaboratively (ACTDEP028)
            - Use project management processes when working individually and collaboratively to coordinate production of designed solutions (ACTDEP039)
            - Develop project plans using digital technologies to plan and manage projects individually and collaboratively taking into consideration time, cost, risk and production processes (ACTDEP052)

Science

Key ideas
- Patterns, order and organisation
- Form and function
- Matter and energy
- Systems

Science strands
- Science understanding
  - Physical sciences
    - Light from a source forms shadows and can be absorbed, reflected and refracted (ACSSU080)
    - Electrical energy can be transferred and transformed in electrical circuits and can be generated from a range of sources (ACSSU097)
    - Energy appears in different forms, including movement (kinetic energy), heat and potential energy, and energy transformations and transfers cause change within systems (ACSSU155)
    - The motion of objects can be described and predicted using the laws of physics (ACSSU229)
- Science as a human endeavour
  - Nature and development of science
    - Science involves testing predictions by gathering data and using evidence to develop explanations of events and phenomena and reflects historical and cultural contributions (ACSHE081)
    - Science involves testing predictions by gathering data and using evidence to develop explanations of events and phenomena and reflects historical and cultural contributions (ACSHE098)
    - Scientific knowledge has changed peoples' understanding of the world and is refined as new evidence becomes available (ACSHE119)
    - Scientific knowledge has changed peoples' understanding of the world and is refined as new evidence becomes available (ACSHE134)
    - Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community (ACSHE157)
    - Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community (ACSHE191)
  - Use and influence of science
    - Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE083)
    - Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE100)
    - Solutions to contemporary issues that are found using science and technology, may impact on other areas of society and may involve ethical considerations (ACSHE120)
    - Solutions to contemporary issues that are found using science and technology, may impact on other areas of society and may involve ethical considerations (ACSHE135)
    - People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people's lives, including generating new career opportunities (ACSHE160)
    - People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people's lives, including generating new career opportunities (ACSHE194)

- Science inquiry skills
    - Questioning and predicting
        - With guidance, pose clarifying questions and make predictions about scientific investigations (ACSIS231)
        - With guidance, pose clarifying questions and make predictions about scientific investigations (ACSIS232)
        - Identify questions and problems that can be investigated scientifically and make predictions based on scientific knowledge (ACSIS124)
        - Identify questions and problems that can be investigated scientifically and make predictions based on scientific knowledge (ACSIS139)
        - Formulate questions or hypotheses that can be investigated scientifically (ACSIS164)
        - Formulate questions or hypotheses that can be investigated scientifically (ACSIS198)
    - Planning and conducting
        - Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS086)
        - Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS103)
        - Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed (ACSIS125)
        - Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed (ACSIS140)
        - Plan, select and use appropriate investigation types, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS165)
        - Plan, select and use appropriate investigation types, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS199)

- Processing and analysing data and information
  - Construct and use a range of representations, including tables and graphs, to represent and describe observations, patterns or relationships in data using digital technologies as appropriate (ACSIS090)
  - Construct and use a range of representations, including tables and graphs, to represent and describe observations, patterns or relationships in data using digital technologies as appropriate (ACSIS107)
  - Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed (ACSIS125)
  - Construct and use a range of representations, including graphs, keys and models to represent and analyse patterns or relationships in data using digital technologies as appropriate (ACSIS144)
  - Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies (ACSIS169)
  - Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies (ACSIS203)
- Evaluating
  - Reflect on and suggest improvements to scientific investigations (ACSIS091)
  - Reflect on and suggest improvements to scientific investigations (ACSIS108)
  - Reflect on scientific investigations including evaluating the quality of the data collected, and identifying improvements (ACSIS131)
  - Reflect on scientific investigations including evaluating the quality of the data collected, and identifying improvements (ACSIS146)
  - Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data (ACSIS171)
  - Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data (ACSIS205)
- Communicating
  - Communicate ideas, explanations and processes using scientific representations in a variety of ways, including multi-modal texts (ACSIS093)
  - Communicate ideas, explanations and processes using scientific representations in a variety of ways, including multi-modal texts (ACSIS110)
  - Communicate ideas, findings and evidence based solutions to problems using scientific language, and representations, using digital technologies as appropriate (ACSIS133)
  - Communicate ideas, findings and evidence based solutions to problems using scientific language, and representations, using digital technologies as appropriate (ACSIS148)
  - Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (ACSIS174)
  - Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (ACSIS20)

Mathematics

Key ideas
- Understanding
- Problem-solving
- Reasoning

Content strands
- Number and algebra
  - Number and place value
    - Solve problems involving multiplication of large numbers by one- or two-digit numbers using efficient mental, written strategies and appropriate digital technologies (ACMNA100)
    - Select and apply efficient mental and written strategies and appropriate digital technologies to solve problems involving all four operations with whole numbers (ACMNA123)
    - Connect fractions, decimals and percentages and carry out simple conversions (ACMNA157)
    - Solve problems involving the use of percentages, including percentage increases and decreases, with and without digital technologies (ACMNA187)
  - Patterns and algebra
    - Find unknown quantities in number sentences involving multiplication and division and identify equivalent number sentences involving multiplication and division (ACMNA121)
- Measurement and geometry
  - Geometric reasoning
    - Estimate, measure and compare angles using degrees. (ACMMG112)
    - Investigate, with and without digital technologies, angles on a straight line, angles at a point and vertically opposite angles. Use results to find unknown angles (ACMMG141)
- Statistics and probability
  - Data representation and interpretation
    - Construct displays, including column graphs, dot plots and tables, appropriate for data type, with and without the use of digital technologies (ACMSP119)
    - Interpret secondary data presented in digital media and elsewhere (ACMSP148)

English

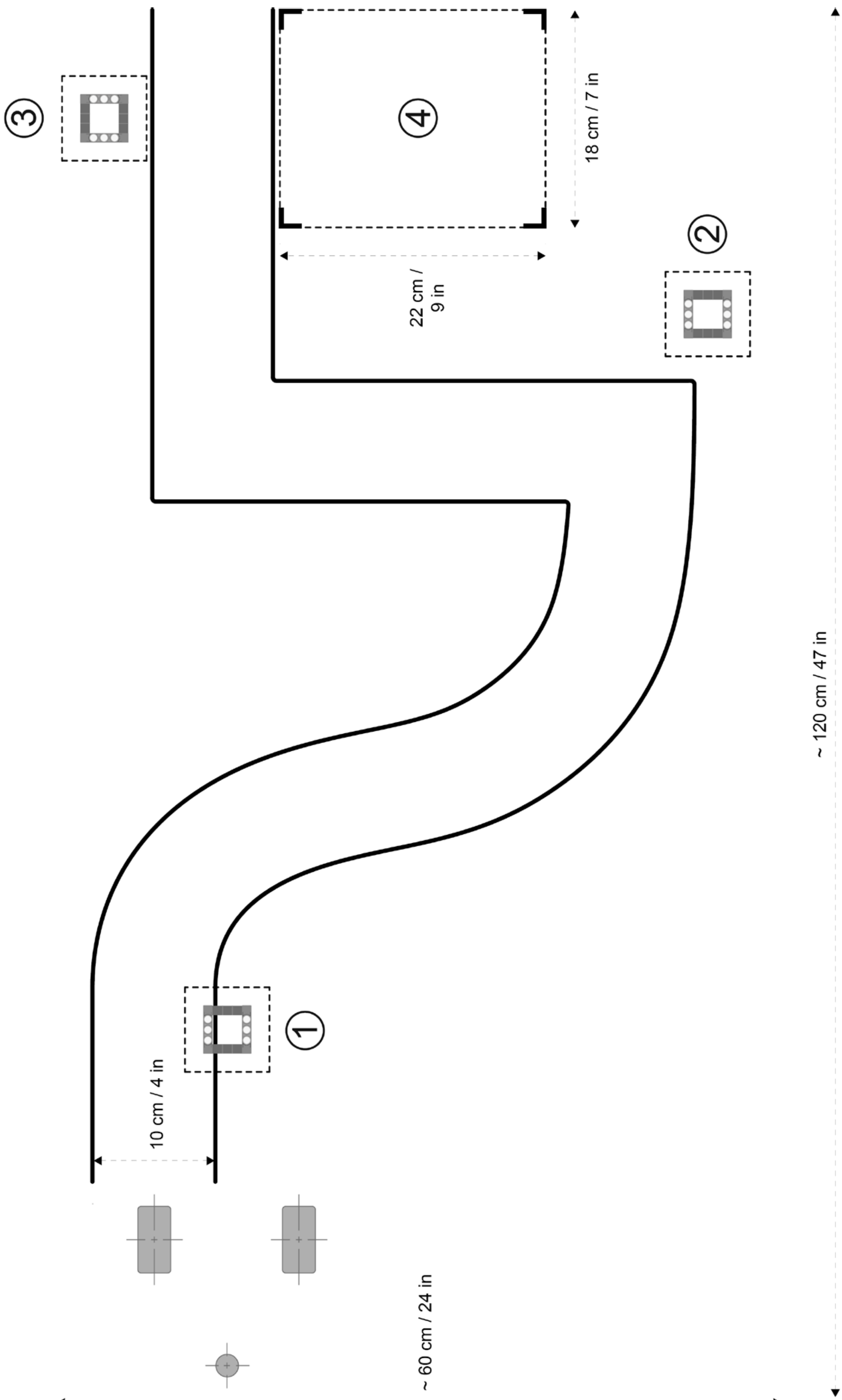
Key ideas
- Texts
- Communication processes
    - Listening, reading and viewing
    - Speaking, writing and creating
- Literacy is language in use

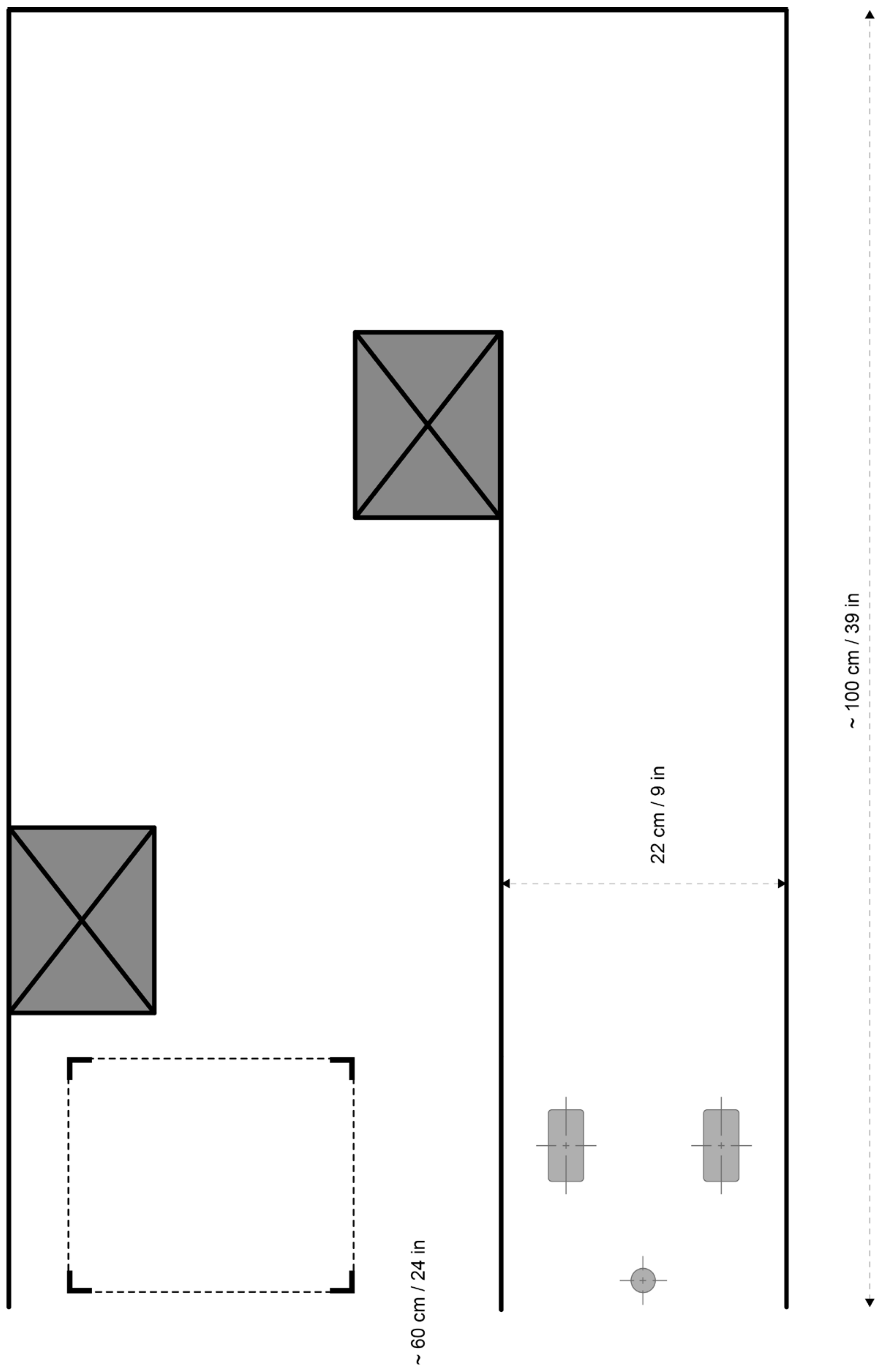
- Literacy strand
    - Interacting with others
        - Clarify understanding of content as it unfolds in formal and informal situations, connecting ideas to students' own experiences and present and justify a point of view (ACELY1699)
        - Plan, rehearse and deliver presentations for defined audiences and purposes incorporating accurate and sequenced content and multimodal elements (ACELY1700)
        - Participate in and contribute to discussions, clarifying and interrogating ideas, developing and supporting arguments, sharing and evaluating information, experiences and opinions (ACELY1709)
        - Plan, rehearse and deliver presentations, selecting and sequencing appropriate content and multimodal elements for defined audiences and purposes, making appropriate choices for modality and emphasis (ACELY1710)
        - Identify and discuss main ideas, concepts and points of view in spoken texts to evaluate qualities, for example the strength of an argument or the lyrical power of a poetic rendition (ACELY1719)
        - Plan, rehearse and deliver presentations, selecting and sequencing appropriate content and multimodal elements to promote a point of view or enable a new way of seeing (ACELY1720)
        - Interpret the stated and implied meanings in spoken texts, and use evidence to support or challenge different perspectives (ACELY1730)
        - Plan, rehearse and deliver presentations, selecting and sequencing appropriate content, including multimodal elements, to reflect a diversity of viewpoints (ACELY1731)
        - Plan, rehearse and deliver presentations, selecting and sequencing appropriate content and multimodal elements for aesthetic and playful purposes (ACELY1741)
        - Plan, rehearse and deliver presentations, selecting and sequencing appropriate content and multimodal elements to influence a course of action (ACELY1751)
    - Interpreting, analysing and evaluating
        - Use comprehension strategies to analyse information, integrating and linking ideas from a variety of print and digital sources (ACELY1703)
        - Use comprehension strategies to interpret and analyse information and ideas, comparing content from a variety of textual sources including media and digital texts (ACELY1713)
        - Use comprehension strategies to interpret, analyse and synthesise ideas and information, critiquing ideas and issues from a variety of textual sources (ACELY1723)
        - Use comprehension strategies to interpret and evaluate texts by reflecting on the validity of content and the credibility of sources, including finding evidence in the text for the author's point of view (ACELY1734)
        - Use comprehension strategies to interpret and analyse texts, comparing and evaluating representations of an event, issue, situation or character in different texts (ACELY1744)
        - Use comprehension strategies to compare and contrast information within and between texts, identifying and analysing embedded perspectives, and evaluating supporting evidence (ACELY1754)

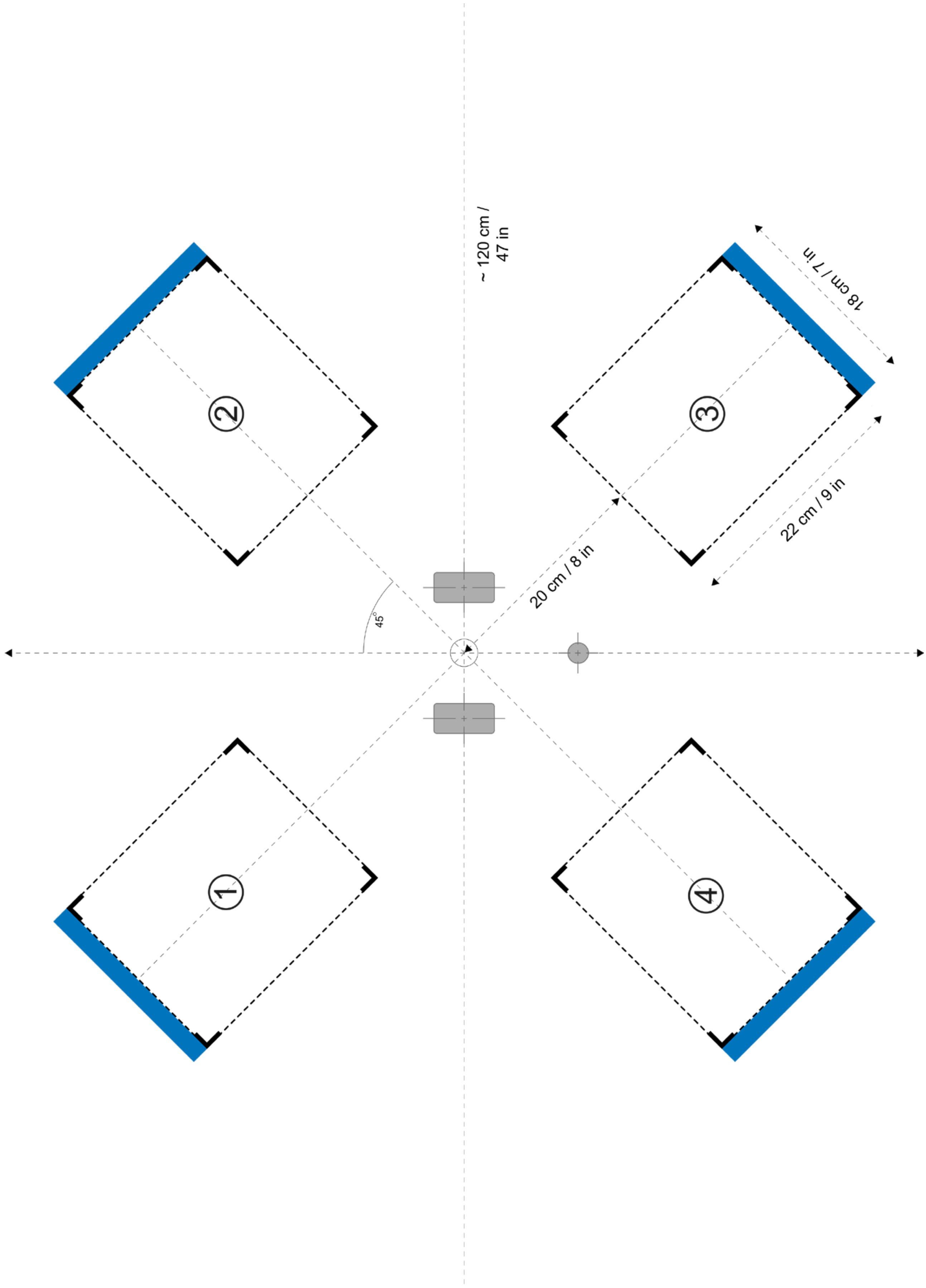
- Creating texts
  - Plan, draft and publish imaginative, informative and persuasive print and multimodal texts, choosing text structures, language features, images and sound appropriate to purpose and audience (ACELY1704)
  - Plan, draft and publish imaginative, informative and persuasive texts, choosing and experimenting with text structures, language features, images and digital resources appropriate to purpose and audience (ACELY1714)
  - Plan, draft and publish imaginative, informative and persuasive texts, selecting aspects of subject matter and particular language, visual, and audio features to convey information and ideas (ACELY1725)
  - Create imaginative, informative and persuasive texts that raise issues, report events and advance opinions, using deliberate language and textual choices, and including digital elements as appropriate (ACELY1736)
  - Create imaginative, informative and persuasive texts that present a point of view and advance or illustrate arguments, including texts that integrate visual, print and/or audio features (ACELY1746)
  - Create sustained texts, including texts that combine specific digital or media content, for imaginative, informative, or persuasive purposes that reflect upon challenging and complex issues (ACELY1756)

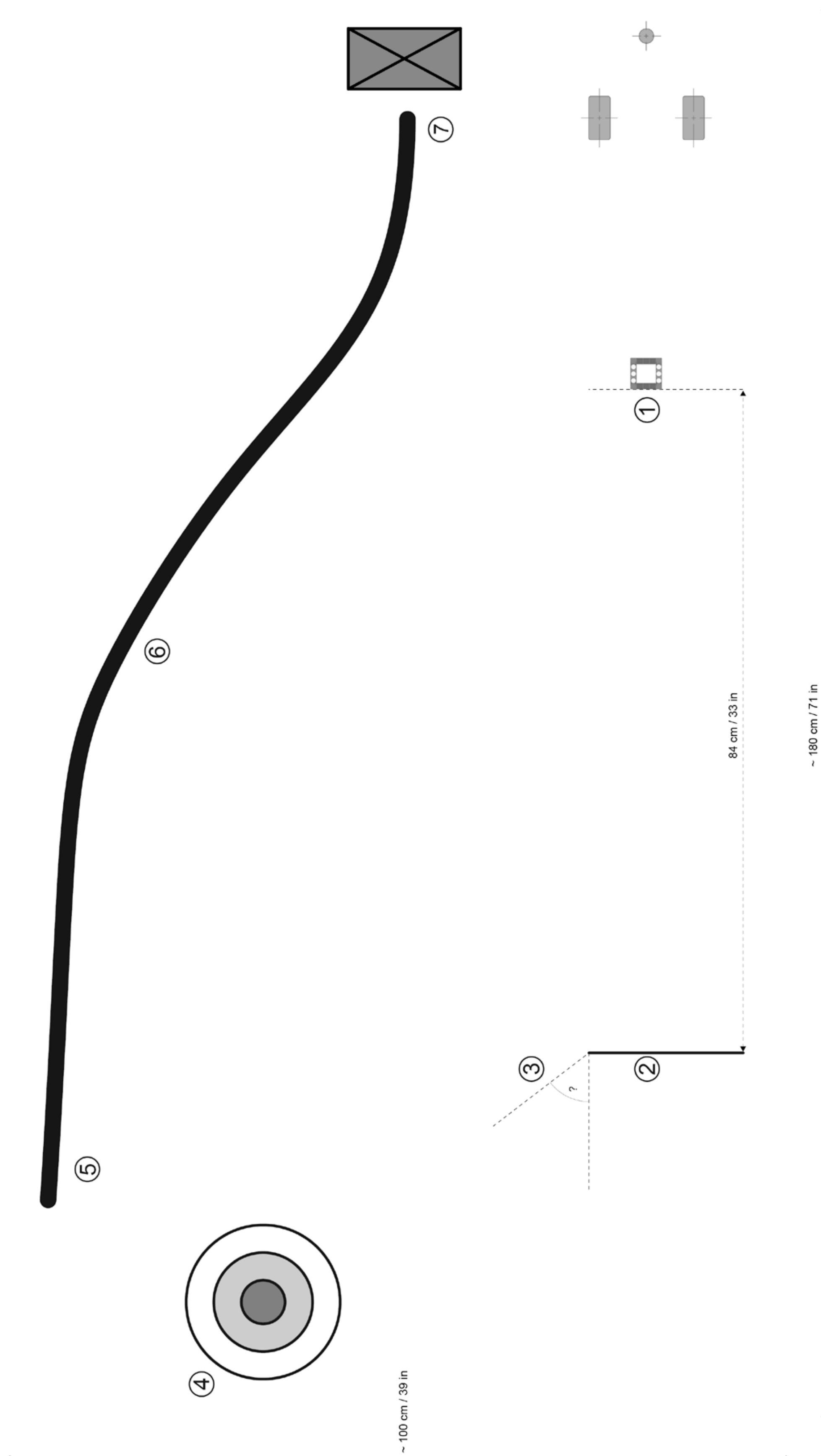
Introduction to Robotics Class Assessment Record

Name	Class	Building and Setup	Curved Move	Move Object	Stop at Object	Stop at Angle	Stop at Line	Follow a Line	Master Challenge 1	Master Challenge 2


③
④
18 cm / 7 in
22 cm / 9 in
②
~ 120 cm / 47 in
①
10 cm / 4 in
~ 60 cm / 24 in


~ 100 cm / 39 in
22 cm / 9 in
~ 60 cm / 24 in


~ 120 cm / 47 in
18 cm / 7 in
22 cm / 9 in
20 cm / 8 in
45°
2
3
1
4



7
1
6
84 cm / 33 in
~ 180 cm / 71 in
3
?
2
5
4
~ 100 cm / 39 in