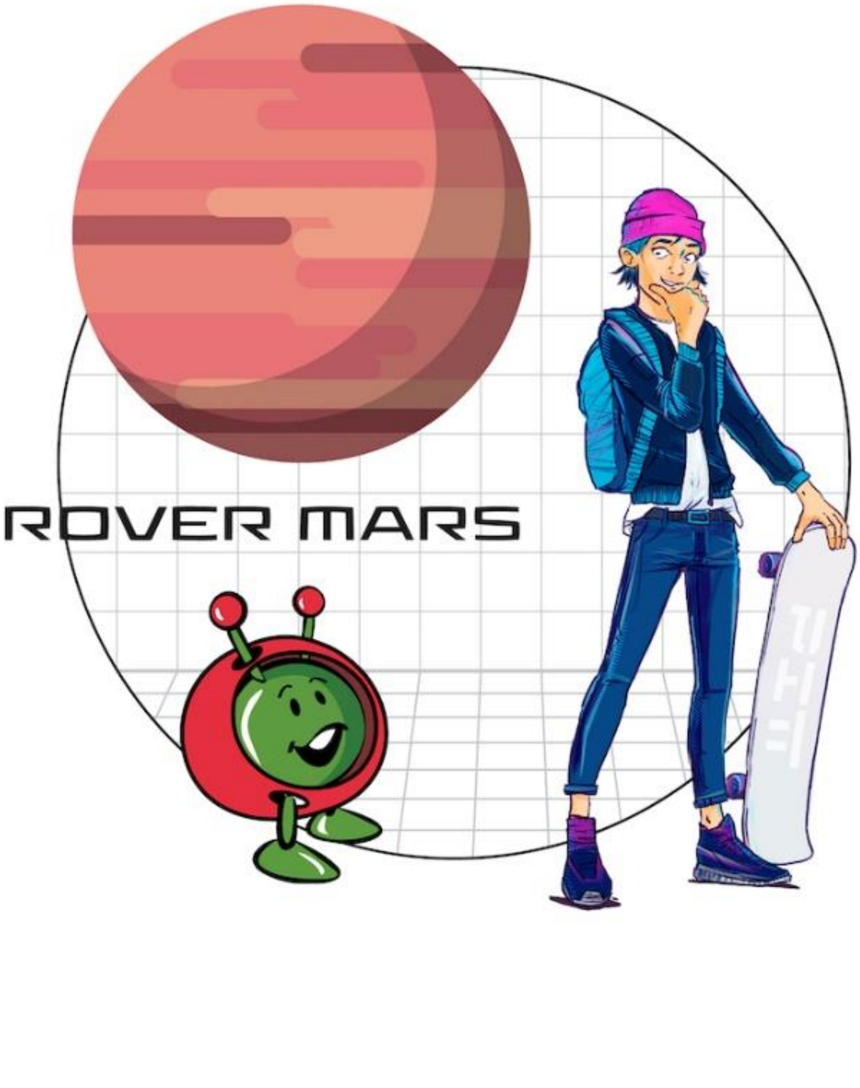
Discover life on Mars with a rover



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Didactic commentary

Sandra Baumann & Ann Kiefer

Our daily, school and working lives are increasingly digitalised. Using digital technologies is one of the key skills of the 21st century - but what skills do children and young people need to meet the demands of the digital world?

In February 2020, the Luxembourg Ministry of Education presented the strategy "einfach digital - Zukunftskompetenze fir staark Kanner", the aim of which is to prepare children and young people for the demands of the future, enabling them to find their way in an increasingly digital world and to acquire the necessary skills for this. As part of this strategy, a new teaching subject, *Digital Science*, is being introduced (National Education 2020). *Digital Science is* intended to be an extension of the teaching of *coding in* primary school and focuses on six main themes, such as algorithms, the Internet, computer language, games, robots and artificial intelligence (National Education 2020).

As a pilot project, the *Digital Sciences* course has been introduced in the 7th grade classes of 18 Luxembourg secondary schools from the 2021/22 school year. In 2022-23, the new subject will be taught across the board in all 7th grade classes and a pilot phase will be launched in a few 6th grade classes. From 2024-25, *Digital Science* will be taught in all classes of 7th, 6th and 5th grade (National Education 2020). The new subject has an explicitly transdisciplinary orientation and a multilingual approach, as it can be taught by all subject teachers and thus involves, in addition to science teachers, teachers of languages, arts and social sciences. Furthermore, the subject will be taught in French as well as in German or Luxembourgish and will be integrated into the normal timetable for a total of 108 hours over the three school years (National Education 2020).

The #Mars *Rover* module was developed in collaboration with ESERO Luxembourg (European Space Education Resource Office) and PITT (Programme for Innovative Teaching and Training). A common logo was also created for this purpose. ESERO develops teaching materials for both primary and secondary schools, adapted to the Luxembourg curriculum in MINT subjects, always with a link to the theme of space. Within the framework of the Bachelor of Science in Education (BScE) programme at the University of Luxembourg, ESERO Luxembourg helps future primary school teachers to develop a global scientific competence. Students work on tasks developed by ESERO in the framework of the "teach with Space" project on the theme of climate change (Andersen et al. 2021).

The present course #Mars *Rover - Discover life on Mars* deals with the topic of robots and has been integrated into the learning theme *Space*. The idea is to bring the fascination of space into the classroom and thus get young people excited about learning. The high potential of this theme is thus used in the learning processes. Space and all its facets are a very popular subject for young people. Especially in connection with the search for (extra)terrestrial life, the module appeals to the imagination of the pupils and arouses excitement and curiosity.

This module on extraterrestrial life makes teaching more exciting and helps to spread young people's enthusiasm for the subject of space to many other areas of learning and disciplines. It thus meets the didactic requirement of modern teaching, which is pupil-centred and "[...] builds as much as possible on their interests, abilities and knowledge level [...]" (Steveker 2015).

In an interview at the *Esero UK Secondary Space Conference*, ESA astronaut Team Peak highlights the benefits of space as a motivating and fascinating learning environment. Peak believes that the fascination with space can be applied to many areas of learning and science subjects in education. In his opinion, the theme of *space* and the work of ESA can be used as a unique platform to enthuse children and young people about space and the universe and to awaken their interest in the work of astronauts, engineers and scientists. Peak sees a decisive advantage in the fact that learning content in the context of *space has a* positive effect on children and young people and that the learning content of mathematics, physics, chemistry or biology becomes alive and tangible (UK ESERO). Pupils are thus challenged in a variety of ways and space serves as a motivating learning environment which, on the one hand, explains how space as such functions and, on the other hand, awakens the fascination and interest of children and young people in the subjects directly related to space. Synergy effects can be created for many science subjects and, according to Peak, "space as an educational outreach tool" can be exploited by making links to the theme of space in science subjects, thus motivating pupils (UK ESERO).

In addition, the *space* context also offers many points of contact with language subjects, and here again generates great added value for the organisation of courses. The teaching of English, for example, can be inspired by this by making students aware that English is the lingua franca of space and aeronautics and that it serves as a common basis of communication for multicultural teams of astronauts.

The success of ESA astronauts Alexander Gerst and Mathias Maurer in combining their space flights with educational projects for primary and secondary schools shows how well the integration of *space* into education works. Pupils can experience science and space up close and personal and accompany astronaut Gerst in the *Flying classroom* series on board the ISS, where simple demonstration experiments are carried out to make the subject of weightlessness research comprehensible to pupils (Deutsches Zentrum für Luft- und Raumfahrt 2022).

In the #Mars *Rover* module, the theme of programming is integrated into the general theme of space. In space, robotic vehicles go on missions to the planet Mars. They are called Mars rovers and have names like Opportunity and Curiosity (NASA 2022). In order for the rovers to know what to do, a programmer has to write a series of instructions that the robot executes one after the other, for example "deploy the solar panels", "deploy the wheels" and "turn on the camera". However, the rover cannot be controlled from Earth, as the radio signal between Earth and Mars can take from four to twenty minutes, depending on the position of Earth in relation to Mars. A remote-controlled rover would only work with a large time lag. Therefore, the Mars rover must be programmed in advance so that it can operate autonomously.

In this unit, the pupils are given four different and successive programming tasks, which increase in complexity, as the programming parts can be partially taken over from the previous tasks. As this unit is designed as an introduction to the topic of programming, the pupils do not need to program all the tasks from scratch. To make it easier for them, parts of the programming are given to them in the form of tasks.

The #Mars *Rover* module uses *mBot* robots from the company *MakeBlock*. These robots are specially designed for beginners and are a fun and easy way to teach and learn robotic coding. The programming itself is done using *MakeBlock* software, which is a block-based programming environment based on Scratch.

Through step-by-step instructions pes, pupils become familiar with the basic principles of block programming and develop their logical thinking and design skills. Access to programming via Scratch provides a first experience of computer systems and is very suitable for initial education. The programming activity focuses on adapting the already existing programming environment to the requirements of successive programming tasks, and thus offers the possibility of building successful products with only a little prior knowledge in the field of programming (Schubert/Schwill 2011).

Furthermore, programming lends itself perfectly to the context of experiential learning and promotes learning by error. Scientists such as Kapur emphasise the effectiveness of productive error, a term that refers to the importance of error in the learning process (Kapur 2011).

"From a neuroscientific point of view, the error is above all treated as a deviation from an expectation, and therefore constitutes valuable information that allows one to readjust one's conceptions and therefore to learn. (INRIA 2020).

By making mistakes, we give ourselves measures to improve. In the school context, however, teaching focuses on error prevention. Pupils can experience a positive approach to error through programming, as it provides the ideal framework for learning, as the detection of an error is immediate (and does not take several hours or days as in traditional exercises in other sciences). Furthermore, a computer program does not make judgements, it only detects and reports the error. This gives the student the opportunity to try again, as often as possible. This way, even weak students get a second chance. In addition, programming helps students to develop rigour, because a program only works if it has been 100% correctly configured. This is where it differs from traditional performance assessment methods, which allow students to pass an exam even if they work less well and less thoroughly: While an exam is considered passed with 30/60 points, a half-configured program is unusable and does not work. Moreover, programming also cultivates the notion of doubt: indeed, the fact that a program works at a given moment does not necessarily mean that it will always do so (non-detection versus absence of bug) (INRIA 2020).

Similarly, programming encourages critical thinking in students. In general, mathematics and science are supposed to encourage critical thinking in students, as these subjects are based on building hypotheses and confirming and/or proving these hypotheses, or rejecting them. Being able and having to change one's mind plays an important role here. However, this cannot be done in one hour of class, as such a scientific process often takes much longer. In computer science, this trial-and-error loop is much shorter, because a computer program signals an error on the first try. Thus, students quickly learn the principle "I thought that..., but I realise that..., I will try something else" (INRIA 2020) and a positive culture of error is formed, which can be transferred to many other areas of school and life.

Robotisation adds another level here, as the robots give "spatial feedback" to the algorithm designed by the students. They add a tangible aspect to computing, allowing students to seek solutions in a less traditional, academic learning environment (INRIA 2020).

Literature

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Planning the lesson

<u>Subject:</u> Digital Sciences

<u>Age range :</u> 13-14 years

<u>Duration :</u> 150 minutes

<u>Cost :</u> The software is free and the hardware is loaned by ESERO Luxembourg

We use robots in space. Robotic cars, for example, go on missions to Mars; we call them *Mars rovers*, and they have names like *Opportunity* and *Curiosity*.

A Mars rover must move itself and send information about Mars to Earth.

But how does it know exactly what to do? A programmer writes a series of steps that the robot performs in sequence. For example, the Mars rover performs steps such as "deploy the solar panels", "deploy the wheels", "turn on the camera" after it has landed safely on Mars.

The question is: how do you control a rover a hundred million kilometres away, driving on Mars? As we are not on site, it will be controlled from the Earth. A radio signal sent from Earth to Mars takes between four and twenty minutes, depending on the position of the Earth in relation to Mars.
A remotely controlled Mars rover would therefore be piloted with a considerable time lag. An example of a direct problem that results from this is that, due to the time lag, it would not be possible to brake quickly enough if the rover encounters an obstacle.

It is therefore necessary to programme the Mars rover in advance so that it can operate autonomously and automatically as much as possible.

In this lesson, students program their own Mars rover in the Scratch programming environment. A satellite map of Mars will be laid out on the ground and their rover will have to complete a mission to find life on Mars.

Objectives of the lesson

- Learn the basics of programming in Scratch,
- solve problems by systematic reasoning,
- learn to formulate short, precise instructions and place them in a logical order to achieve a specific goal.

Structure of the lesson

The lesson starts with a short introduction to Mars and the robots that travel to the red planet. In addition, the Scratch programming environment is introduced . At home, the pupils should familiarise themselves with Scratch on the basis of an example of a small program.
Then, in class, pupils are introduced to some basic functions, after which they can start programming their Mars rover. As this resource is meant to be a first approach to Scratch, programming is not done from scratch, but in the form of small exercises where part of the solution is already given.

Materials needed

- ✓ A free area on the floor of $6m^2$: 3m x 2m
- ✓ In groups of 2 students :
  - A laptop or PC with Windows or MacOS with
    - An internet connection
    - One available USB port
    - mBlock software installed

The rest of the material is provided by ESERO

- ✓ the map of Mars
- ✓ the decoration material needed for the challenges:
  - 3 photos to set the scene,
  - parts to hold the photos,
  - a cave,
  - a stuffed tardigrade,
  - a Petri dish to put hot water in (see if we change)
  - The Paxi plush that is the ESERO mascot
  - Paxi stickers
- ✓ 10 mBots equipped with all necessary sensors, for a class of up to 20 students.

Presentation of the mBot rover

The mBot is a robot for beginners created by the company MakeBlock, which makes teaching and learning robot coding simple and fun. With step-by-step instructions, students learn the fundamentals of block programming, develop their logical reasoning and design skills.

Like any robot, the mBot interacts with its environment according to the instructions it is asked to execute.

To do this, it is able to collect information thanks to its sensors and to carry out actions thanks to its actuators.

Actions

- The robot is able to **move** thanks to its two independent motors, each of which drives a drive wheel.
- It can **emit sounds** thanks to a buzzer.
- It can **emit light** thanks to LED lamps whose colour can be adjusted.

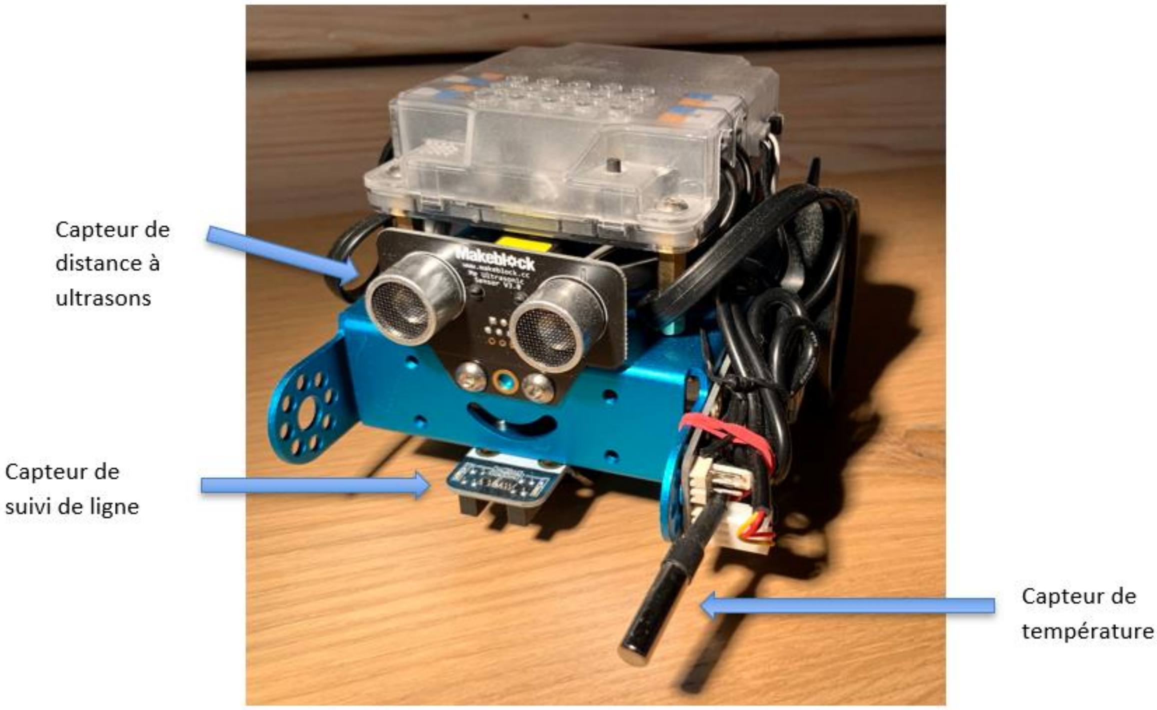
Buttons and sensors

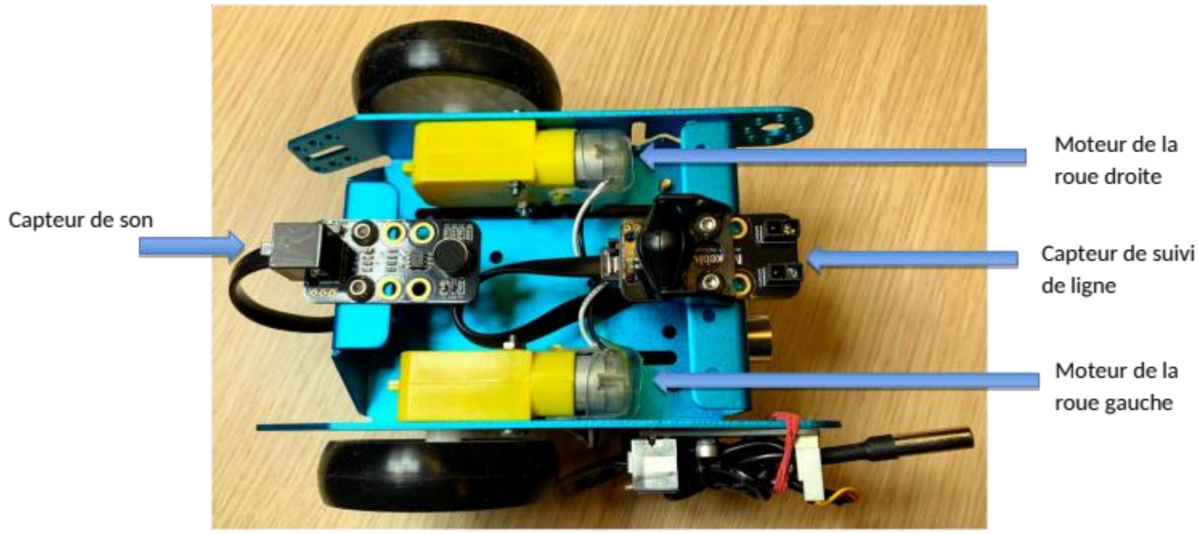
To interact with its environment and gather information, the robot has :

- A power ON/OFF button,
- a program start button,
- a ground line tracking module,
- an ultrasonic module that allows it to "see" obstacles in front of it and know their distance,
- a brightness sensor that informs it of the ambient brightness,
- a sound sensor that tells it about the level of ambient noise,
- a temperature sensor that measures the temperature of the ambient air.

Line tracking sensor

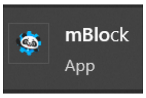
Installed on the front of the mBot, the line tracker has two sensors that can detect a white surface (within 1-2 cm) by emitting IR (infrared) light and recording the amount of reflected light.
If a large amount of light is reflected, it can be deduced that it is close to a white surface. If the reflection is low, it can be deduced that the surface is black or that the sensor is not close to a surface.




Moteur de la roue droite
Capteur de son
Capteur de suivi de ligne
Moteur de la roue gauche

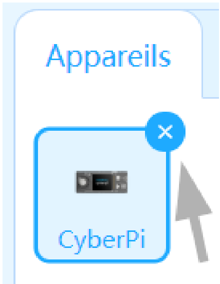
Using the programming software

1- Open the mBlock program

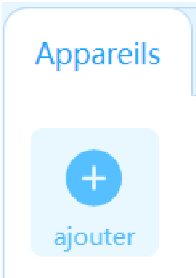


2- At the top left of the screen, choose your language by clicking on 

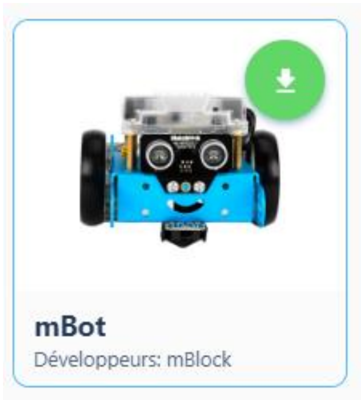
3- In the "Device" tab on the left, delete the CyberPi device by clicking on the cross



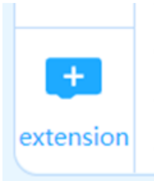
4- Still in the "Device" tab, click on the "Add" button



5- Choose the mBot and click on "OK".

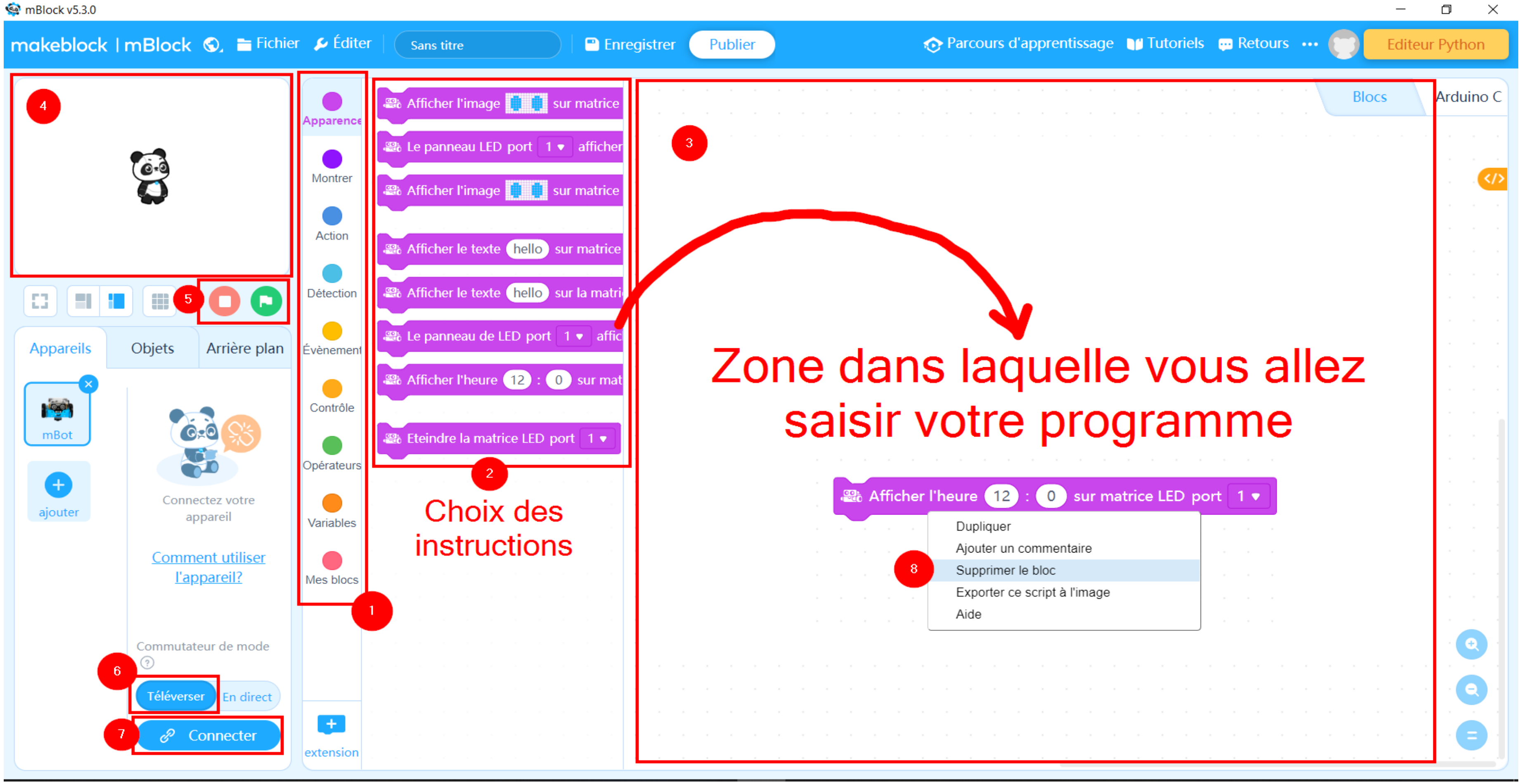


6- At the bottom of the screen, click on "Extension".



7- Add the "Detection Gadgets" extension

8- Description of the programming interface



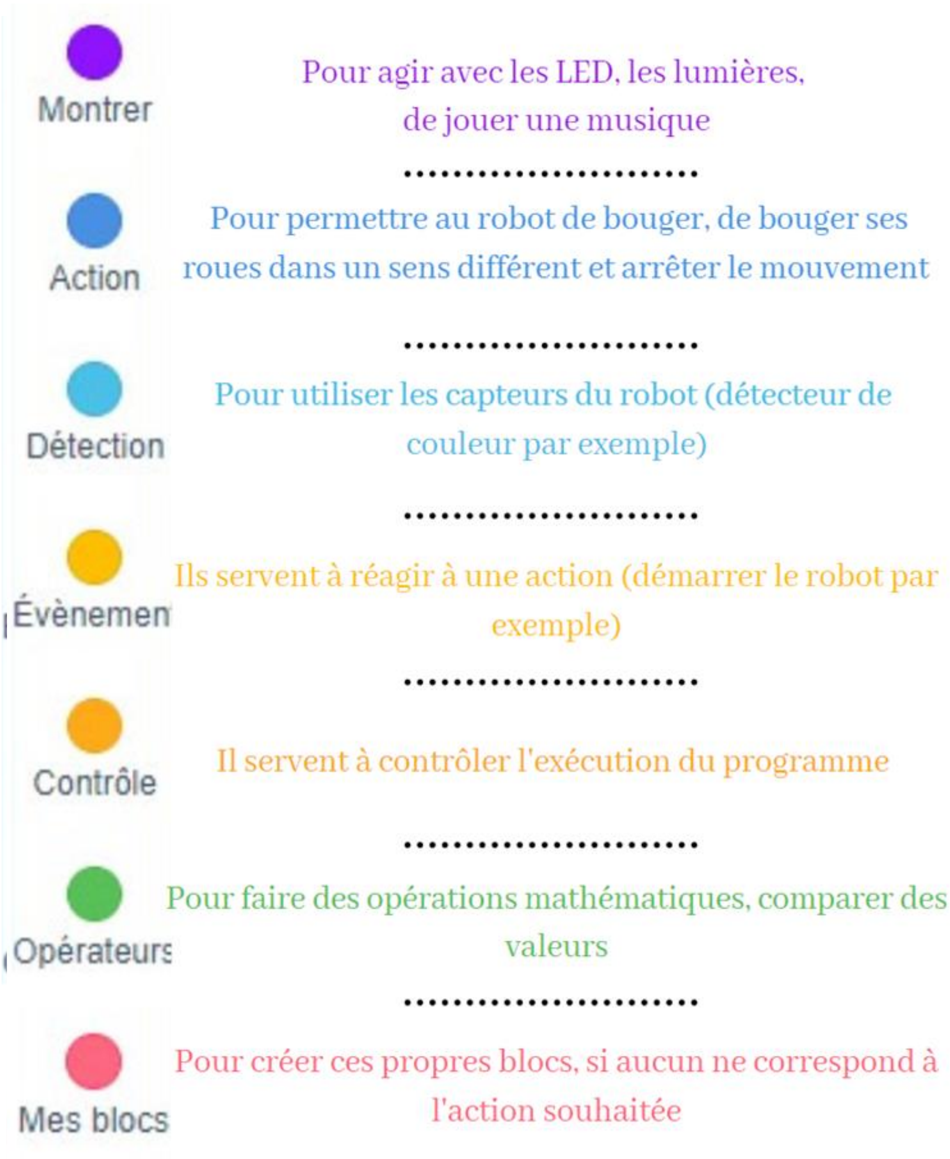
To create the program, simply drag and drop the elements from the library into the program creation area.
Be careful, sometimes you have to drop them in precisely so that they fit together.

(1) Instruction library selection area	(5) Start/stop of the program when you program an image
(2) Drag and drop instruction selection area (3)	(6) Button to be selected to upload your programme to the mBot
(3) Field in which you enter your programme	(7) Button to click to connect to the mBot
(4) Test area for programming an image instead of the mBot	(8) To delete an instruction, right click -> delete block

Library of 'instructions

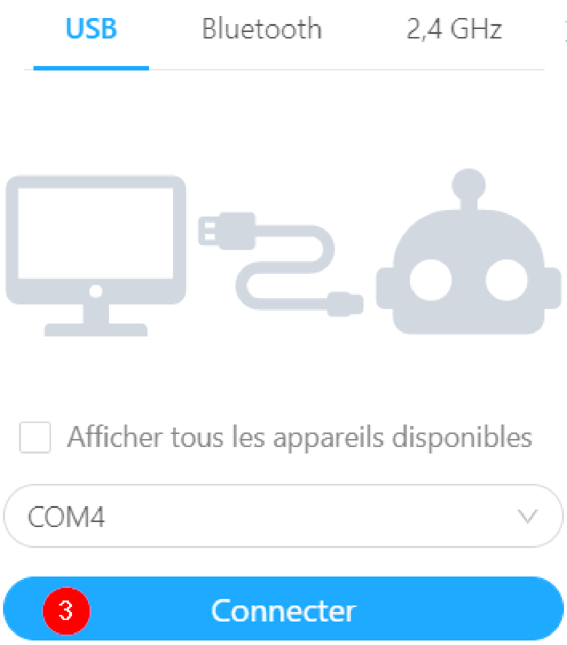
Several instruction libraries are available

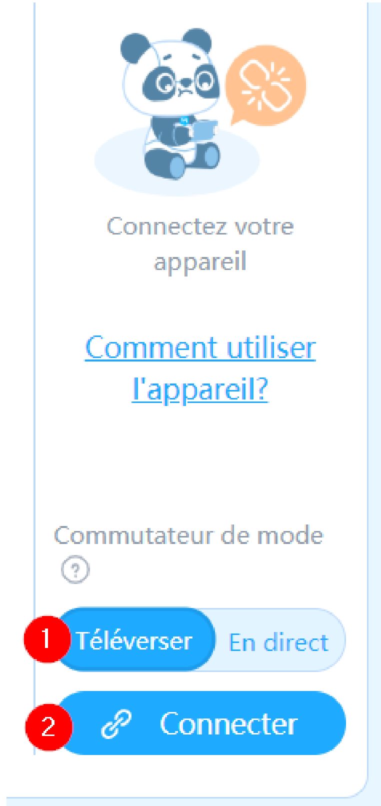
- Events
- Sensors
- Actions
    - Movement
    - Watch
    - Sound
- Checks
- Operators
- Gadgets



Procedure for sending the program to the mBot

1- Place the robot on a stand, connect it to the computer.
2- Check that the switch on the robot is "ON".
3- Ensure that the "Upload" button is selected (1)
4- Click on the "Connect" button. (2)
5- In the next screen, click on "Connect" again. (3)





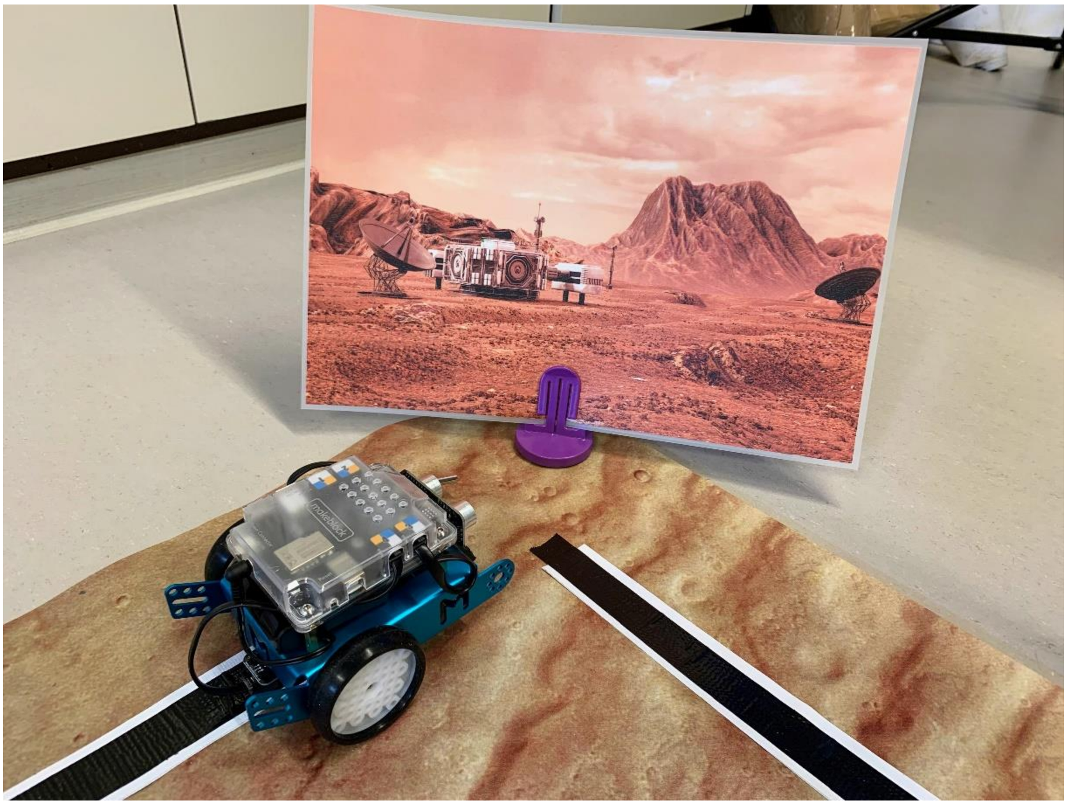
6- When the connection is established, click on the "Download" button (4)

Presentation of the Mars map

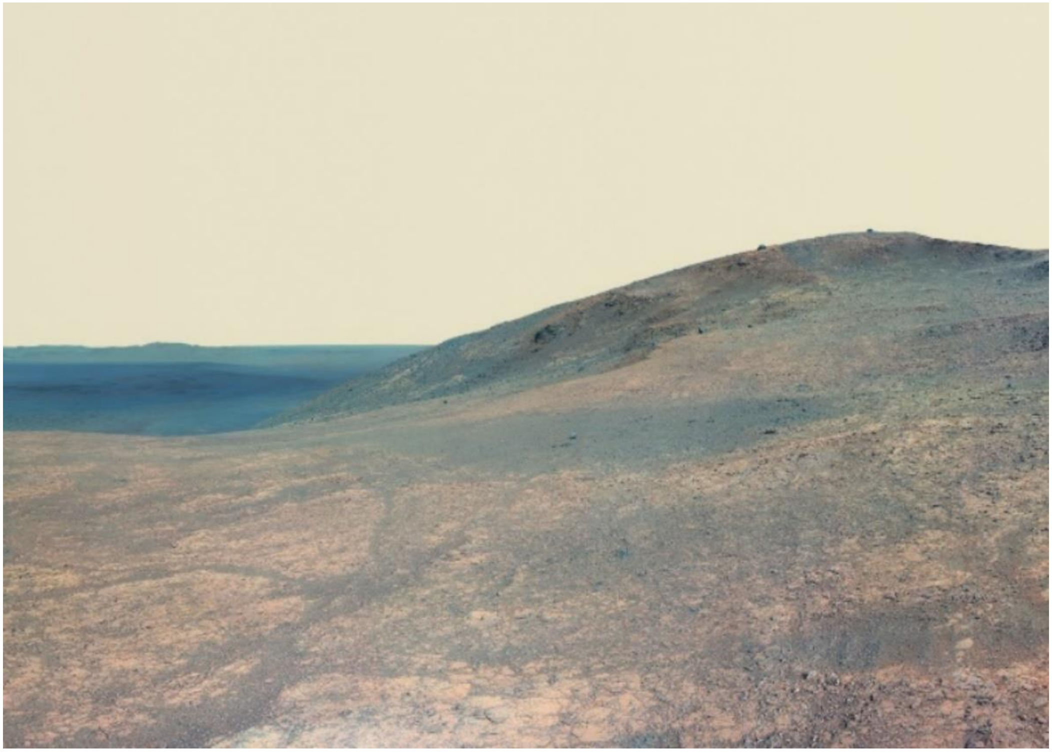
The map is a real satellite image that was taken by the satellite ESA's Mars Express in November 2018. It is divided into 9 areas which will be mentioned in the description of each mission.

Setting up

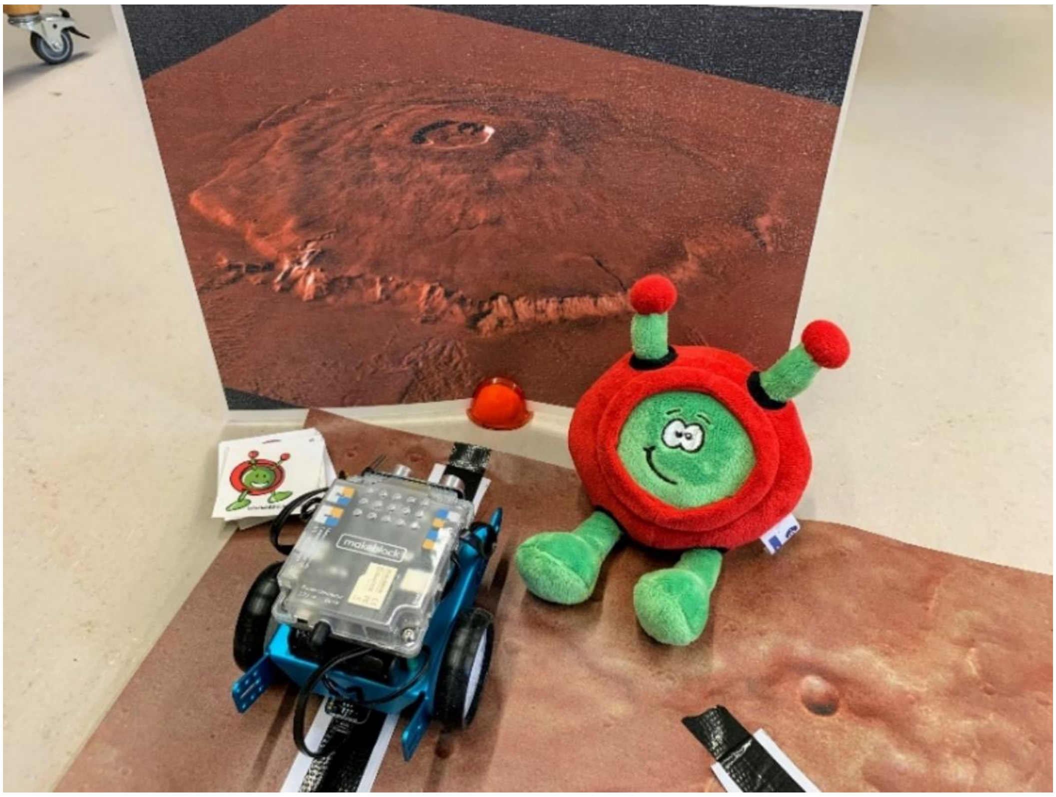
1- Place the picture of the Martian base in the corner of zone 3



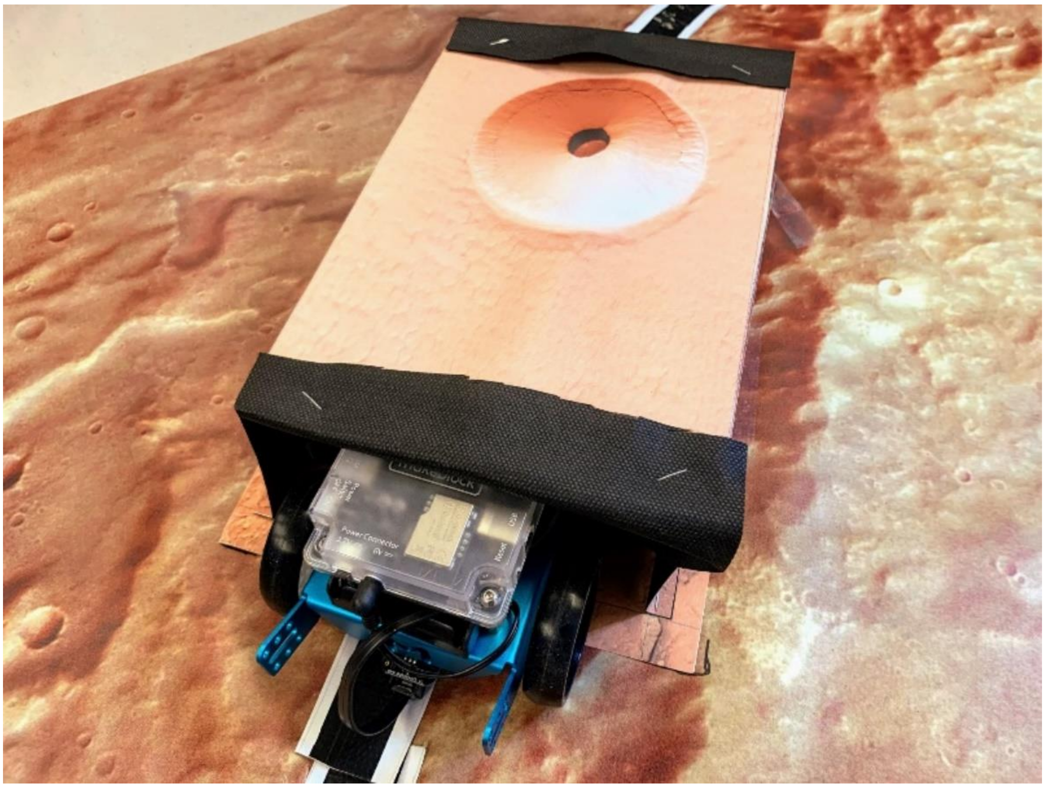
2- Place the picture of the Mars landscape just outside the map, next to area 6.



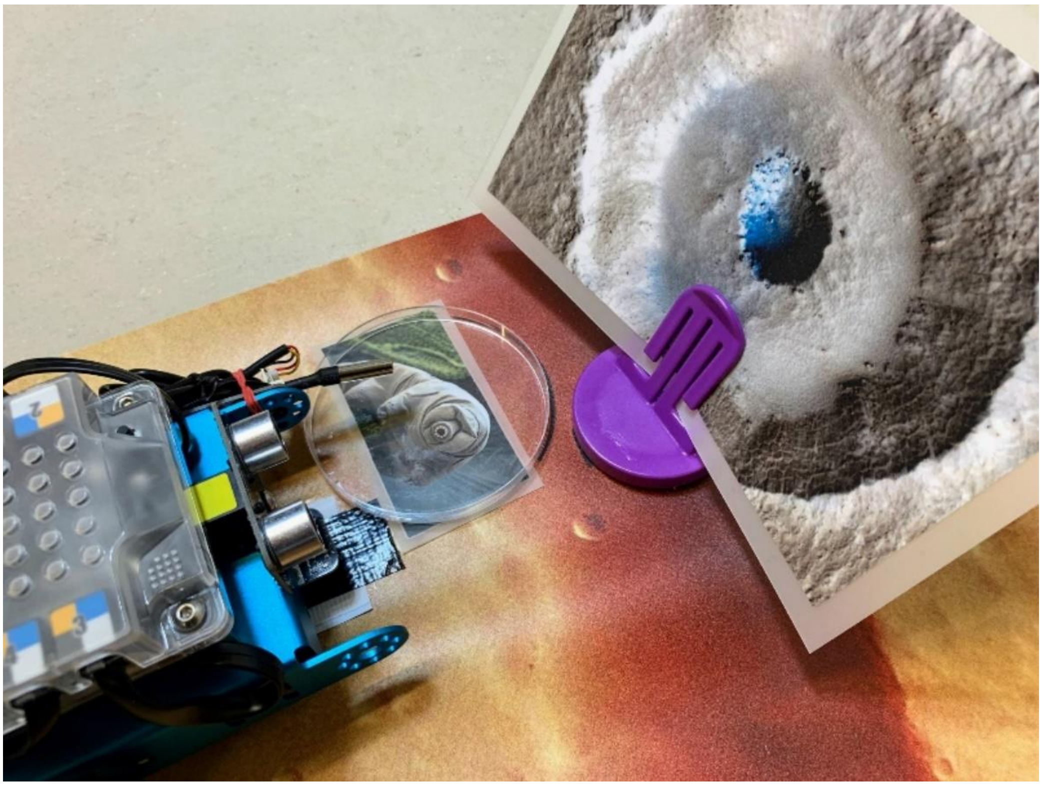
3- Place the Olympus Mons image vertically at the end of the road, below area 9 on the map.
4- Place Paxi (the ESERO mascot) and the Paxi stickers next to Olympus Mons.



5- Place the Mars cave on area 8, stick it to the map with sticky paper, place the piece of black road through the cave and stick it also to the map.



6- In Area 1, place the Mars Crater impact image vertically at the end of the road.
Place the petri dish to the left of the road, just in front of the Mars crater impact.
Place the tardigrade image under the petri dish and the stuffed tardigrade next to the petri dish



. Just before the start of Challenge 4, fill the petri dish with almost boiling water.

Preparation of the lesson

1. In order to be more comfortable, we strongly advise you to read, understand and test the solutions to the 4 missions before starting the lesson with the students.
2. Ensure that a lithium battery or AA batteries are charged on the mBot
3. Connect the rover to your PC using the USB cable
4. Press the ON button.

Read your first programme

In order to become familiar with the mBlock program, the students should do a first exercise at home to prepare the lesson. This exercise can be done on the web version of the mBlock program, so they do not need to install anything. Ask the students to do the following things:

- Go to the Tutorials menu -> Example programs
- Select the scene -> Happy Panda
- Press "OK".

Check that students have understood

- how the Panda is controlled by the coloured blocks. The coloured blocks are the instructions it follows. It is not necessary to explain all the blocks in detail. The pupils have to find out for themselves what they can do with each block.
- The function of the green flag and the red square.

Then the students should change the Chinese message in the "say" block and show what it changes when the program is run. Encourage them to play with the program and discover the features for themselves.

Let's go!

The lesson can begin. The programming game is divided into 4 missions, preceded by a test challenge, called *pilot training*, to be completed by programming the mBot to perform specific tasks.

As this module is for many students a first familiarization with Scratch, students do not have to program each exercise from scratch. At the end of each mission files are given. These files contain part of the solution. The students only have to complete the file in order to get the final solution. To do this, the students have to save the files on their computer. Then from the mBlock interface they have to open them from their computer.

For classes of students who already have experience with Scratch, there is of course nothing to stop you from not using these files and letting the students program the missions from scratch.

The missions were designed to be of increasing difficulty, first asking students to focus on the values of the variables (mission 1) and then on the logic of the programme (mission 2) and then to mix the two aspects (mission 3 and mission 4).

Write your first programme : pilot training

For this first exercise, the mission is to

1- Roll the mBot straight across the table,
2- stop the mBot as soon as it comes within 10 cm of an obstacle using the ultrasonic sensor. The obstacle can be the student's hand, a book or any other object.

Mission 1

Context :

The rover is in the centre of the map in a dry valley and is ordered to return to its home base to receive a new mission.

Mission:

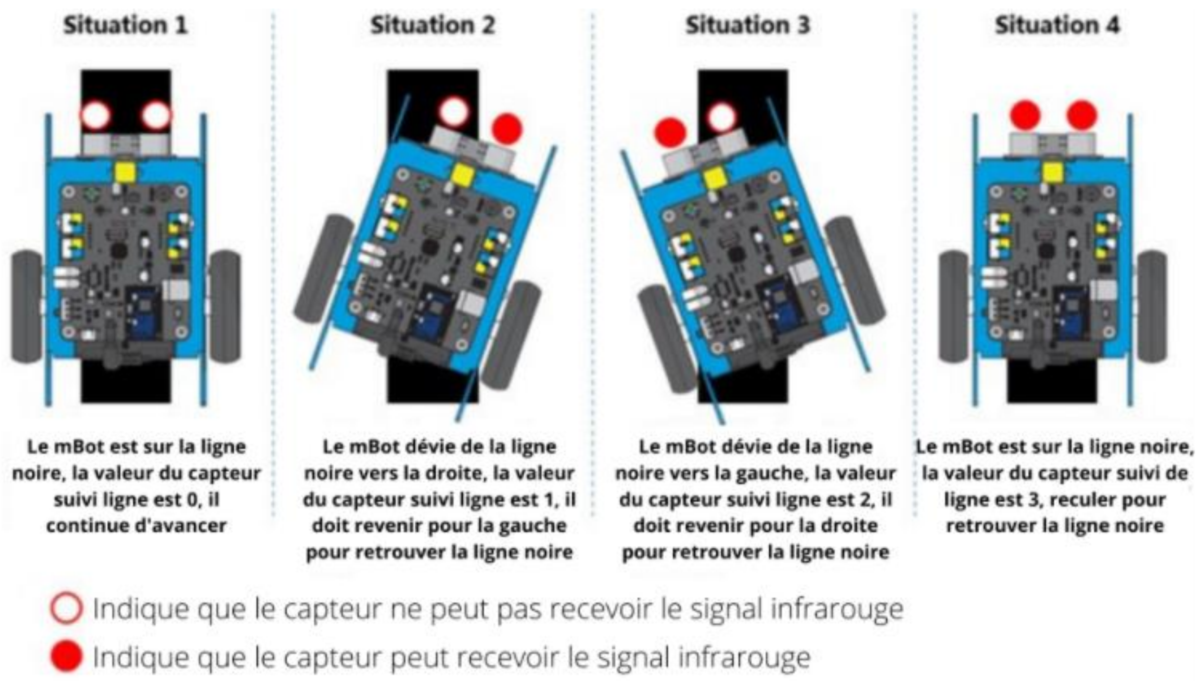
Students should return to the base of zone 3 by following the black line with the line tracking sensor.

In the "Detection" instruction library, there are **2 blocks** associated with the line follower:

This first block will return a number between 0 and 3 based on the following values:

Sensor 1 (Left)	Sensor 2 (Right)	Return value
		0
		1
		2
		3

The second block returns either true or false.

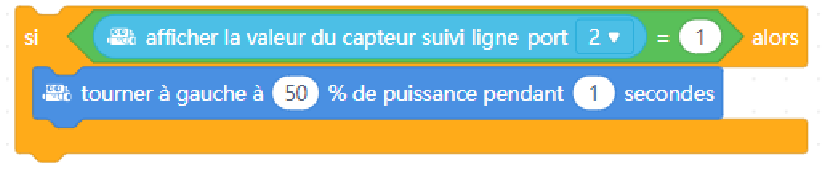


Programming :

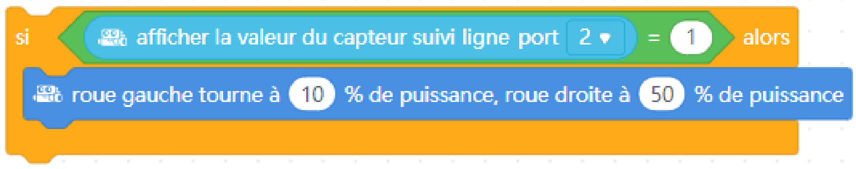
✓ Students should download the exercise to be completed

Important note: In general, for line tracking students intuitively tend to program using **time-based commands** to turn left or right, which makes line tracking very difficult since the notion of time depends on the power of the motor at that moment . In addition we have noticed that students, and adults, underestimate the length of a second.

Instead of programming this,



it is much more reliable to use the reaction time of the line following sensor and to slow down the power of the engines



Unfortunately, for the backwards command, you have to work with seconds. Be careful here that the students do not set the time too high (not more than one second).

Mission 2

Background:

The rover is back at its base and is ordered to **try to discover life on Mars**!

The ExoMars satellite found potential locations of interest and gave the GPS points to visit.

The base also received an emergency message from Paxi, which is experiencing technical problems with its spacecraft near Olympus Mons, the highest mountain on Mars.

The students must first rescue Paxi, who will be a great help to our mission because of his knowledge of the Martian landscape.

Mission:

1- Follow the black line from zone 3 to zone 9.
2- Stopping in front of Mount Olympus with the ultrasonic sensor.
3- Produce a light signal with the mBot's LED lights to warn Paxi of your arrival
4- Get Paxi on board by giving the student a Paxi sticker

Programming :

✓ Download the exercise to complete

Mission 3

Background:

The ExoMars satellite has indicated the location of a Martian cave to be explored, which may contain life. The students have to go under the cave and scan it.

Mission:

1- Follow the black line from zone 9 to zone 8
2- Stop inside the cave when the light sensor detects a decrease in light intensity.
3- Produce a sound signal simulating a laser scanning the interior of the cave.

Programming :

✓ Download the exercise to complete

Mission 4

Background:

The students did not find any life inside the Mars cave, but there is still another promising location.

Suddenly, they hear the sound of a meteorite crashing not far from the cave. They have to go to the crash site to look for signs of life.

Mission:

The crash of the meteorite is simulated by clapping in the hands.
Using the sound sensor, the mBot must

1- Waiting for the sound of the meteorite crashing with its sound sensor.
2- Measure whether the temperature inside the cave is positive to test the temperature sensor.
3- Stopping at the meteorite impact
4- Measure the temperature to detect a hot water source above 30°C containing life.
5- Play a "victory song", which you have composed on the mBot, when the temperature is above 30°C!

Programming :

- ✓ Download the exercise to complete

Important notes:

Before rolling the rover, fill the petri dish with very hot, almost boiling, water .

The lesson

Read your first programme (to be done at home)

- Go to the Tutorials menu -> Example programs
- Select the scene -> Happy Panda
- Press "OK".

If you start this program, can you **predict what** it will do?

Think about the following questions:

- How is the Panda controlled by the coloured blocks?
- The coloured blocks are the instructions he follows. Try to find out what you can do with each block.
- Try to understand the function of the green flag and the red square.
- Change the Chinese message in the "say" block and show how this changes when the program is run.

Write your first programme : pilot training

This is your first exercise:

1. F aite the mBot straight on the table in front of you.
2. Stop the mBot as soon as it comes within 10 cm of an obstacle using the ultrasonic sensor. The obstacle can be your hand for example.

Mission 1

Context :

The rover is in the centre of the map in a dry valley and is ordered to return to its home base to receive a new mission.

Mission :

You must return to the base of zone 3 by following the black line with the line tracking sensor.

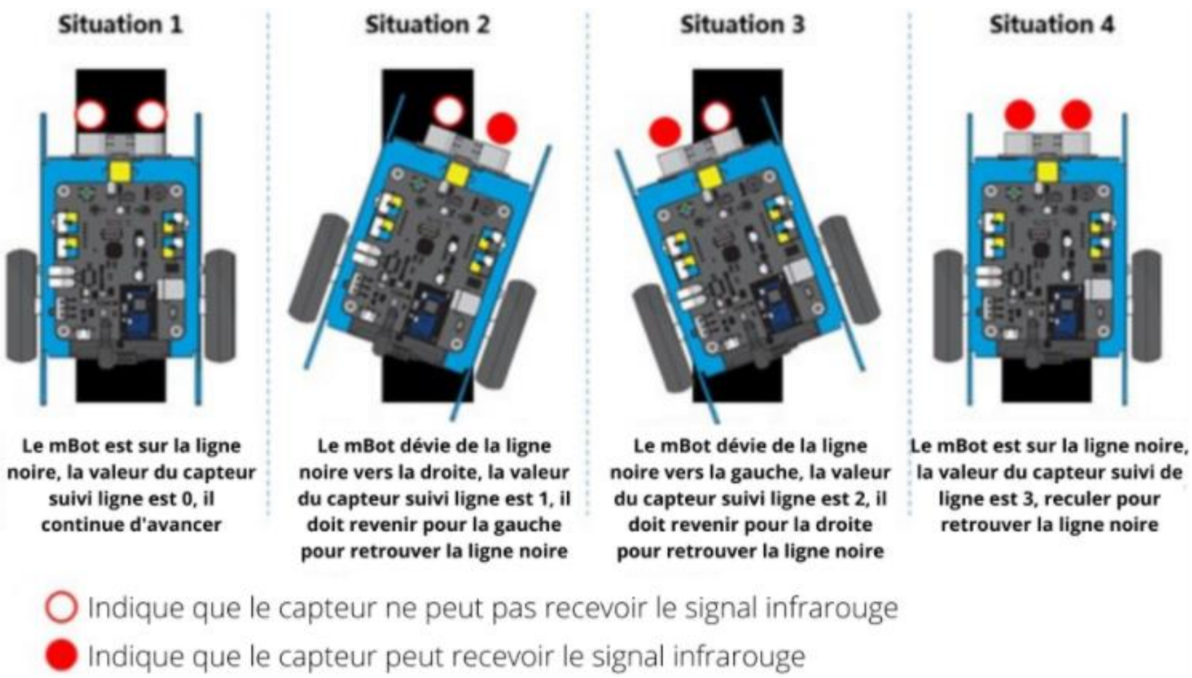
Help :

In the "Detection" instruction library, there are **2 blocks** associated with the line follower:

This first block will return a number between 0 and 3 based on the following values:

Sensor 1 (Left)	Sensor 2 (Right)	Return value
		0
		1
		2
		3

The second block returns either true or false.



Programming :

- ✓ Download the exercise to complete

Mission 2

Background:

The rover is back at its base and is ordered to **try to discover life on Mars**!

The ExoMars satellite found potential locations of interest and gave the GPS points to visit.

The base also received an emergency message from Paxi, which is experiencing technical problems with its spacecraft near Olympus Mons, the highest mountain on Mars.

First you have to rescue Paxi who will be a great help to our mission because of his good knowledge of the Mars landscape.

Mission :

5- Follow the black line from zone 3 to zone 9.
6- Stop in front of Mount Olympus with the ultrasonic sensor.
7- Produce a light signal with the mBot's LED lights to warn Paxi (the ESERO mascot) of your arrival
8- Get Paxi on board by taking a Paxi sticker.

Programming :

- ✓ Download the exercise to complete

Mission 3

Background:

The ExoMars satellite has indicated the location of a Martian cave to explore, which may contain life. You have to go under the cave and scan it.

Mission:

4- Follow the black line from zone 9 to zone 8
5- Stop inside the cave when the light sensor detects a drop in light intensity.
6- Produce a sound signal simulating a laser scanning the interior of the cave.

Programming :

- ✓ Download the exercise to complete

Mission 4

Background:

You didn't find life inside the Mars cave, but there is still another promising place.

Suddenly, you hear the sound of a meteorite crashing not far from the cave. You must go to the crash site to look for signs of life.

Mission :

Simulate the crash of the meteorite by clapping your hands.

6- Wait for the sound of the meteorite crash (simulated by your hands) using the mBot's sound sensor.
7- Measure whether the temperature inside the cave is positive to test the temperature sensor.
8- Stop at the meteorite impact
9- Measure the temperature to detect a hot water source above 30°C containing life.
10- Play a "victory song", which you have composed on the mBot, when the temperature is above 30°C!

Programming :

- ✓ Download the exercise to complete

Idea s of learning assessment

Write a small program from start to finish

In this task, students give a sequence of instructions to an image, for example the image of Paxi, or another image that they choose.

Preparation:

1. Download the Paxi image to your computer
2. Open the "mBlock" program
3. In the "Objects" tab on the left, delete the image of the Panda
4. Still in the "Objects" tab, click on the "Add" button and then "Export" and select the Paxi image you have previously downloaded.
5. Click on "OK".
6. Still in the "Objects" tab, reduce the size of the Paxi image from 100 to 30

Exercise :

Create a new program where Paxi follows your mouse pointer indefinitely **without ever touching it**.

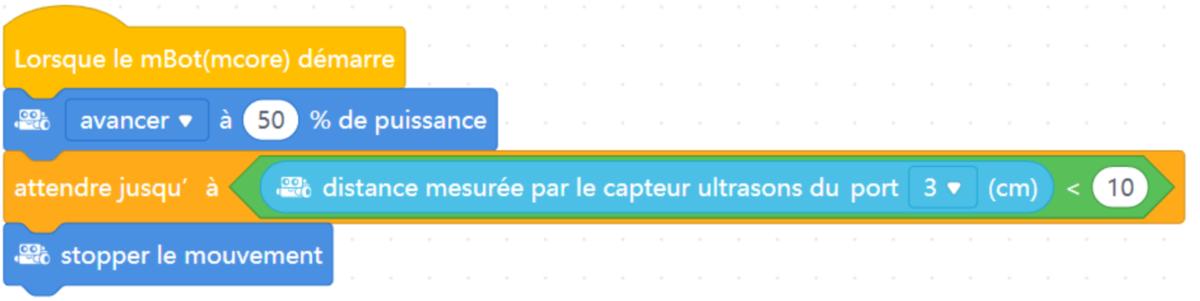
To reflect

In groups, think about the following question:
What do you think are the differences with the programming of the real ExoMars rover?

Make a mini-lecture, poster or essay.

Solutions

Solution: Write your first program



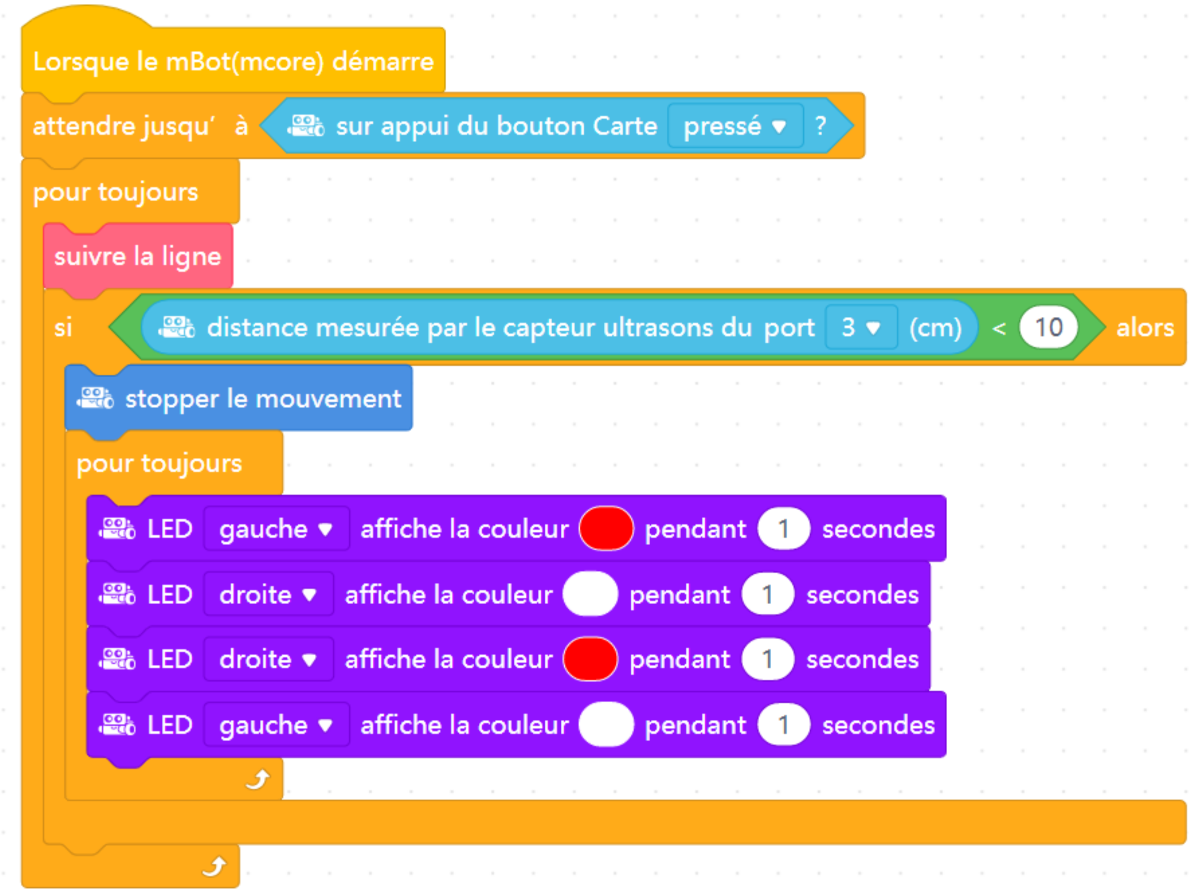
Solution: Mission 1 - return to base

Alternatively you can download the solution.

Remarks :

1. The first command "wait until the card button is pressed" is not really necessary for the program to work properly. We added this command so that the robot only starts when the button is pressed. Otherwise it starts directly on the table when the students connect it to the computer to load the program.
2. It is normal for the robot to finish this mission by alternately moving backwards and forwards to infinity.
3. Make sure that the students do not put too many seconds into the last command. Otherwise the robot will move too far back and leave the line. The backward/forward loop at the end of the mission is a good test to check that the students have not put in too many seconds.
4. Also make sure that the students do not set the power percentage too high. 30% is more than enough to move forward and backward. 50% and 10% are fine for turning. Of course small deviations from these numbers will work fine too.

Solution: Mission 2 - Stop in front of Olympus Mons

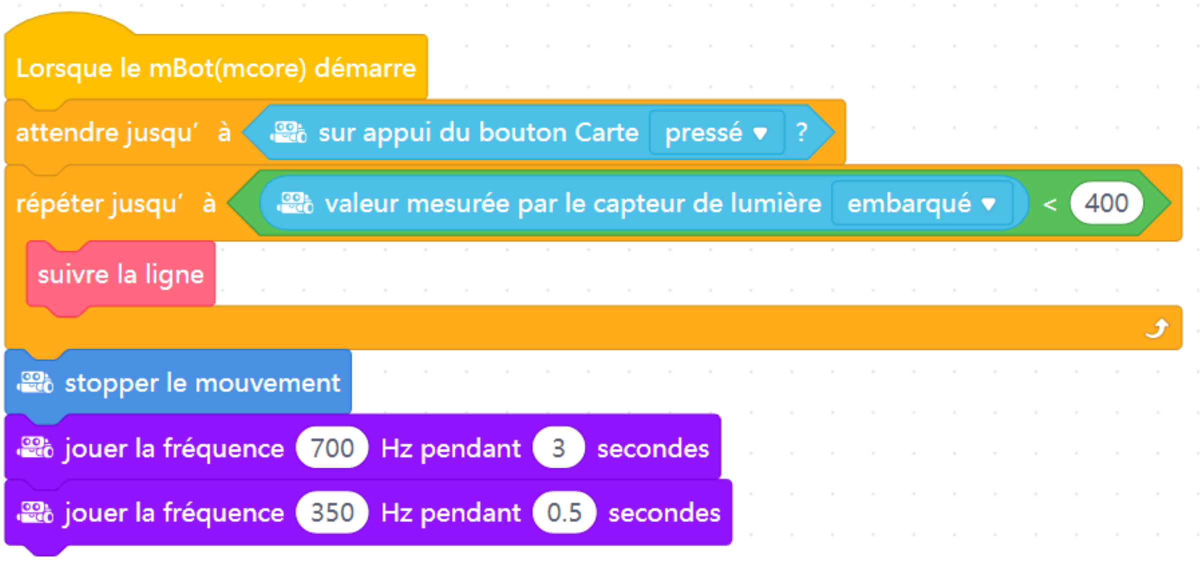


Alternatively you can download [the solution.]

Remarks :

The *follow the line* command is simply a name given to the mission 1 program.

Solution: Mission 3 - Exploring a cave on Mars



Alternatively you can download the solution.

Remarks :

1. The powers are slightly increased in the "follow the line" program. This is due to the fact that the batteries will be more worn out after a while and therefore the power must be increased to make the robot run.

Solution: Mission 4 - Finding Life!

Alternatively you can download the solution.

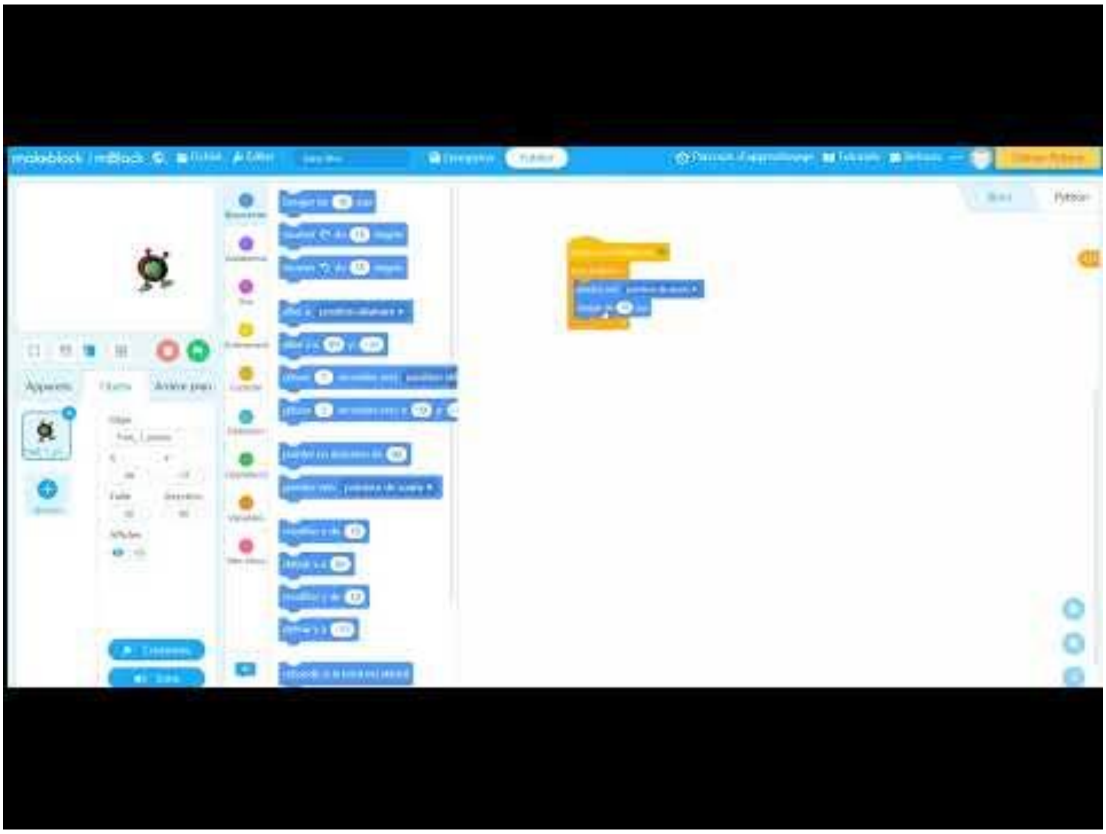
Note:

1. The powers are increased in the "follow the line" program. This is due to the fact that the batteries will be more worn out after a certain time and therefore the power must be increased to make the robot run.

2. The command "Send the signal: we have discovered life on Mars" is a separate little program in which the pupils can compose their own victory music.

Solution: Learning assessment:

Video illustration:



Source: https://youtu.be/hBSLWoGTa_8

To go further

Discovering the planet Mars

Humans have been undertaking missions in search of the planet Mars since the 1960s. NASA's Mariner 4 probe was launched on 28 November 1964 and was the first to fly over Mars on 14 July 1965. To date, four space agencies have successfully completed missions to the Red Planet: the National Aeronautics and Space Administration (NASA), the Indian Space Research Organisation (ISRO), the space programme of the Soviet Union and Russia and the European Space Agency (ESA).

During the 1960s and early 1970s several probes were sent to fly over Mars. The most successful mission was NASA's Mariner 9 probe, which was launched at the end of 1971. Mariner 9 stayed for almost a year in the orbit of Mars and was able to take more than 7000 pictures of Mars, which drastically changed our perception of this planet.

It was finally in 1975 that NASA sent two pairs of orbital probes and landers. Note that an orbital probe is a spacecraft that orbits a celestial body, whereas a lander is a spacecraft that lands on the surface of a celestial body. Viking 1 and Viking 2 landed on Mars and stayed there for several years. Unfortunately, they did not find any obvious evidence of life on Mars.

At the end of the 1990s a complete map of Mars from the North Pole to the South Pole was made by NASA's Mars Global Surveyor orbiter. At about the same time, NASA launched the Mars Pathfinder, which consists of a lander and a rover, the famous Sojourner, which was the first rover to operate outside the Earth and the moon. A rover is a motorised vehicle designed to move across the surface of a planet or moon (as opposed to a lander, which remains stationary once it has landed on a star). For a complete classification of the different spacecraft, please consider this NASA explanatory page.

The Mars Odyssey orbiter, which is still in orbit around Mars, was launched by NASA in 2001. In 2003, ESA sent a mission with an orbiter and a lander, called Mars Express and Beagle, to Mars. The lander was unfortunately lost during the landing, but the orbiter is still on mission. Here you can see the pictures and movies sent by the Mars Express.

In 2004 NASA sent two more rovers to Mars, called Spirit and Opportunity. Spirit broke up in a sand dune in 2010 while Opportunity survived until 2018, when it shut down in a sandstorm.

In 2006, another NASA orbiter, the Mars Renaissance Orbiter, was put into orbit and since then it has sent us more data on Mars than all the other missions combined. A year later, NASA sent the Mars Phoenix, another stationary lander. Unfortunately NASA lost contact with it after a few months and declared it dead in 2010.

A new NASA rover that is far more powerful than any other, Curiosity, arrived on Mars in 2012. Curiosity's design inspired the development of the Perseverance rover, which landed on Mars in February 2021. One of the main missions of Perseverance is to collect samples of the soil of Mars. These samples are scheduled to be returned to Earth in 2031 by a joint NASA and ESA mission. For the latest news on Perseverance, see the following page.

Finally, let's not forget the ExoMars mission, which is a collaboration between the ESA and the Russian space agency Roscosmos. The mission contains a lander, called Schiaparelli, which was sent to Mars in 2016 but broke up on landing and an orbiter, called Trace Gas Orbiter, which was sent the same year and is still there. Then in the same mission, a rover, called Rosalind Franklin, should be sent to Mars again this year (2022). The name refers to the British scientist behind the discovery of the structure of DNA. "The name reminds us that exploration is in the human genes. Science is in our DNA, and in everything we do at ESA. The Rosalind rover captures this spirit and transports us all to the forefront of space exploration," said the ESA Director (ESA, 2019b). Unfortunately, in view of the current situation, ESA has cancelled the ExoMars mission completely (Science.lu, 2022).

Other countries are also developing missions to Mars: h

- India's Mars Orbiter Mission, which reached orbit in 2016,
- the Arab Emirates' Hope Probe mission, sent to Mars in 2020,
- China's Tianwen-1 mission, which will arrive in orbit and on Mars in 2021,
- Japan's Mars Moons Exploration Mission, planned for 2024.

Finally, it should be noted that this summary gives the impression that the quest for Mars is full of successful missions, whereas in reality, alongside the successful missions mentioned above, there were many missions that failed. This is a good illustration of how scientific research works: history often only retains the successes, whereas in reality every discovery, invention or scientific breakthrough was, is and will always be preceded by many failures, which will not be mentioned and forgotten later.

Why explore Mars?

Of course, the quest for the universe and the challenge to go further has always interested mankind. The purely scientific reasons for exploring Mars are as follows:

- the search for life on Mars,
- characterise the climate and geology of the Red Planet,
- prepare the ground for future human exploration.

Understanding whether there is life outside of life on Earth is a fundamental question. As Mars is the planet most similar to our Earth, it is an ideal place to investigate this question.

Understanding the geology of Mars is important for understanding the planet's history. Studying the atmosphere of Mars can help to understand the evolution of that atmosphere and why Mars today has much less atmosphere than the Earth. In the long term, these studies will help to better understand our Earth and the other planets in the Solar System.

Finally, one of the ultimate goals is human exploration. To prepare the ground, it is necessary to study the risks in advance. This is why robots are currently exploring and categorising the surface of Mars.

In the following video, planetary scientist Joel Levine explains nicely why Mars missions are important from a scientific point of view:

https://www.ted.com/talks/joel_levine_why_we_need_to_go_back_to_mars/transcript?referrer=playlist-what_s_the_big_deal_about_mars#t-254765

The video is part of a series of eight talks on Mars (TED, n.d.).

Is there life on Mars?

Probably the most exciting question of all the Mars missions is whether there is life on Mars, in fossil or even living form.

A Martian day is close to 24 hours on Earth and the planet has a corresponding tilt, so there are Martian seasons and even weather patterns that correspond at least somewhat to ours. There is much evidence that Mars was once much more like our planet earth. Photos and data from the various orbiters and space probes that study Mars indicate that although Mars is a dry planet today, there was water flowing on Mars in the past. Water means life, because water is the main element necessary for the development of life.

The first probes, Viking 1 and Viking 2, which landed on Mars in the 1970s did not find life on Mars. But this is not proof that there is no life. On the contrary, discoveries of microbes at the bottom of frozen lakes in Antarctica made by NASA give us hope of finding life on Mars, because the climate of Antarctica is similar to that of Mars today. On Earth, microbes have also been found in sedimentary rocks more than 1000 metres below the Earth's surface, but also in salt deposits and deep water vents (Alonso & Szostak, 2019). These findings indicate that our robots may not yet have been looking in the right places on Mars.

The Viking mission did four different experiments to see if there were bacteria in the Martian soil. At the time, the results of all four experiments seemed to rule out the possibility of life. Now, almost 40 years later, scientists have explanations for the failure of the Viking experiments and the hunt for Martian life remains open.

Today scientists have also developed much more refined and discrete techniques to detect the presence of (ancient) life. The best known of these is based on the detection and sequencing of DNA. However, there is a big problem with this method: even if DNA is common to all terrestrial life, it is not clear that extraterrestrial life has DNA. Even more pointed research is taking different types of proteins and amino acids as a starting point for the search for extraterrestrial life (McKay & Parro García, 2014).

NASA's Curiosity rover and the future Rosalind Franklin rover are equipped with measuring instruments to perform new experiments based on these new technologies in the search for past or present life. An important aspect is the strategic choice of landing sites for these rovers.

Finally, another method of searching for life is the detection of biosignature gases in the atmosphere of planets and exoplanets. This is one of the missions of the new James Webb Space Telescope (Wolchover, 2021).

Fermi's Paradox : Where are they?

The question of the existence of life in the universe outside our earth is called Fermi's paradox. In 1950, physicist Enrico Fermi (Nobel Prize winner in 1938) was having lunch with colleagues at Los Alamos and they were discussing a cartoon about aliens that had appeared in the New Yorker, when suddenly Fermi said, "Where are they? The colleagues immediately understand that Fermi is referring to the fact that the sun is a rather young star in our galaxy and therefore civilisations more advanced than us should have appeared in the older planetary systems and should have already colonised our galaxy in some way and thus shown themselves to us. Note, however, that Fermi most likely did not doubt the existence of other civilisations. More likely explanations for the paradox are that inter-stellar travel is simply not possible, that the journey was not worth the effort, or that civilisations do not survive long enough to develop the necessary technologies. (Gray, 2015).

What is life?

We have seen in the previous paragraphs that one of the problems in the search for extraterrestrial life is the fact that we do not know what life will be like outside our planet earth. This question is only the beginning of a much deeper question: what is life? This rather philosophical question seems quite simple, but is currently very far from having a clear answer, even from a purely scientific point of view.

At first glance, it seems easy to decide whether something is alive or not. Unfortunately, the world is full of examples that lie on the borderline and that, according to one definition, are alive, while according to another definition they are not. In everyday life, this does not seem to be a big problem. But in science it is catastrophic, as NASA microbiologist Radu Popa explains: "This is intolerable for any science. [...] A science in which the most important object has no definition? This is absolutely unacceptable. How are we going to discuss it if you think the definition of life has something to do with DNA, and I think it has something to do with dynamical systems? [...] We can't find life on Mars because we can't agree on what life is." (Zimmer, 2021).

Finding a definition of life that satisfies everyone, however, is very complicated. This is what molecular biologist Edward Trifonov tried to do in 2011. He reviewed 123 common definitions of life and tried to find a common sub-definition. The end result was that life would be 'self-replicating with variation'. But this definition was quickly discarded: a computer virus is self-replicating with variation, but no one would say that it is alive.

This is where philosophers try to find an answer by taking different voices. One stream of philosophy adheres to the principle of operationalism. The idea is that it is not absolutely necessary to find a universal definition of what life is, but that each field of scientific research works with the definition that suits them best. For example, the definition that NASA uses to look for life outside our planet differs from the definition that doctors use to distinguish between living and dead. But that doesn't matter, the important thing is that the definition works for its own field of research.

Another trend is towards family resemblance, which is a philosophical idea that objects are classified into different groups, where objects in the same group may be related to each other by similarities without necessarily all sharing a common similarity. To illustrate this idea, if you ask a person to define the word game, they probably won't be able to. A game can be played by two people, several people or even alone. A game can have a winner and a loser, but does not necessarily have to meet this criterion. A game can be for children, but there are also games for adults. Finding a clear definition of the term game is obviously not easy. However, if we are asked to identify which of many objects are games, we will probably have no problem doing so. Intuitively we can recognise a game, without having an exact definition. A game satisfies a certain number of criteria from a list of criteria, but not necessarily all of them. What if it was the same with the term life? In (Abbott & Persson, 2021), researchers at Lund University classified a long list of things into different categories in the hope of finding the category that defines life. They tried to establish a list of properties that are associated with life without every living thing necessarily meeting all these criteria. Unfortunately, this approach is also problematic. One of the properties of living things was order (living things have coordinated and organised structures), just like snowflakes (which we would not like to classify as a living thing). Another property was that of DNA. But red blood cells have no DNA, although we would like to classify them as living things.

One category of organism has really changed the game of what life is: extremophiles. Extremophiles are organisms whose normal living conditions are lethal to most other organisms. A well-known example of an extremophile is the tardigrade.

The tardigrade, the cutest of the extremophiles

The tardigrade, also known as the water bear, is a half-millimetre long organism (just long enough to be seen with the naked eye) that lives all over the world. It can be found in salt or fresh water, as well as in moist terrestrial places, such as in mosses in forests. The tardigrade is often referred to as the champion of extremes because it can survive in the most hostile conditions: it can withstand temperatures of -272 to 150 degrees and pressures of up to 6000 bar. It can also be exposed to ultraviolet and X-ray radiation. It can be deprived of food and water and go into a state of stasis for more than 10 years. Once its stasis is over, it can reactivate its metabolism.

In the TARDIS (Tardigrades in Space) experiment, ESA researchers sent 3000 tardigrades on a 12-day space mission in 2007. "Our main finding was that the vacuum of space, which leads to extreme dehydration and cosmic radiation, was not a problem for the water cubs," explains the head of the TARDIS project (ESA, 2008).

Recently tardigrades have been installed by ESA for longer periods outside the International Space Station (ISS) and have survived the vacuum of space, extreme temperatures and solar radiation. Scientists were previously convinced that these conditions were incompatible with any kind of life (ESA, n.d.b)

We also refer you to the Space Bears activity of ESERO Luxembourg.

A more radical approach is taken by Carole Cleland, a philosopher from the University of Colorado. For many years she observed, collaborated and discussed with many researchers from different fields and institutions (including NASA) who all had in common that their research revolved around the subject of life. The result is a series of scientific papers collected in a book (Cleland, 2019). His conclusion is that scientists should simply stop looking for a definition of life, as life would be one of those concepts that cannot be defined. After all, according to Cleland, "we don't want to know what the word life means to us, but we do want to know what life is.

For a complete overview of the scientific and philosophical discussions around life, we refer the reader to (Zimmer, 2021a) or (Zimmer 2021b).

The importance of robots (and digital science) in missions to Mars

Sending robots to Mars has many advantages. First of all, it is much easier to keep a robot safe than a human being. When humans didn't know any better, they sent animals like dogs or monkeys on space missions to find out what a human needed. Today we know that it can be very dangerous for humans to go much further into space than the International Space Station (ISS). Moreover, robotic missions are always cheaper than a human mission (even if they are clearly less spectacular). From an organisational point of view, robots are less vulnerable than humans and can operate in much more hostile environments. Finally, there are many tasks that a robot can do better than a human.

However, as we have seen in this module, these robots cannot be programmed immediately from Earth, as a signal from Earth would take too long (more or less 20 minutes) to travel from Earth to Mars. Therefore, these robots must be programmed in advance and then operate autonomously.

The robots on Mars collect a lot of information that they have to send back to Earth. This represents a fairly consistent data stream that cannot currently be processed in space and must be sent as raw data. In addition, these Mars rovers do not have all the laboratories available here on Earth. Apart from the ISS, the only computers that can be used in space today are about as powerful as those we had on Earth 20 years ago. "Without the protection of the Earth's magnetic field or the shielding of the ISS," explains Professor Marcus Völp, a researcher at the Interdisciplinary Centre for Security, Reliability and Trust (SnT) at the University of Luxembourg, "the computers we use on Earth would make a lot of mistakes and end up burning out because of the radiation in space. But we need computing power, at the latest when we want to retrieve raw materials from asteroids with swarms of robots. ". This is why research is investing in the development of 'supercomputers' that will be able to exist in space and process raw data directly on site, sending only usable data.

"Of course, we must not only make robots and supercomputers safe from natural sources of error," Professor Völp continues, "but also protect them from sabotage. The best way to do this is to allow the robot to make mistakes, as students sometimes do at school, without anything serious happening (for example, by allowing other students to help the robot and other robots to do so).

Given that astronauts are now on the ISS and will soon be near the Moon, and one day on Mars, and that we cannot train all astronauts to be computer literate, these supercomputers must be as autonomous as possible. This is where artificial intelligence comes in.

Artificial intelligence will also play an increasingly important role in robots. The European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) plan to send a rover to Mars in 2026 with the mission of retrieving tubes containing samples of Martian soil. These tubes will have been placed on the ground by the Perseverance rover (see above). The new rover will be called Fetch. It must be able to move as autonomously as possible, find the tubes and retrieve them. To do this, the Fetch rover will use artificial intelligence and image recognition techniques to autonomously find the tubes on the ground (ESA, 2020).

The University of Luxembourg and the SnT are conducting research in all these areas: error tolerance, artificial intelligence on robots and many others.

Educational videos

- Paxi visits the red planet
- Paxi: Do Martians exist?
- Exomars: a promising future

Kahoot Quiz

- Expeditions to Mars
- Atmosphere and life on Mars
- Valles Marineris
- Mount Olympus
- sThe Martian caves

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