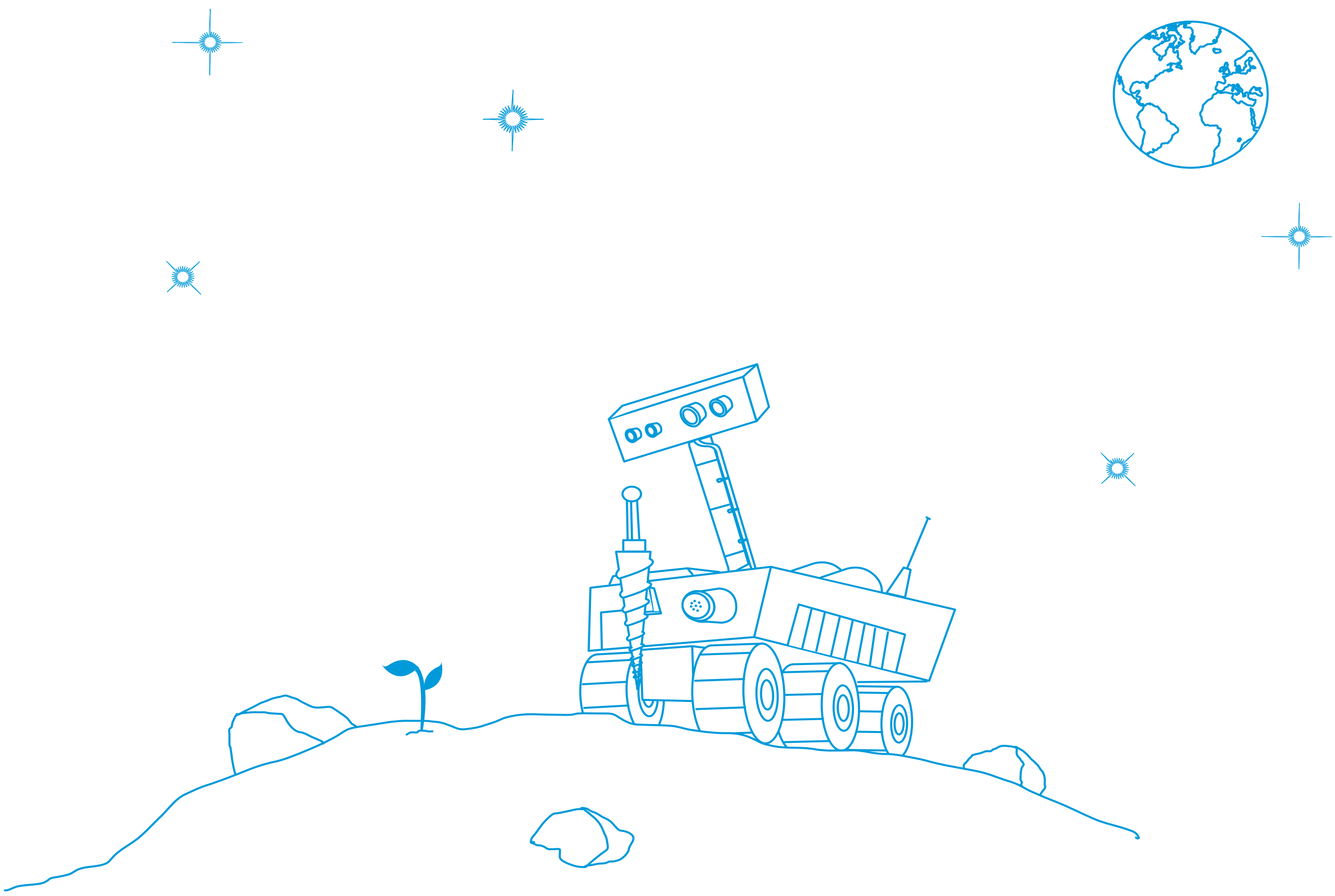
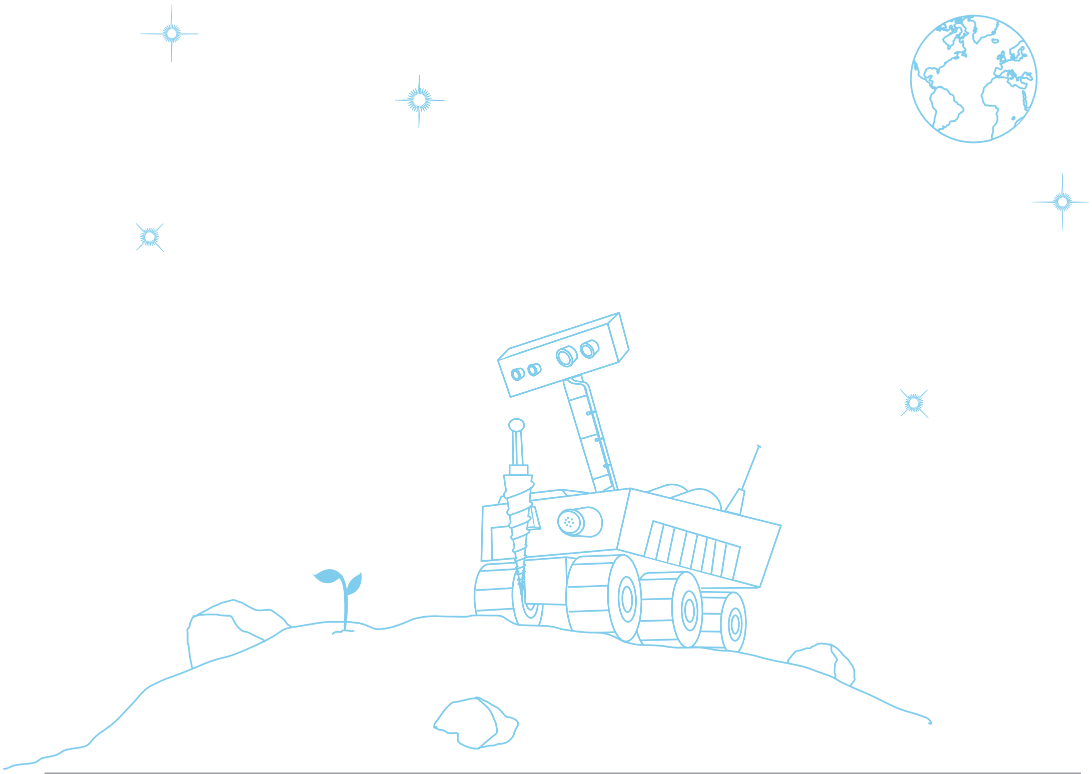
teach with space

→ BUILD YOUR MARS EXPLORATION ROVER

Building and programming a LEGO rover to collect science data





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→ BUILD YOUR MARS EXPLORATION ROVER

Building and programming a LEGO rover to collect science data

Fast facts

Age range: 12-16 years old
Type: hands-on inquiry-based activity
Complexity: easy, for beginners
Teacher preparation time: 15 minutes
Lesson time required: 5 periods of 45 minutes
Location: indoors (space to test robots)
Includes use of: LEGO Education Mindstorms EV3 (one core set, one expansion set, and one temperature sensor for 1 group of students).
Keywords: Rover, Mars, mission, program, engineering, experiment, data

Outline

Students will design and program a LEGO-built rover. Basic instructions are first programmed with the LEGO brick. Then, to remotely control the LEGO-built rover, students will program it with the LEGO Mindstorms EV3 software. The objective is to conduct a space experiment using a scientific approach and collect data. Measurements will be analysed and modelled so that they can be compared with the student's hypothesis.

Students will learn

- To recognise and program basic instructions in a block-based computer language
- To use a robotic tool to explore scientific content
- To develop scientific experiments and engineering skills for controlling individual experiment parameters
- To design a rover structure with mechanical constraints
- To design and evaluate a wheel system based on scientific experiments
- To collect data with a sensor
- To analyse data and processes to answer scientific questions
- To work and communicate together as a team

Additional information

In order to replicate the surface of Mars in the classroom and perform the activities included in these resources in a more engaging way you can produce a 'Mars carpet'. For this, all you will need is a high resolution image of the surface of Mars (download here). In ours, we have used a 4 x 2.5 metres mat made out of 510-grams frontlit (typical material used in banners) in order to ensure the necessary traction for the rovers.

→ Summary of activities

Summary of activities				
	Title	Description	Outcome	Requirements
1	What is the link between science, engineering, and programming?	Identifying the role of satellites and space technology.	To clarify students' preconceptions of satellites and introduce space technology.	None
2	How does the LEGO brick work?	Identifying components of the LEGO brick. Introducing motors and sensors.	To understand and apply the LEGO brick language and code basic instructions with a space context.	None
3	How do you remotely control a robot?	Introducing basic programming with the LEGO brick and software.	Develop a strategy to determine and program experiment parameters.	Activity 2
4	How do you build a rover and have it move safely?	Designing a rover using engineering skills.	To identify a technical problem and propose a solution based on technical reasoning.	None
5	How do you collect data from a rover?	Recording data from a specific experiment.	To collect data using a scientific approach, analyse it, and evaluate it against a hypothesis.	Activity 3

→ BUILD YOUR MARS EXPLORATION ROVER

Building and programming a LEGO rover to collect science data

→ Activity 1: What is the link between science, engineering, and programming?

This activity offers an opportunity for students to discuss with one another the main aspects of a scientific satellite mission, and hypothesise some suitable designs.

Exercise

It is a good idea to give the students the same kits and to explore the different possibilities – allow the students' creativity to flow.

Here, there are really no right or wrong answers. Question the students' decisions and try to ensure they understand the consequences of their chosen design features. Have they thought about all of the elements involved in a mission to space? When they come across a problem, or realise their design isn't optimal, encourage adaptation and 'learning by doing' to experiment with the materials they have.

→ Activity 2: How does the LEGO brick work?

This activity introduces students to programming using the on-board software on the EV3 Mindstorms LEGO 'brick'. This is a simple block-based programming language that will allow students to explore the main functions of the motors and sensors that will later become their rover.

Exercise

1. This question is an opportunity for students to demonstrate what they already know about programming. Again, here there are really no right or wrong answers; try to steer the discussion when needed but otherwise, explore!

2. Students should follow the instructions in the worksheet to start making their first program on the LEGO brick. To access the menu of instruction blocks, the 'up' button needs to be pressed when the central dotted line appears (see Figure A6 of the student worksheet). The up, down, left, right buttons can then be used to navigate through the menu.

3. & 4. It might be useful for the students to write down their interpretation of the instructions, step-by-step in the form of a flow diagram. Not only will this help create a clearer picture, it also acts as a useful diagnostic tool to identify if they have made a mistake and why. The program they have been asked to create will rotate the motors for 2 seconds.materials they have.

5. Instruction 1: Rotate the servo motors forwards.
   Instruction 2: When the touch sensor is pressed, rotate the servo motors backwards...
   Instruction 3: ...for 2 seconds.

The final instruction that was already included when the program was created means 'Repeat this program 1 time'. This number can be changed to define how many times the robot repeats the program.

6. Students should explore the menu to find the 'sound' block and change which sound the robot makes. Encourage an inquiry-based approach: to investigate, make predictions, test and evaluate the actions and results.

→ Activity 3: How do you remotely control a robot?

This activity gives students the chance to get to grips with the Mindstorms EV3 computer software. This software provides more functionality over the on-board block language used in Activity 2. Whilst it remains a block-based language, there are many more possibilities. Blocks are grouped into several categories, and easily identified by their colour.

Exercise

1. This question allows students to explore the different parameters of perhaps the most important block that can be used in any program used to operate a rover. Students should understand the main principles:

- The first parameter determines how the amount of rotation from the motors is governed: on, off or for a given amount of time, rotations, or degrees.
- The second set of parameters gives the power of each motor, from -100 to +100, where 0 is off. When it comes to incorporating the motors into a rover, it is this parameter that allows for steering.
- The third parameter is the amount of whichever constraint was chosen in the first parameter i.e. seconds, number of rotations, or degrees of rotation.

In the example, the motors have been set to 50 and -60 power (opposite directions) for 3 seconds. It may be difficult to determine the difference between 50 and 60 power in terms of rotational speed, but it is worth making a point that this slight difference would be enough to stop the rover travelling in a perfectly straight line (if the motors were turning in the same direction!).

2. As with any programming challenge, there is more than one way to complete this task. The most obvious is to use the turn tank block and select a turn to the right, denoted by the direction of the arrow.

However, some students may decide to use the 'move tank' block, and manually change the power of each motor, generating a turn. This is much easier to conceive if the students already have a demonstration rover that they can use to model their actions on.

3. The instructions given will show a picture on the on-board screen, play a sound, and then change the LEDs to a yellow colour.

→ Activity 4: How do you build a rover and have it move safely?

Students are now given the task of building their own rover. With the kits provided, there are many possibilities so you may wish to structure their thoughts and guide them towards a suitable solution, or, let them explore!

Exercise

1. The most suitable 'wheel' system depends upon the surface that will be explored using the LEGO rover. In most situations, any wheel system can be justified and used. However, if exploring a rough or uneven surface, students may find that the 'caterpillar tracks' like those used in the previously mentioned 'Tank Bot' provide more traction and easier movement across the surface. This is an opportunity to discuss friction and traction, and why it is actually a useful force!

2. This exercise allows students to properly explore the consequences of their chosen wheel system with a scientific method. If available, you could introduce different surfaces so that students can explore first-hand how their rover deals with different environments.

→ Activity 5: How do you collect data from a rover?

This activity explores the 'experiment' section of the EV3 Education Software using a simple experiment of the students' choice as context. The experiment section allows for live-viewing of data collected by any connected sensors. The graphs can then be analysed.

Exercise

The scope of this exercise is very broad, with the students deciding which sensor they will use. An important step is to first discuss with the students the limitations of each of the sensors (and their different modes) and what they could reasonably expect from them. Some sensors will naturally provide more interesting experiment opportunities than others here, but the main aim is to become familiar with the software and how it can be used to display data. As is often the case in science, the result itself is not so important, but understanding why it happened is!

→ Activity 1: What is the link between science, engineering, and programming?

Exercise

Create your own satellite model with the LEGO pieces given to you (Figure A1).

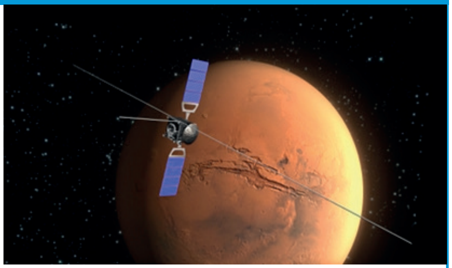
1. Describe the shape and scientific objective of the satellite model you created. Identify links between science, engineering, and programming.

Figure A1

↑ LEGO pieces

2. Are there differences between your model and those of your fellow students?

Did you know?

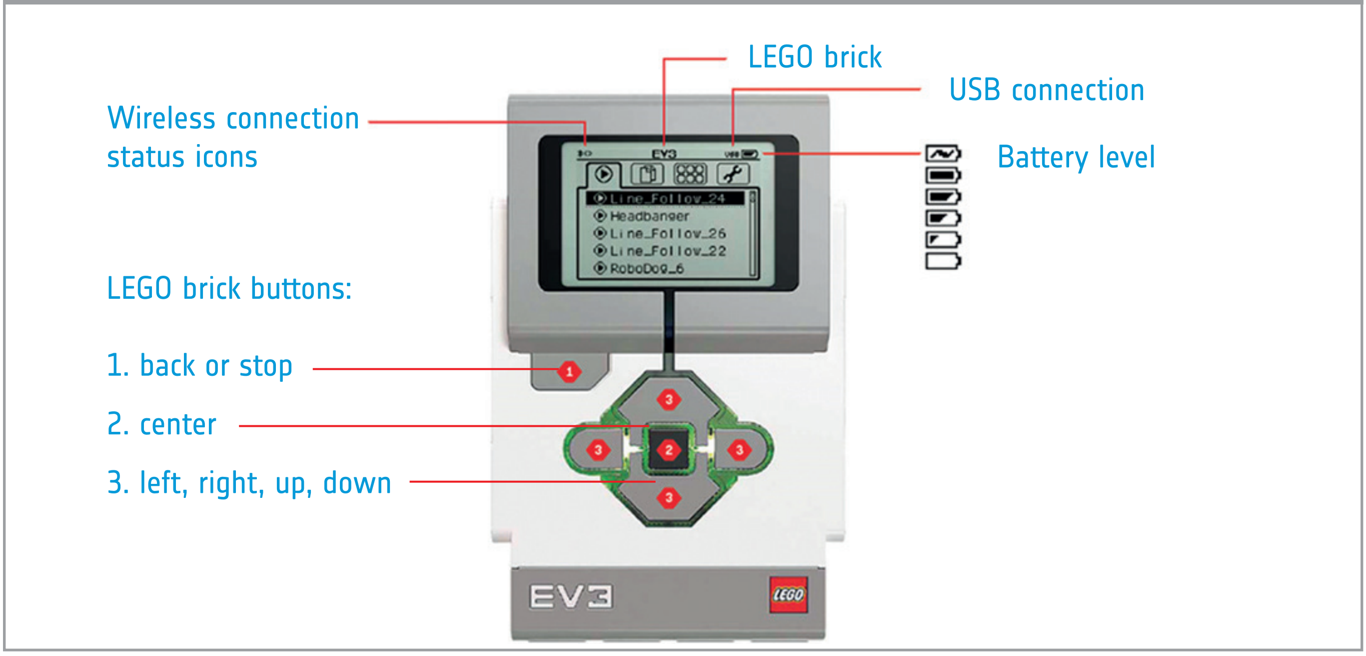


Mars has always been a source of great fascination for humankind. In a couple of decades we will hopefully be able to walk on the surface of Mars, just like we did on the Moon. Before getting there though, ESA, together with other space agencies around the world, needs to collect more information about Mars' evolution and environment. ESA also needs to gradually build the technology foundation for the more complex elements required by human missions. This is being achieved with the many orbiters and landers launched to explore Mars, each advancing our understanding one step at a time. The first European mission to the Red Planet was Mars Express, launched in 2003.

→ Activity 2: How does the LEGO brick work?

Take the LEGO brick and switch it on by pressing on the central button (Figure A2). The general parameters displayed on the LEGO brick screen are described in the image.

Figure A2



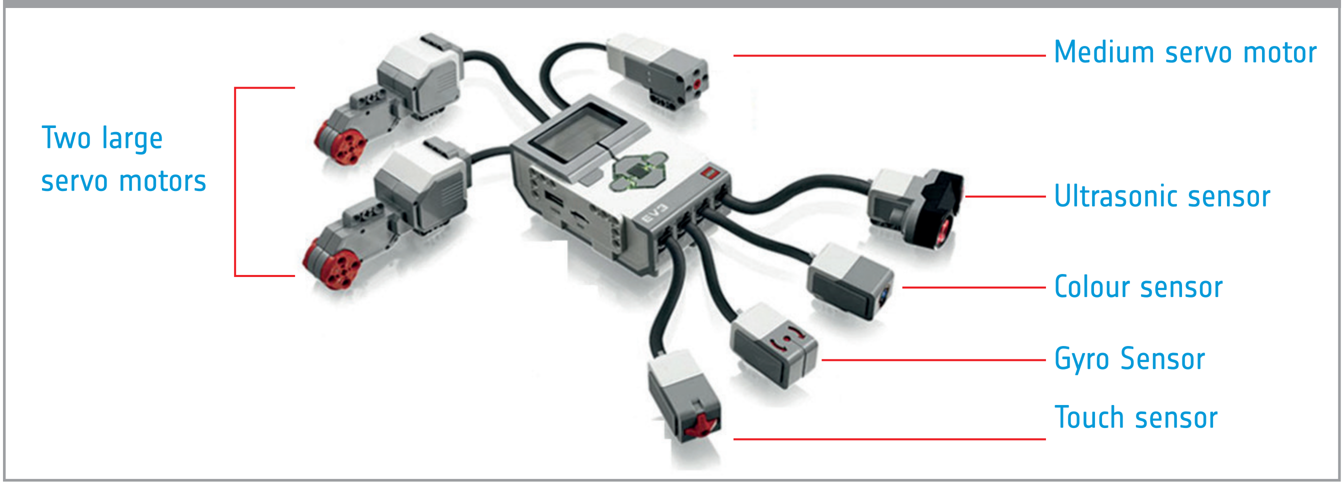
↑ LEGO brick computer screen description

Turn the LEGO brick on its side to identify the ports :

- There are 4 ports at the top (A to D) to connect **the robot's motors**
- There are 4 ports at the bottom (from 1 to 4) to connect the **robot's sensors.**

The LEGO brick motors and sensors are the heart of your robot. In the basic version of the LEGO Education Mindstorms EV3 kit, you have 3 motors and 4 sensors (Figure A3). You also have the possibility of adding other sensors, such as the temperature sensor.

Figure A3



↑ LEGO brick with motors and sensors connected

Exercise

1. Before working with the LEGO brick, look at Figure A4 and write what 'programming' means to you :

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Figure A4

```
#include <iostream>

using namespace std;

int main()
{
    cout << "Hello world!" << endl;
    return 0;
}
```

↑ Programming code C++

In order to give instructions to the LEGO brick and have it execute actions, it is essential to structure the actions in a very logical way. To help do this, the LEGO brick uses icons representing basic sets of instructions.

2. Connect the two large servo motors to ports B and C and connect the touch sensor to port 1.

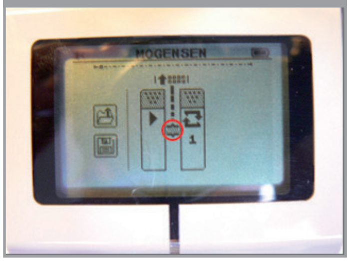
1. In the third section (Figure A5), select the 'Brick program' tab to create a program.

Figure A5

↑ Brick program menu

2. Select the area (circled in red) between the ▶ and [loop icon] (Figure A6) to add the instructions.

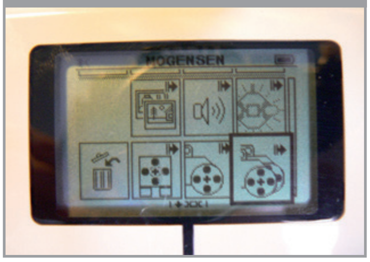
Figure A6



↑ Empty brick program

3. Look at the different icons on Figure A7 and select the large servo motors icon.

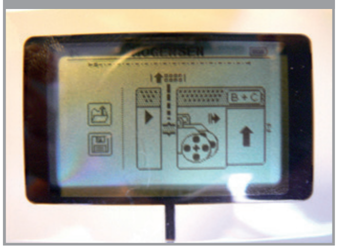
Figure A7



↑ Brick instructions

4. The large servo motors have been added to the program. Make sure the motors are properly connected to ports B and C.

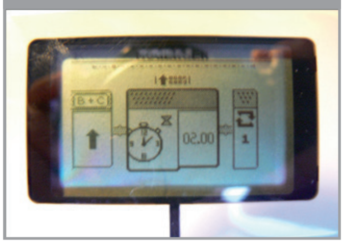
Figure A8



↑ Brick program with motor

5. Define a precise period of time you want the motors to run for by selecting the clock icon and placing it to the right of the motor icon.

Figure A9



↑ Brick program with clock

3. Before testing the program, write down what you predict will happen when it starts.

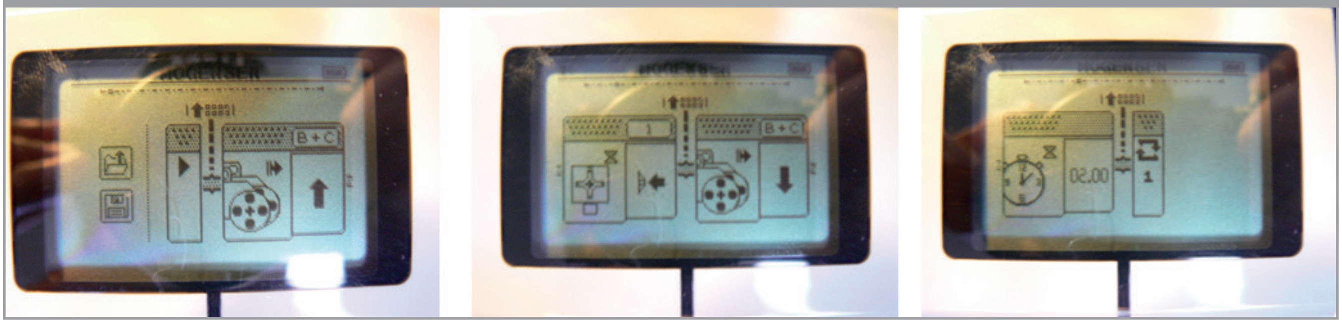
To start the program, press the ▶ icon.

4. Describe the actions of the robot and compare them with your predictions.

Exercise

Look at Figure A10. In the boxes below, describe the actions you expect from the robot when you will run this program.

Figure A10



↑ Brick program

Instruction 1	Instruction 2	Instruction 3

To verify your expectations, insert the same instructions you see in Figure A10 into your LEGO brick. If necessary, correct your predictions using another colour.

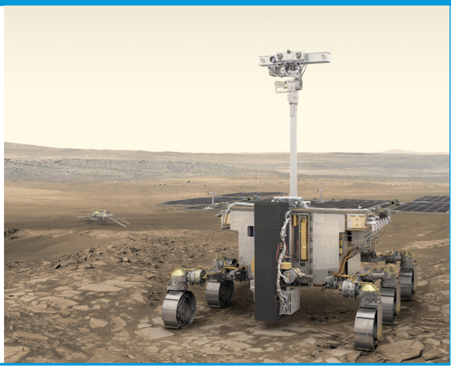
Exercise

1. Define a new set of instructions in order to move the two large servo motors in the opposite direction after you press and release the touch sensor. Draw the icons to be used in your program below.

2. Complete your program by adding an icon that will produce the sound of the word 'STOP' at the end of the action. Explain your approach below.

Did you know?

Mars is a potential destination for human space exploration. Before astronauts can be sent there, key technologies must be demonstrated using robotic missions. An important step will be a mission that can land, then move to collect interesting samples of soil and rocks, before finally returning them to Earth. The ExoMars rover, developed by ESA, provides important mission capabilities that will be needed for a Mars Sample Return: surface mobility, subsurface drilling for collecting samples, sample processing, distribution, and analysis with instruments.



→ Activity 3: How do you remotely control a robot?

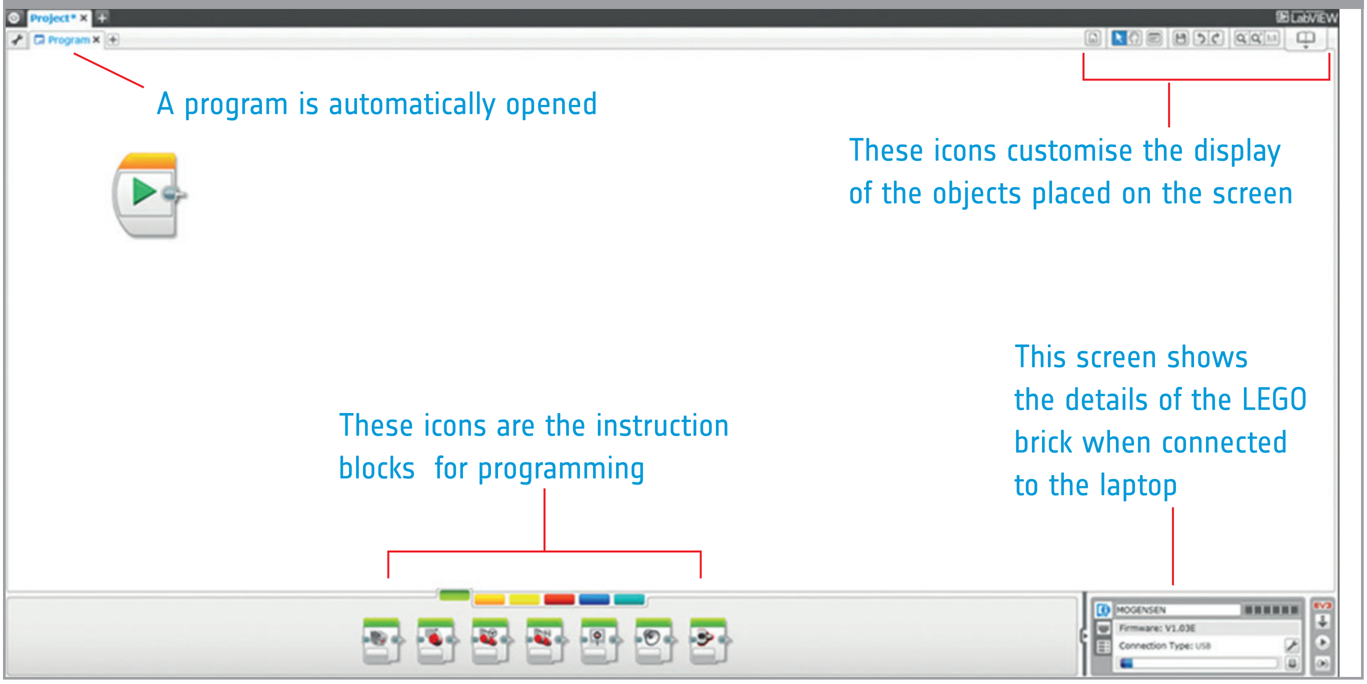
The LEGO Mindstorms software remotely controls a robot by communicating with the LEGO brick. Launch the LEGO Mindstorms EV3 Education software and click on '+' (circled in red in Figure A11) at the top left of the window to open a new project.

Figure A11

↑ LEGO Mindstorms EV3 Education interface

The project window is described in Figure A12. It allows you to arrange instruction blocks to program the LEGO brick. Identify all the tabs to fully understand their functions. Connect the LEGO brick to your laptop using the USB cable.

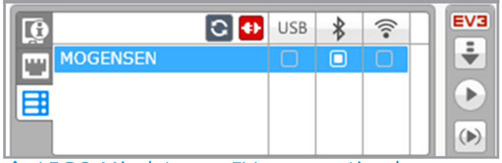
Figure A12



↑ LEGO Mindstorms EV3 program window

Start the wireless communication between the robot and the laptop by using Bluetooth and disconnecting the USB cable. The Bluetooth button is filled when the connection is established (Figure A13).

Figure A13



↑ LEGO Mindstorms EV3 connection box

Exercise

1. In the green category of instruction blocks, select the fourth icon which runs the two large servo motors. Using the 'drag and drop' method, place it beside the 'play' icon. Adjust the settings of the block as shown in Figures A14/A15. Describe each parameter's function before starting the program.

Figures A14/A15

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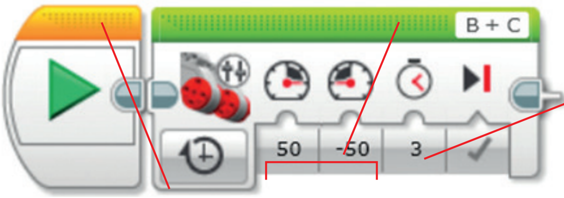
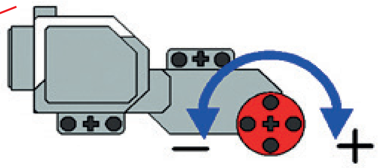


↑ Large LEGO servo motors block



↑ Direction of LEGO motors

To verify the explanation of your parameters, click on the green play button or on the small play button ▶ at the bottom right of your screen. To execute the program without the USB cable, first download it onto the LEGO brick, then remove the USB cable and start it by pressing the centre button of the LEGO brick.

2. Write a set of instructions to move the robot forward for two seconds and then turn right. Complete Figure A16 with the correct block, and fill the small boxes with the defined parameters.

Figure A16

↑ Large LEGO servo motors block to be completed

3. Write down how you expect the robot to behave if it receives the following set of instructions:

Figure A17

↑ LEGO instructions blocks

____

____

____

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4. Verify your prediction by inserting these instructions on your laptop and running the program on the LEGO brick.

→ Activity 4: How do you build a rover and have it move safely?

Using the LEGO pieces, build the structure of a robot that will safely move on the Martian surface. You can either follow the instructions given in Annex 1 or, using your imagination, create a rover to your liking. Look at Figure A18. Decide how to build the wheel system necessary for the rover to move safely, by identifying all the constraints and limitations related to a Martian terrain.

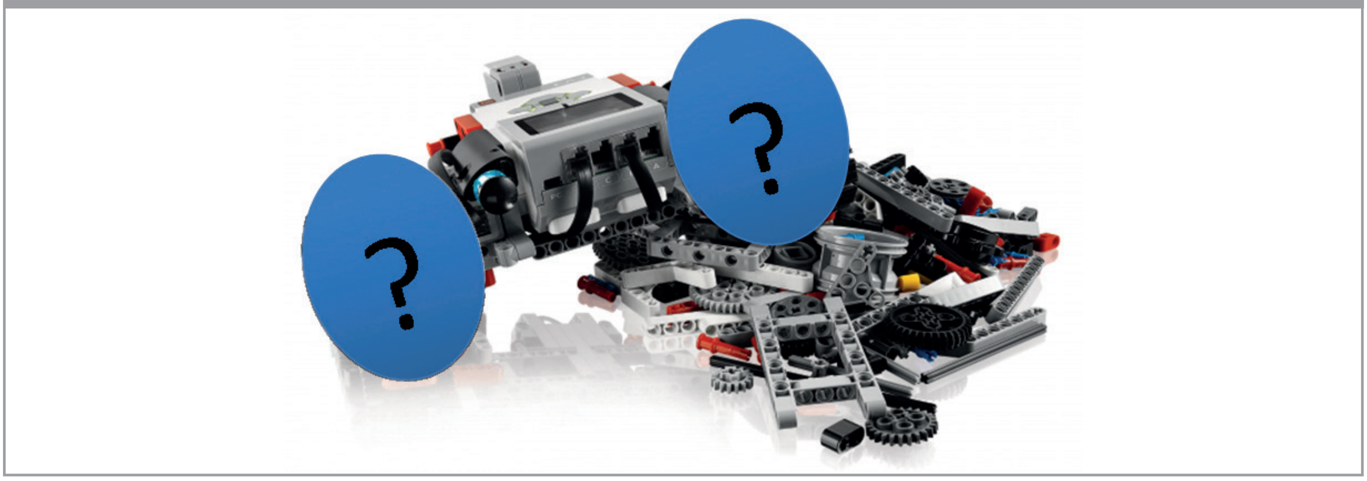
Figure A18

↑ LEGO wheel systems

Exercise

1. Justify your chosen wheel system below:

Figure A19



↑ LEGO wheel systems to be defined

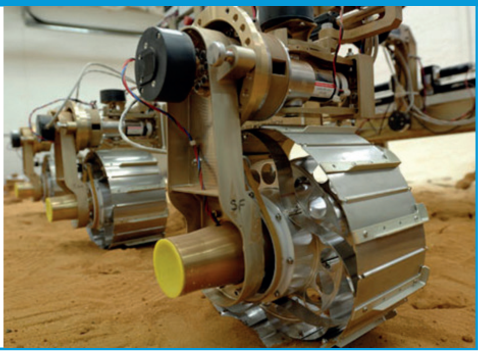
2. Think about how your rover will behave on Mars with this chosen wheel system. How will it react to different parameters (e.g. the slope of the surface, the unevenness of the surface)? Consider the impact of the wheel constraints on the movement of the rover. Implement different situations to test the rover's performance, and write your results in Table A1.

parameters	observations	explanations

Table A1: Specifications of the rover.

Did you know?

The locomotion of ESA's ExoMars rover is achieved using six wheels. Each pair of wheels is suspended on an independently pivoted bogie (the framework holding the wheel drives), and each wheel can be independently steered and driven. All wheels can be individually pivoted to adjust the rover's height and angle with respect to the local surface, and to create a sort of walking ability, particularly useful in soft, non-cohesive soil (e.g. dunes).



→ Activity 5: How do you collect data from a rover?

As robotics assists with scientific experiments, it is necessary to add a sensor that will collect data from the robot.

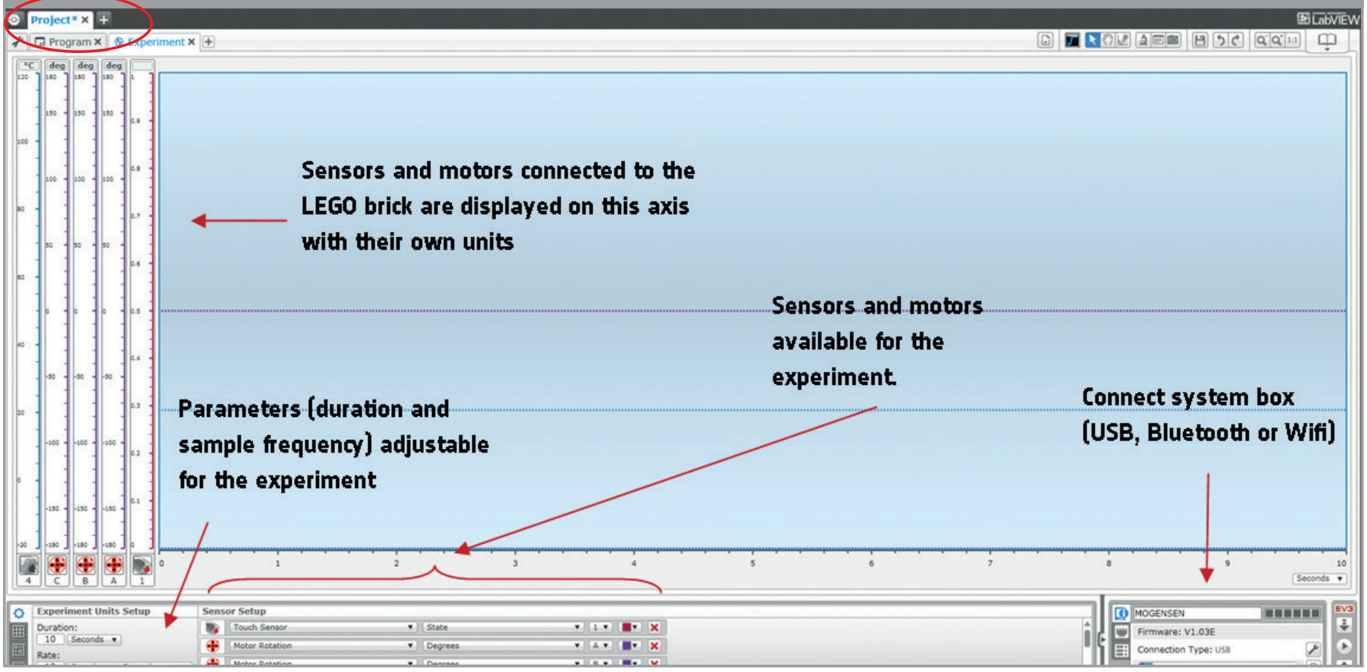
Select one sensor from this list: touch, colour, gyro, ultrasonic, or temperature, and connect it to port 1 of the LEGO brick.
Selected sensor : ____

Launch the LEGO Mindstorms EV3 Education software (Figure A11) and open a new experiment by clicking on the '+' at the top left, circled in red in Figure A21. The experiment window is described in Figure A21. It allows you to collect the sensor measurements during an extended period of time. Identify all the tabs to fully understand their functions.

Figure A20

↑ Ultrasonic sensor connected to the LEGO brick

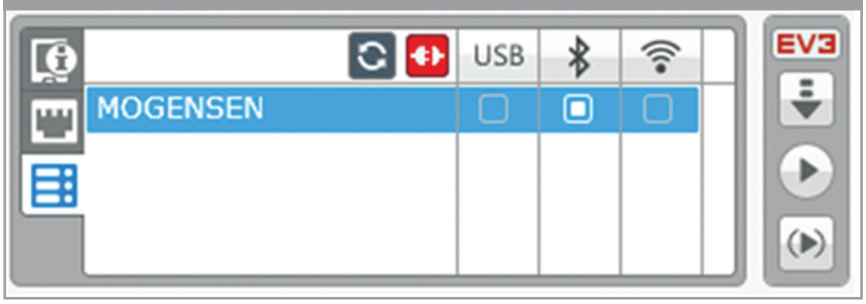
Figure A21



↑ LEGO Mindstorms EV3 experiment window

Start the wireless communication between the robot and the laptop by using Bluetooth and disconnecting the USB cable. The Bluetooth button in Figure A22 is filled when the connection is established.

Figure A22



↑ LEGO Mindstorms EV3 connection box

Exercise

Imagine a context to conduct an experiment with the sensor you selected. In Table A2, define and comment on the experiment parameters (e.g. scale, sample frequency, duration ...).

context	
parameter 1:	
parameter 2:	

Table A2: Experiment parameters

This icon shown at the top right of the screen enables you to draw the experiment prediction. Use this tool to draw your prediction curve before starting the program using the icon shown at the bottom right of the screen. Measurements will be plotted on the screen in real time during the selected time-interval.

Complete the graph with the data collected (label axes and include units) and analyse the differences between your predictions below.