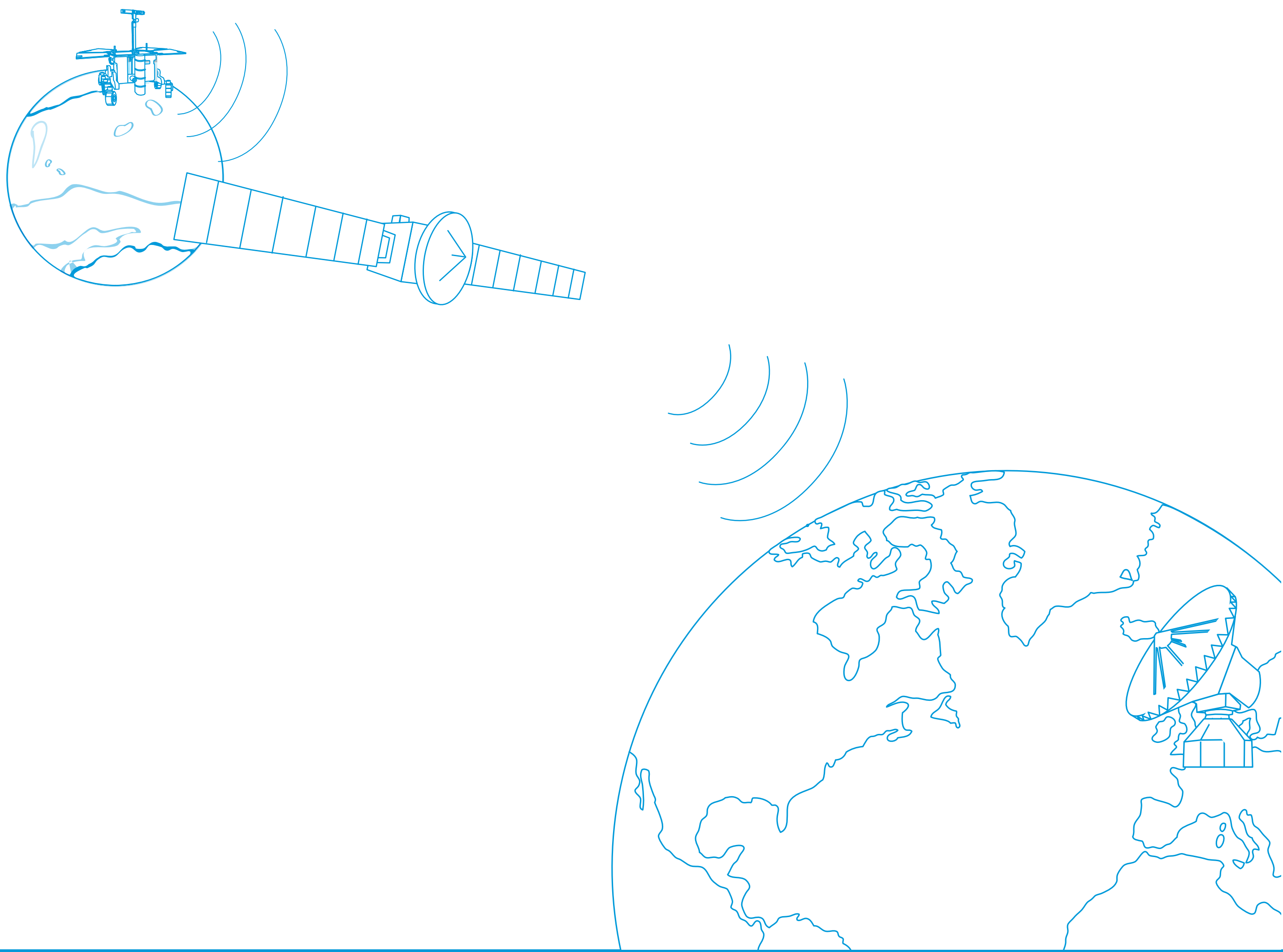
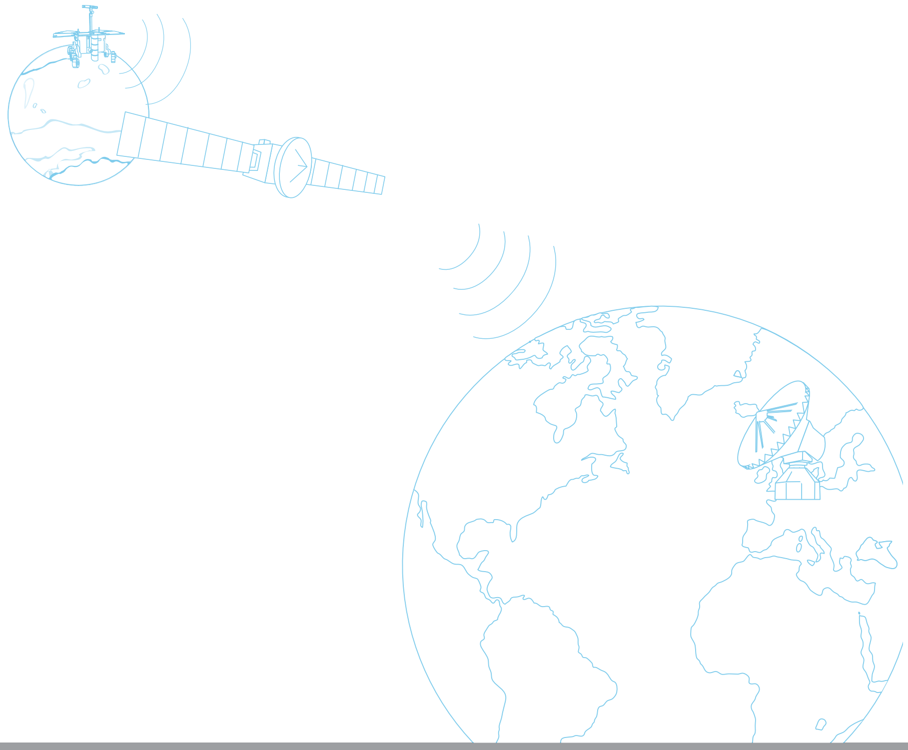
teach with space

→ "HELLO, IS THIS PLANET EARTH ?"

Programming a LEGO rover to communicate using light



European Space Agency



teach with space – hello, is this planet earth? | T03
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→ "HELLO, IS THIS PLANET EARTH?"

Understanding how to communicate with light

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: 6 periods of 45 minutes
Location: indoor (space to test robots)
Includes use of: LEGO Education Mindstorms EV3 (one core set, one expansion set, and one temperature sensor for 2 students), laser, mirror
Keywords: Rover, Mars, communication, signal, mission, hypothesis, program, sensor.

Outline

In this activity, students will communicate with a rover on Mars. The objective of the mission is to send an automatic message from Earth to a rover located on Mars via an Orbiter. This message is sent by a programmed, LEGO-built, robot running an automatic switch. The rover on Mars receives the code via a LEGO light sensor, and students analyse and model the data to translate the message. Students learn how a basic telescope works by magnifying images of Mars using two lenses.

Students will learn

- To understand optical propagation of a light source
- To model a light ray
- To verify the law of light reflection on a plane mirror
- To magnify an object with lenses: bi concave and bi convex
- To model data or processes to answer scientific questions
- To develop scientific research experiments and engineering skills, for controlling individual experiment parameters
- To collect data with a sensor
- To use a robotic tool to explore scientific content
- To work and communicate 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	How does space communication work?	Identifying and explaining how information is transferred through space.	To clarify students' preconceptions about communication between Earth and Mars.	None
2	How is a mission managed?	Planning a scientific mission by describing and explaining the various steps involved.	To understand the processes necessary for a successful mission.	None
3	How do you send an automatic laser signal?	Ensuring the correct orientation of the model with the laser with optimum direction of propagation.	To understand how light propagates through space and describe a strategy for the LEGO rover to send a message.	Activity 3 of ESA teach with space - build your mars exploration rover | T01
4	How do you relay a signal?	Carrying out an experiment to observe light reflection on a plane mirror.	To understand that data can be modelled and implement this to interpret data more easily.	Activity 3
5	How is the signal collected?	Collecting a laser signal and interpreting the message using a light sensor.	To understand that data can be modelled to make it easier to work with.	Activity 4 Activity 5 of ESA teach with space - build your mars exploration rover T01
6	How do you magnify images with a telescope?	Designing an experiment to magnify an image using lenses. Investigating convex and concave lenses.	To understand how telescopes use lenses to allow us to see a larger image of a distant object.	None
7	How do you complete a mission successfully?	Considering the skills and knowledge acquired through planning a mission.	To understand that a mission requires many different skills and areas of knowledge, and to self-evaluate.	None

→ "HELLO, IS THIS PLANET EARTH?"

Understanding how to communicate with light

→ Activity 1: How does space communication work?

This activity gives students the opportunity to research several different communications devices and find out about how they operate.

Exercise

1 & 2. Students should identify, through research or their existing knowledge, that information is sent from a transmitter and received by a receiver, often using of an antenna. It's possible to draw analogies to sending a message with a voice. Firstly, the transmitter sends the signal (speaks), the vibrations travel through the air as sound and the ear receives the signal. The speed the signal travels at depends on what type of signal it is. If it is electromagnetic (all of the examples mentioned in exercise 2) then the signal travels at the speed of light. If it is audio (e.g. speaking) then the signal travels at the speed of sound.
This is the same basic premise behind how all the other communication devices mentioned work, the main difference is how the energy is transferred. With sound, it is the vibrations of the air particles themselves that carry the sound from transmitter to receiver. In the electromagnetic case the energy is carried by photons that travel through the air.

3. Students should identify that the Orbiter acts as a relay between the rover and the antenna as the rover does not necessarily have a line of sight to the antenna. It's also important to note that the communication is two-way, that is, the rover and antenna in this model are both sending and receiving messages.

4. The main point to understand in this exercise is that the geometry of the system is dynamic, and a constant link to the rover is not necessarily possible. This is due to combinations of the rotation of Earth and Mars and the orbits of the the two around the Sun, as well as the orbit of the Orbiter around Mars. To extend this, you could discuss the consequences of the type of orbit the Orbiter was in, does it make a difference if it is in a geo-stationary orbit or a polar orbit? The take-home message is for the students to understand that for the communication to work, there must be line of sight between the antenna and orbiter and the orbiter and the rover.

→ Activity 2: How is a mission managed?

This activity tasks students with formulating a hypothesis about light communication, which can be later investigated using a laser and the LEGO Mindstorms EV3 tools.

Exercise

The scope in this exercise is quite wide and open-ended, so allow students to be creative and discuss amongst one-another when formulating a hypothesis. Moderate the discussion and ensure that it will be possible to investigate with the materials available.

Some ideas to start a discussion:

- Is the speed of communication important?
- Does ambient light affect communication?
- Does the colour of the light have a role?

→ Activity 3: How do you send an automatic laser signal?

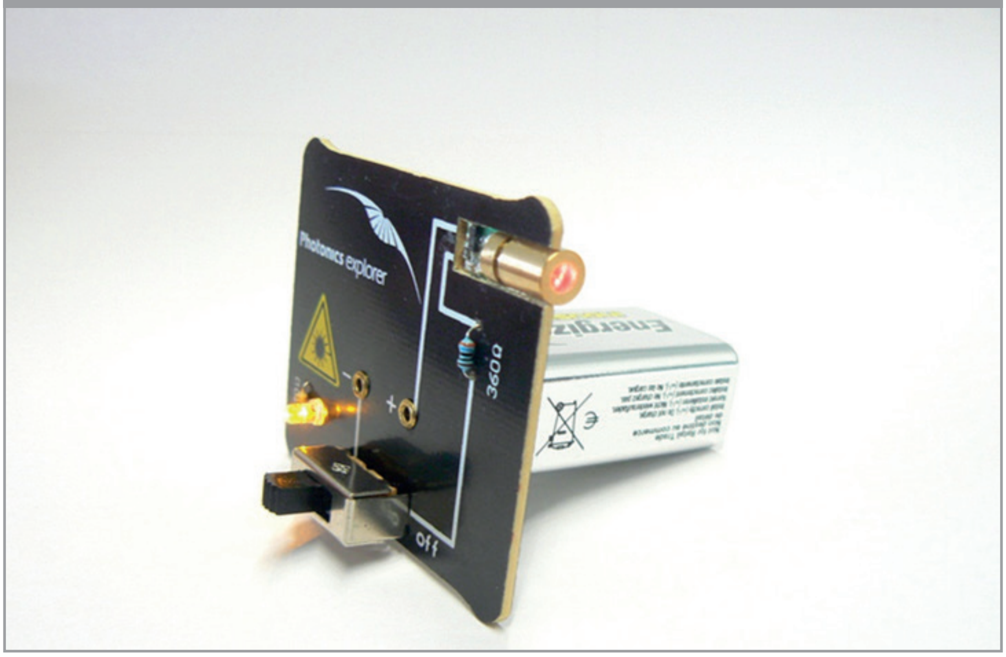
This activity introduces the basic principles of using light for communication, incorporating a Mindstorms model and program to help produce a message to be sent. Again, there is flexibility and the option to explore many methods of communication.

This simple exercise is to ensure that the model that is later built to help send the laser communication signal is built with the correct orientation. If you are using the same lasers used in Figure A7 (from the Photonics Explorer kit) then the direction of propagation is shown below:

Exercise

1. There are two main methods of operation that can be chosen here. The first, is to design a system that can switch on and off the laser directly. The second system is to have the laser constantly switched on, and design a model that can interrupt the passage of the signal periodically. Within these two systems, there are many possible configurations, again, let creatively flow.

Figure 1



↑ Code

→ Activity 4: How do you relay a signal?

This activity gives students the opportunity to demonstrate their understanding of the law of reflection.

Exercise

1. Students should explain how incident photons are reflected by the mirror and form an image, seemingly behind the surface of the mirror.

2. Ensure that the students accurately measure angles using a protractor and that angles are measured from the normal of the mirror.

→ Activity 5: How is the signal collected?

This activity explores the light sensor included in the Mindstorms EV3 hardware and its 3 modes of operation, so that students can correctly identify the most suitable method to collect the laser signal. It's important to note that two Mindstorms kits must be used in order to send and receive a signal. This is a natural opportunity to split students up into teams of senders and receivers and have them swap to learn both halves of the mission.

Exercise

1. The findings of the students and which mode of operation is determined to be the most suitable may vary depending on the environment of the room used for the experiment, however the modes can be summarised as follows:

Colour mode:
- Assigns an integer between 0 and 7 depending on the colour observed by the sensor (closely linked with the colours of bricks used across the Mindstorms set)

Ambient light:
- Returns an integer between 0 and 100 that scales as the intensity of the ambient light measured increases.

Reflected light:
- Emits a red laser and returns an integer between 0 and 100 depending on the intensity of the reflected red laser that is received

2. To improve the readability of the message received, students should first setup the axes of their graph. The collection time can be changed, as well as the axes minimum and maximum values, to ensure that the data uses as much of the available space as possible. Note, the y-axis does not necessarily have to start at 0!

Have the sending team design the program to send a message of their choosing and send it using the software. The receiving team must then measure and interpret the signal. To improve the chances of a successful transfer, ensure that students establish common rules for the code they choose to use to communicate. i.e. establish the 'length' of a space for part of a character, a new letter and a new word.

→ Activity 6: How do you magnify images with a telescope?

Extending earlier work on reflection, activity 6 briefly discusses refraction, and how it can be used to magnify images. This activity should be used to confirm existing knowledge of lenses and magnification, and not as an introduction.

Exercise

Using a smartphone and logging images is an optional part of this exercise and measurements could instead by measured qualitatively, in order to understand the differences between the convex and concave lenses. It is also important to point out that not all lenses of the same type have the same focal length – this can be easily demonstrated.

1. The ultrasonic sensor may have difficulty consistently detecting the lenses. To overcome this, once the correct distances to produce a sharp image have been set, the lenses can be replaced with objects that are more easily detected – large, flat objects work best.

→ Activity 7: How do you complete a mission successfully?

The final activity is an opportunity to discuss with one another the lessons learned throughout the mission and to revisit the hypothesis from activity 2.

→ Activity 1: How does space communication work?

Exercise

1. Explain how information travels from one point to another e.g. through space from Earth to Mars. Identify the medium that it travels through and the speed that a signal travels at.

2. Explain how these useful communication devices work. Find their similarities and differences:

Figure A1

↑ Old radio

Figure A2

↑ Smartphone

Figure A3

↑ Wifi router

Figure A4

ESA/ATG/medialab

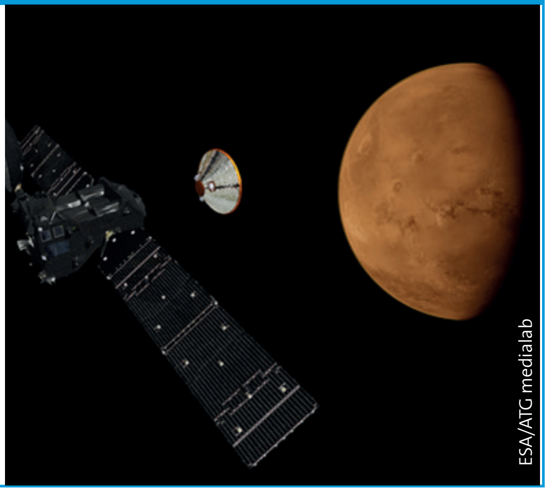
↑ ESA's ExoMars 2016 spacecraft.

Figure A5

↑ Galileo antenna at ESA's Redu station

Did you know?

The second of the two missions in the ExoMars programme will deliver a rover and a Russian experiment-filled surface platform to Mars. The ExoMars rover will travel across the Martian surface to search for signs of life. It will collect samples with a drill and analyse them with next-generation instruments.
The ExoMars Trace Gas Orbiter (TGO), launched in 2016 and now in orbit around Mars, will support communications with the rover. Commands to the rover will be transmitted via the TGO and ESA's space communications network that is operated by ESA's European Space Operations Centre (ESOC) in Germany.



3. In Figure A6, illustrate how communication from Earth to the rover on Mars is possible, taking the ExoMars Trace Gas Orbiter into account.

Figure A6

↑ Illustration of the communication route between Earth and Mars

4. Explain whether this system of communication always works.

→ Activity 2: How is a mission managed?

Planning a space mission means defining scientific objectives by first formulating a scientific hypothesis, which is a proposition or theory to explain things we observe. The objective of the mission will be to test and answer this hypothesis.

Exercise

1. After discussing it with your teacher, formulate your research hypothesis regarding light communication:

" ____

____ ?"

Did you know?

The ExoMars programme consists of two missions. The first one, launched in March 2016, consists of the Trace Gas Orbiter (TGO) which is now in orbit around Mars. The second mission, to follow in 2020, features a rover called Rosalind Franklin and a Russian, experiment-filled surface platform. A number of important scientific investigations will be carried out, such as searching for signs of past and present life on Mars, investigating how the water and geochemical environment varies, and investigating Martian atmospheric trace gases and their sources.

2. To achieve your mission objective, you have to structure it – this involves identifying all the different steps that are needed in order to complete the mission.

In Table A1, describe the different steps of your mission :

steps	description	skills / knowledge requirements

↑ Table A1: Mission steps.

→ Activity 3: How do you send an automatic laser signal?*

The Earth gets its energy from the Sun, which warms us with radiation. This light energy can also be used as a means of communication in space. For our experiment on the properties of light, we propose to use a safe laser source so that we can observe light propagation.

Exercise

1. Using a laser source (Figure A7), design an experiment to determine the direction of light propagation. Illustrate your experiment in the box below, and share your conclusions. Then complete Figure A7 with a vector ⟶ from the laser source to model this property.

Illustration of the experiment :

Conclusion :

____

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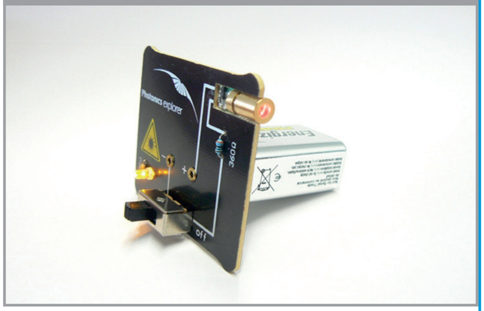
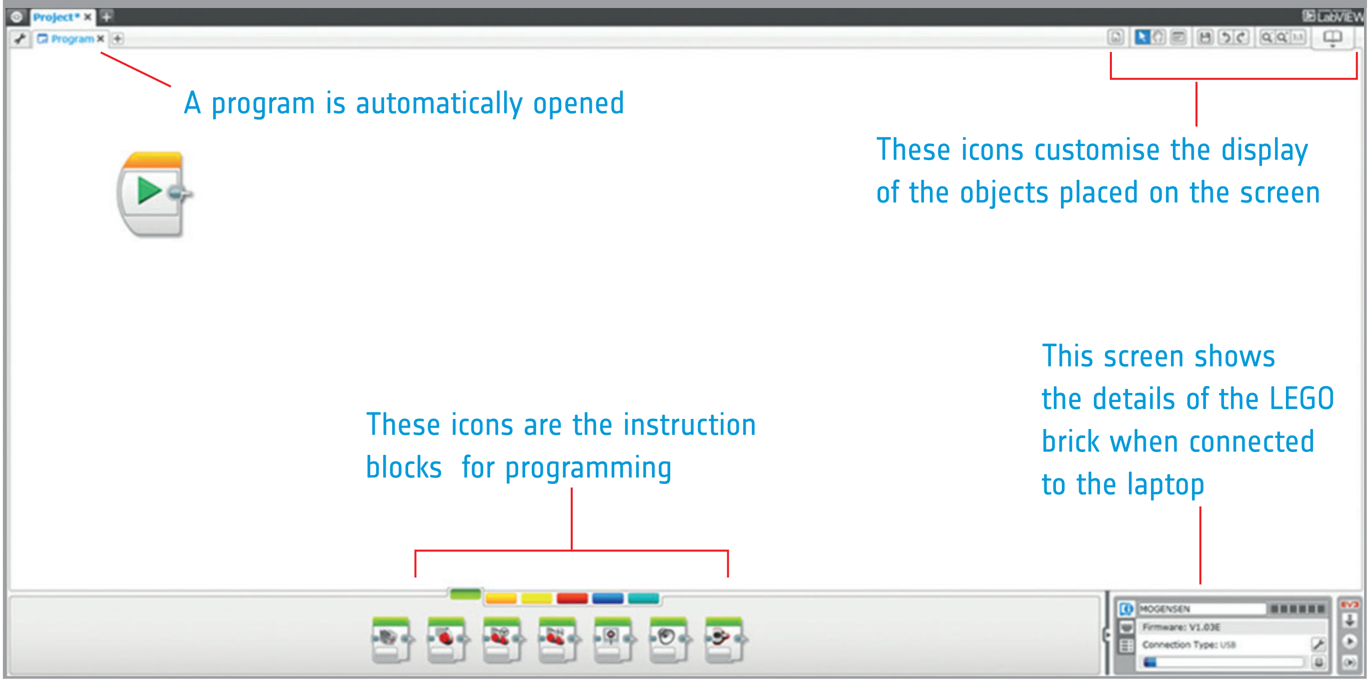
Figure A7



↑ Laser source

Launch the LEGO Mindstorms EV3 Education software to program a LEGO-built robot and create a new project.

Figure A8



By assembling the instruction icons in an appropriate order, design a program that will automatically switch on the laser source. Build a LEGO structure using motors and/or sensors if needed. Once the program is running, the laser should automatically be switched on/off to send messages properly. Alternatively, rather than designing a system to automatically turn the laser on/off, you might find it easier to build a system that temporarily blocks the path of the laser.

*Requirement: Activity 3 of ESA teach with space - build your mars exploration rover | T01

Exercise

Figure A9 is an example of a code that could be used to send a message to Mars. To send an A, the laser should be switched on three times, each time for a duration of one unit of time. To send a J, the laser should be switched on for two units of time and then switched off, switched on for one unit of time, switched off, and again switched on for one unit of time.

Figure A9

1	1	1	**A**	1	2	1	**D**	1	3	1	**G**
1	1	2	**B**	1	2	2	**E**	1	3	2	**H**
1	1	3	**C**	1	2	3	**F**	1	3	3	**I**
2	1	1	**J**	2	2	1	**M**	2	3	1	**P**
2	1	2	**K**	2	2	2	**N**	2	3	2	**Q**
2	1	3	**L**	2	2	3	**O**	2	3	3	**R**
3	1	1	**S**	3	2	1	**V**	3	3	1	**Y**
3	1	2	**T**	3	2	2	**W**	3	3	2	**Z**
3	1	3	**U**	3	2	3	**X**	3	3	3	␣

↑ Code

1. Use this code or create your own to send a message. Write down the message you want to send.

   ____

   You might want to extend this by using morse code instead! Morse code has internationally-recognised rules, so more people have a better chance of being able to decipher your message!

2. Explain the strategy you would use to send the message using a LEGO-built robot. Describe the role of each motor and/or sensor you would use to send the message.

motors	
sensors	

↑ Table A2: Strategy to send a message automatically.

→ Activity 4: How do you relay a signal?

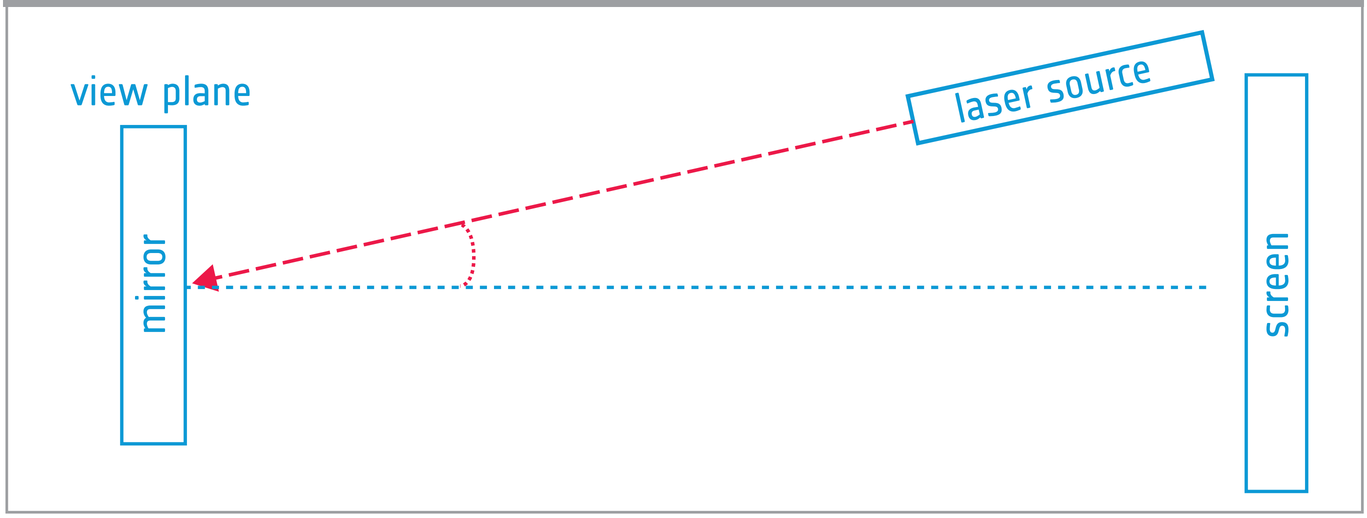
Exercise

1. Look at Figure A10. Explain how we see multiple images of candles using mirrors.

Figure A10

↑ Mirrors and candles

Figure A11



↑ Light reflection property

2. Place the laser, mirror, and screen as in Figure A11. Switch on the laser source and model its reflection with a blue vector in Figure A11. Measure the angles of the incident ray (in red) and the reflected ray. Regarding those angles, describe the property that light demonstrates when reflected on a plane mirror.

→ Activity 5: How is the signal collected?*

Exercise

1. You need a light sensor to collect a laser signal and interpret the message sent. Three properties of the light sensor are proposed: colour, ambient light, and reflected light. Try them on the brick and write down your observations in Table 3.

	colour	ambient light	reflected light
observations			
explanations			

↑ Table A3: LEGO light sensor properties.

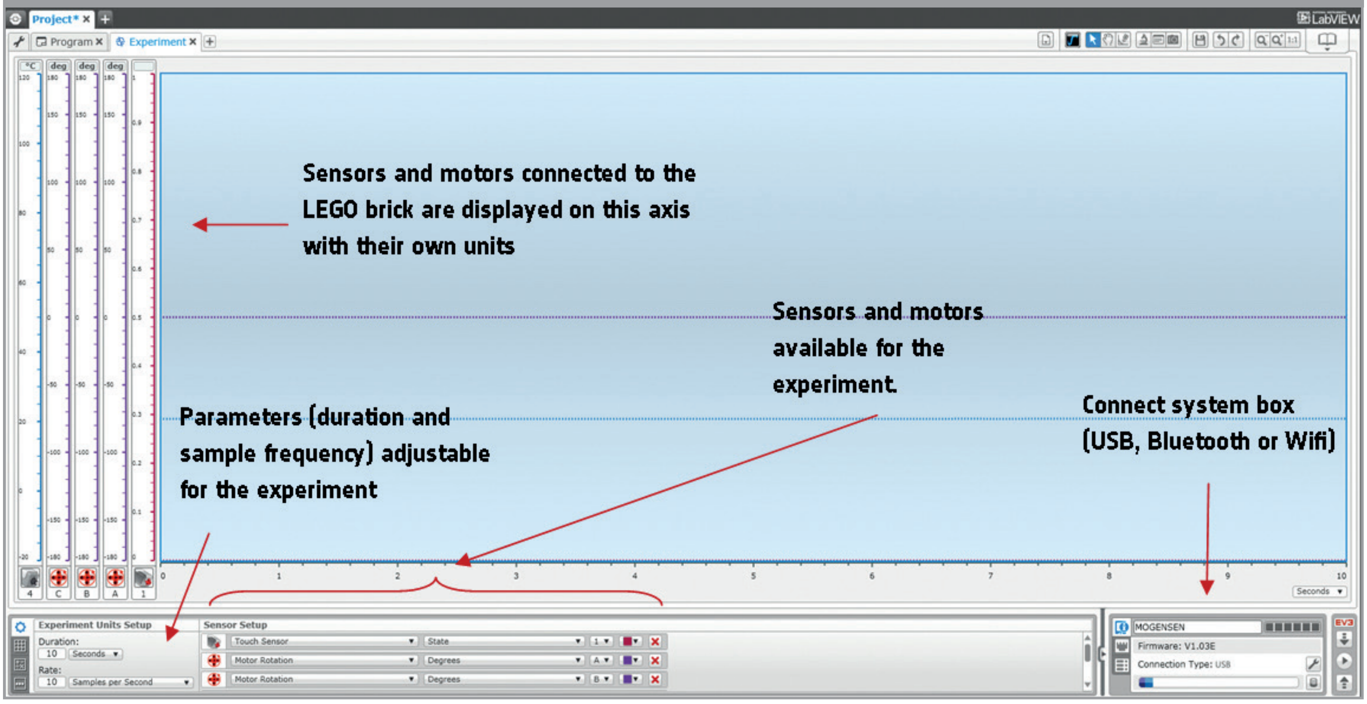
Figure A12

↑ LEGO light sensor

2. Regarding your observations, which property is useful for the laser signal?

Open a new experiment by clicking on the '+' symbol at the top of your 'project' screen. Choose the adequate scale.

Figure A13

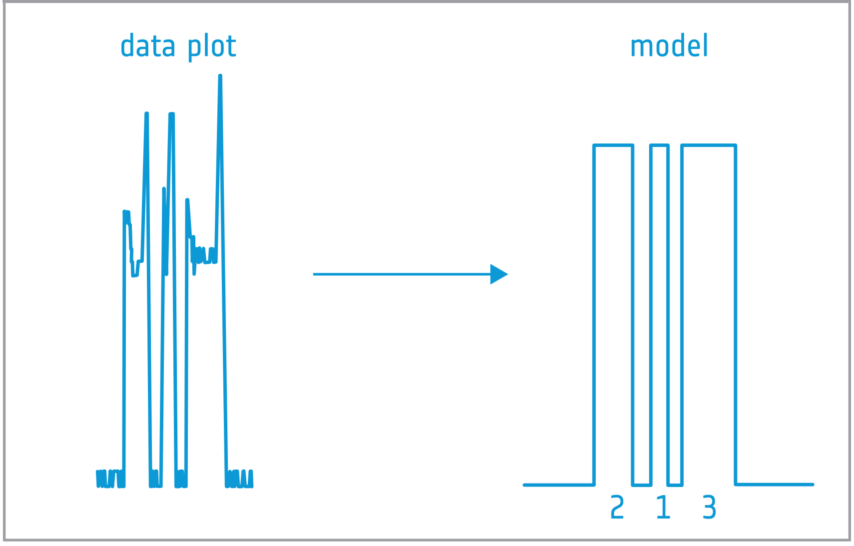


↑ LEGO experiment window.

*Requirement : Activity 5 of teach with space - build your mars exploration rover T01

The data transmission experiment is plotted on the experiment screen. To interpret the message, you have to identify a small (1), medium (2), and large (3) duration of the laser signal. To simplify the task, you need to create a model using straight lines, to highlight different intervals.

Figure A14



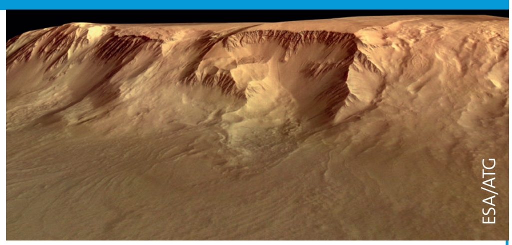
↑ Laser signal collected

Exercise

Using the illustration in Figure A14, model the laser signal collected by the light sensor, and translate the message.

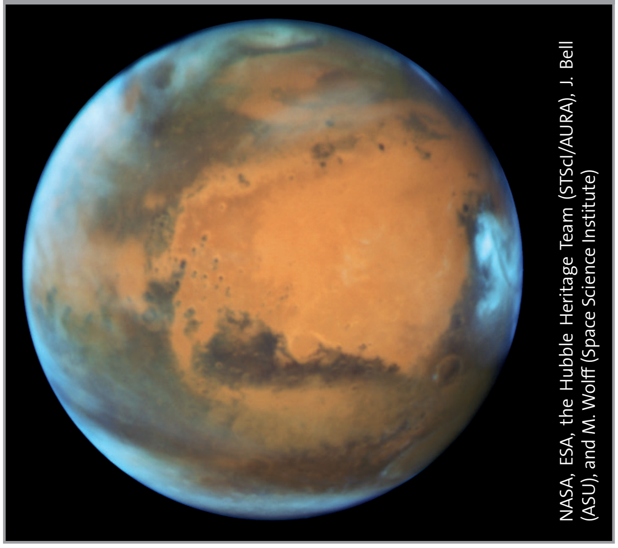
Did you know?

This perspective view taken by ESA's Mars Express shows the Olympus Mons on Mars, the highest volcano in our Solar System. Olympus Mons has an elevation of 24 km relative to the surrounding surface, and its caldera has a depth of about 3 km. The volcanic region hosting Olympus Mons and several other large volcanoes is thought to have been active until tens of millions of years ago, relatively recent on the planet's geological timescale that spans 4.6 billion years!



→ Activity 6: How do you magnify images with a telescope?

Figure A15



↑ Picture of Mars taken by the NASA/ESA Hubble Space Telescope

This amazing picture of Mars (Figure A15) was taken by the NASA/ESA Hubble Space Telescope. Even though 80 million kilometres separate the telescope from Mars, the picture is very detailed.

What is the process that enables us to magnify an object?

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Exercise

Use an application on your smartphone that can share images on your computer. Place your smartphone so that you target an object you want to magnify (e.g. a picture on the wall) and begin a connection.

1. Take 2 lenses (bi convex and bi concave) and place each lens in front of the smartphone's camera. Determine the distance and the size of the image when it is clear. Write your observations in Table A4.

type of lens	focal length	image distance	image size
Bi convex			
Bi concave			

↑ Table A4: Lens specifications and image observations.

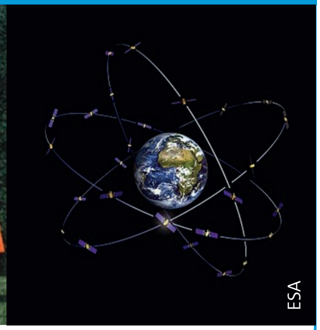
Did you know?

The NASA/ESA Hubble Space Telescope is a long-term, space-based observatory. The observations are carried out in visible, infrared, and ultraviolet light. In many ways, Hubble has revolutionised modern astronomy, not only by being an efficient tool for making new discoveries, but by driving astronomical research in general.

Did you know?

Galileo Galilei was an Italian astronomer, physicist, engineer, philosopher, and mathematician who played a major role in the scientific revolution during the Renaissance. Galileo is also the name chosen for Europe's own global navigation satellite system, which will provide a highly accurate, guaranteed global positioning service under civilian control.

↑ Galileo presenting his Moon drawings.



↑ ESA's Galileo navigation system

2. In 1606, Galileo's drawing of the Moon was not appreciated. Why not?

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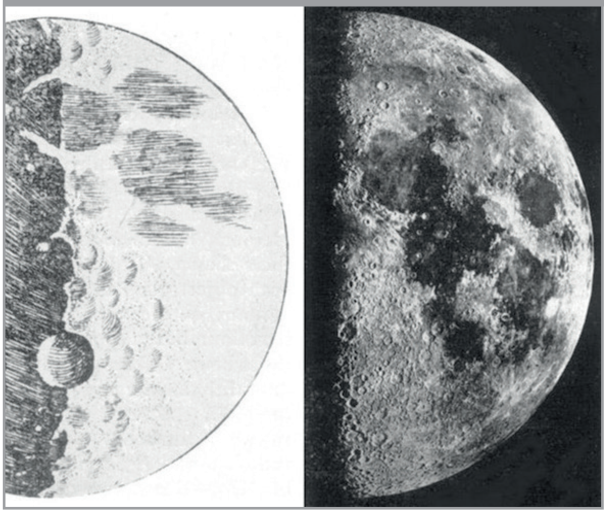
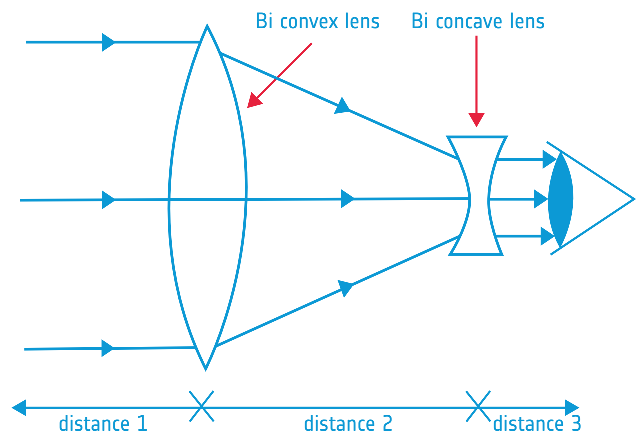
Figure A16



3. Galileo was the first to magnify the Moon thanks to the two lenses system shown in Figure A17. Determine the distances indicated in Figure A17 in order to be correctly in focus with the magnified object. To increase its precision, add an ultrasonic sensor (Figure A18) on your smartphone to determine these specific distances.

Figure A17



↑ Galileo's telescope with distances

Figure A18

↑ LEGO ultrasonic sensor

Distance 1 = ______________

Distance 1 = ______________

→ Activity 7: How do you complete a mission successfully?

Exercise

1. Complete Table A5 with the skills and knowledge you have acquired at every step of your mission.

Steps	Skills / knowledge acquired

↑ Table A5: Skills and knowledge acquired.

2. To conclude, rewrite your scientific hypothesis and write your answer below. Use appropriate vocabulary to discuss the concepts you have learned.