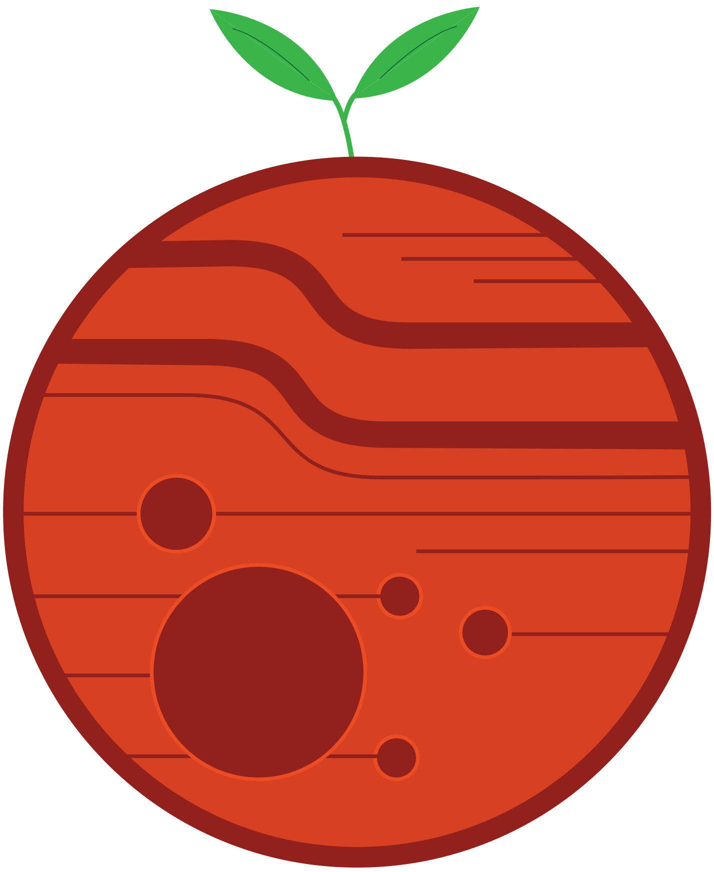
# teach with space

## → PLANTS ON MARS

### Build an automatic plant watering system





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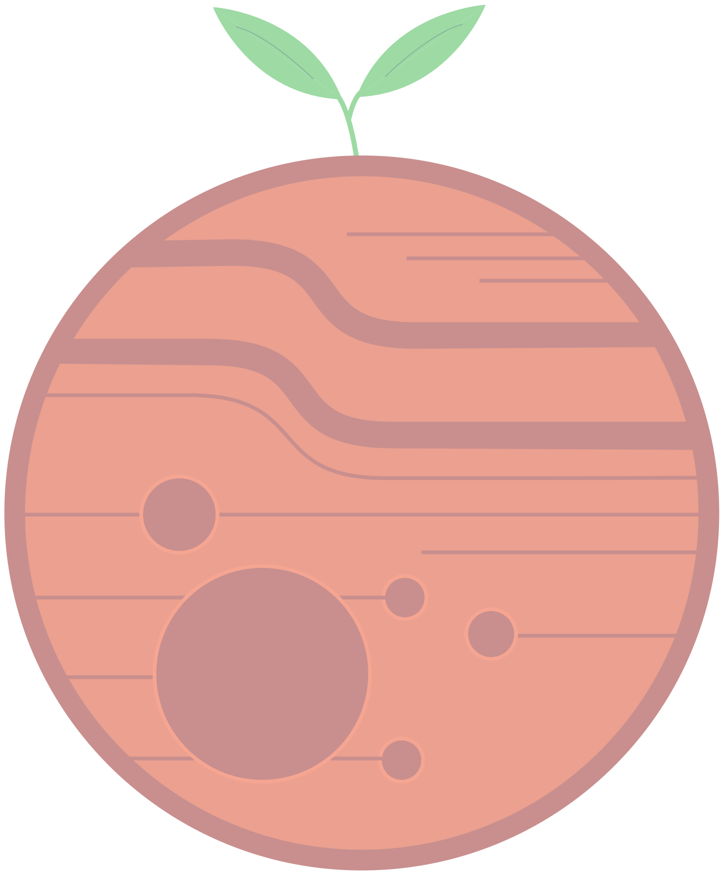


# → PLANTS ON MARS

## Build an automatic plant watering system

## FAST FACTS

**Age range:** 14-19 years old
**Complexity:** Medium
**Lesson time required:** 2/3 hours
**Location:** indoor
**Includes use of:**

- A computer
- An Arduino
- A breadboard
- Circuit cables (male-male and male-female)
- A micro servo
- A humidity sensor
- A bottle
- Poster tack
- Cable ties
- Watering tube
- A bucket
- A plant (or soil)

## Outline

Students will explore technology used in space through the Arduino tool. They will build an automatic watering system that measures soil humidity and waters a plant accordingly. The basics of programming in C++ will be introduced using the Arduino Integrated Development Environment (IDE) software.

## Students will learn

- To identify electronic components
- To understand the basics of programming in C++
- To use sensors to take measurements
- The basics of fluid physics
- To use technology to solve a problem
- To communicate and discuss hypotheses
- To work in teams and share ideas
- About risk and hazards on Mars
- About natural resources
- About closed loops and self-sustainability

# → ACTIVITY 0: WELCOME TO MARS

## Introduction

This activity introduces students to the context of a Mars space mission, and the challenges that might be associated with living on Mars. The differences between Earth and Mars and what that means for living things is discussed, and students are asked to think about what is needed to sustain life. Students are encouraged to familiarise themselves with the use of Arduino by following the Meet Arduino! classroom resource.

## Background information:

From what we already know about Mars, it would be difficult to imagine the life that has evolved on Earth being able to survive the Martian environment. Despite having an axial tilt close to that of Earth's (25° versus Earth's 23°), providing seasons similar to those we experience on Earth, the lack of oceans to help regulate surface temperature and a thin atmosphere (approximately 1% of the density of Earth's) means that the temperature varies wildly from day to night.

Mars' orbit is also much more eccentric (elliptical) than Earth's, meaning at some times of the year it is much closer to the Sun than at other times, compounding the problem of extreme temperature variations. The thin atmosphere and lack of ozone, combined with no protection from a magnetic field, means that the surface of Mars is bombarded with harmful UV radiation and solar winds. Searches for a vital resource on the surface of Mars, liquid water, have so far been unsuccessful. There are, however, signs of a significant amount of water ice.

To increase problems further, $CO_2$ makes up approximately 96% of the atmosphere, certainly too high for animals on Earth, and too high for many plants. If we are to terraform Mars, we may have to incorporate our modern day technologies and tools in order to create sophisticated, artificial habitats and irrigation systems.

However, there are several positive factors. Firstly, a Martian day is very close to an Earth day, lasting 24 hours and 37 minutes. This means that plant photosynthesis-respiration cycles would remain largely the same. Also, despite being further from the Sun than Earth, Mars still receives sufficient sunlight to allow a plant to photosynthesise. Combined with water that it might be possible to extract from Mars' icy poles, we would have two of the vital components needed to support a plant. This could potentially reduce the amount of materials a mission would need to bring onboard the spacecraft.

## Exercise answers

1) The main things that plants and other living organisms need to survive and that students should identify here are:

- An energy source (food for animals and sunlight for plants)
- Water
- Nutrients
- Oxygen
- Carbon dioxide (necessary for plants to photosynthesise)

They may also discuss things such as shelter and warmth and safety in their environment. These aspects are all relevant, and can be linked to a more in depth discussion on ecosystems and the environment.

2) Using the background information above:

| Statements about Mars - Table A1 | |
|---|---|
| **Statement** | **True or False** |
| Mars experiences seasons, just like we do on Earth. | True |
| The orbit of Mars is a similar shape to Earth's, meaning that the temperature on the surface is fairly constant. **The orbit of Mars is much more eccentric, meaning temperature varies much more than on Earth.** | False |
| Mars has a thick atmosphere, trapping heat from the Sun. **Mars has a very thin atmosphere, meaning that the temperature drops drastically during night-time.** | False |
| Mars has no magnetic field, this means that there is less protection from harmful UV radiation and solar winds. | True |
| We have found liquid water on the surface of Mars. **We have found signs of frozen water near the poles, but no liquid water.** | False |
| The atmosphere of Mars has a similar composition to Earth's atmosphere. **The Martian atmosphere has a much greater percentage of $CO_2$ than the Earth's atmosphere, and almost no oxygen.** | False |
| Plants on Mars would need to adapt to the massively different day and night cycles on Mars. **The Martian day is 24 hours and 37 minutes, so the day and night cycles are very similar to those on Earth.** | False |
| Mars does not exist inside the 'Goldilocks' (habitable) zone, so it is impossible for liquid water to exist on the surface. **Mars exists just on the edge of the habitable zone, so it is possible for liquid water to exist on its surface.** | False |

# → ACTIVITY 1: PREPARING THE ITEMS AND FIRST DESIGN

## Introduction

The students are tasked with thinking about how they would design an automatic watering system. They are given a list of supplied materials and knowledge of how each of the components work.

## Exercise answer

You should expect a wide range of proposals in this exercise. Whilst there are indeed some ideas that may not be feasible, there are many, many more that could be implemented. The students' design here is likely to not be their final design, and students should not be disheartened if they have to change their plan throughout the activities, as this is part of the process. As a teacher, you should look to see if they have thought about the questions posed, and if their proposal makes sense.

# → ACTIVITY 2: DESIGN AND TEST YOUR WATER RESERVOIR

## Introduction

In this activity the students will introduce water into their prototype systems to see how their design behaves. This allows the students to go through an iteractive scientific process of designing and building a system.

## Background

## The continuity equation

Assuming there are no leaks in the system, then the mass of water flowing in per unit time is always the same.

As mass is volume times density: $m = V \cdot \rho$

We can assume the volume of a certain length of the pipe L and area A, so then this will be:

$$m = L \cdot A \cdot \rho_{water}$$

If the mass per unit time is always the same, we have the following:

$$\frac{m_1}{t_1} = \frac{m_2}{t_2}$$

We can substitute the previous equation for both and see that the density cancels out as it's always the density of water. It will result as follows:

$$\frac{L_1 \cdot A_1}{t_1} = \frac{L_2 \cdot A_2}{t_2}$$

Knowing $\frac{L_1}{t_1}$ is the velocity of the fluid in that part, we can substitute:

$$v_1 \cdot A_1 = v_2 \cdot A_2$$

This is called the continuity equation.

## Torricelli's theorem

After applying the principle of conservation of energy in our system, we get to the Bernoulli equation:

$$P+\frac{1}{2}\rho v^2+\rho gh=\text{constant}$$

with the first term P being the pressure, the second term ( $\frac{1}{2}\rho v^2$) being equivalent to the kinetic energy per unit volume, and the third term ( $\rho gh$ ) the potential energy per unit volume. We also consider the velocity in the reservoir to be approaching 0, and the area of the flow pipe to be approaching 0.
This takes us to a very important relationship known as Torricelli's theorem:

$$v=\sqrt{2gh}$$

## Exercise

1) Important considerations are:

- the length of the tube
- the height of the water bottle
- the height of the U-bend

These factors will affect how the water flows in the pipe, and whether or not the flow is stopped in the 'off' position.

2) Resistive forces are responsible for terminal velocity that is reached in a fluid.. When the resistive force is equal to the force from gravity, there is no more acceleration, and terminal velocity is reached. The resistive forces are different depending on the medium. In the case of the water in the pipe, the resistive forces come from friction between the water and the pipe.

3) The students are introduced to some aspects of fluid physics. Although it isn't necessary to be familiar and confident manipulating all the equations that are discussed, it is useful to understand their consequences for the plant watering system. This could be done as part of a demonstration to the class.

| Statement | True or False |
|---|---|
| The water will flow more quickly through the tube than in the reservoir | True |
| The width of the bottle is important in determining the flow rate | False |
| The width of the pipe is important in determining the flow rate | True |
| The height difference between the bottle and the pipe is not important | False |

4) The main point to take away from these exercises is that the greater the drop in height between the water bottle and the pipe, the greater the flow of water in the pipe. Students will have to find a balance between the heights they use and the orientation of the pipe in order to build a complete system.

Again, there is no single correct answer here, but you should look for justifications for their chosen design in their sketch.

# → ACTIVITY 3: MOUNTING THE SERVO AND CONNECTING THE WATER PIPE

## Introduction

Now the students are ready to begin the automation of their system. A servo is used to turn the system 'on' and 'off' automatically. You may wish to take an independent direction to the suggested design here, based on the designs proposed by your students.

## Exercise

Firstly, the students will connect the servo to the watering pipe and a suitable wall. Students will then make use of the 'sweep' routine, included in the Arduino IDE, to understand how the servo works, and to gain a better understanding of how to incorporate it into their system.

# → ACTIVITY 4: TEST THE MOISTURE SENSOR

## Introduction

In order to fully automate the plant watering system, we have to know when the plant needs watering. So in this activity students are introduced to the soil moisture sensor. The specific instructions required may vary from those given in the guide, depending on the soil moisture sensor you use. You should always refer to the data sheet and any supporting material from the manufacturer when building the circuit.

## Exercise

If the students have completed the Meet Arduino! classroom resource, then this activity is straightforward. If problems with the code or sensor persist, double check that the connections between the components are correct and that the chosen baud rate is suitable.

The values that the students get for the dry and wet readings will vary from sensor to sensor. The value chosen to switch between 'on' and 'off' should be between the two values.

# → ACTIVITY 5: CONNECTING ALL THE COMPONENTS

## Introduction

Now the students are ready to combine all the elements of their system into one complete plant watering system.

## Exercise

This exercise requires that the students combine the circuits they built in activities 3 and 4, and so should be straightforward. Again, consult the datasheet of the sensors you use to ensure that the correct ports on the Arduino are chosen.

# → ACTIVITY 6: PROGRAM YOUR SYSTEM

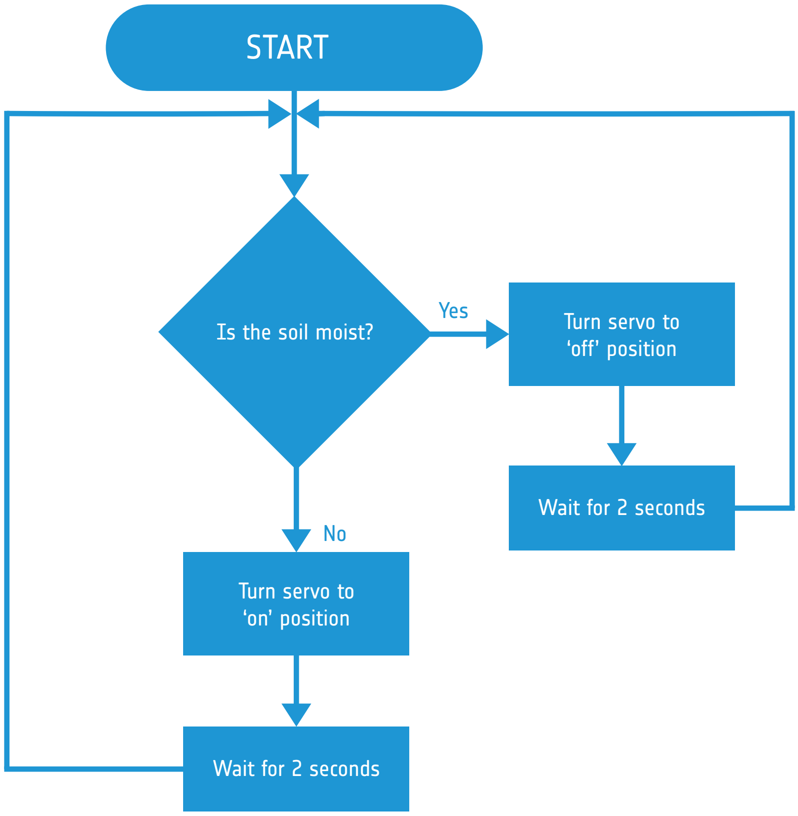
## Introduction

Now that the students have their system built, it's time to program the Arduino to operate all the components automatically. The problem is broken down into manageable steps, and students are asked to produce a flow chart before writing any code.

## Exercise

1) Although thought processes and the designs of the watering systems your students propose will vary, it is almost certain that they will include the use of an if, else statement in their code. The flow chart should therefore make use of a 'decision' box, indicated by a diamond.

A simple flow chart of what we want our code to do is shown below.




2) The most obvious improvement to the design of their system would be to incorporate an average reading to take care of any anomaly data. Students may also discuss the benefit of a more robust system than the servo can provide. Again, there are many suggestions that could be made. You should look for the reasoning and justification when judging the validity of each one.

# → ACTIVITY 7: WHAT NOW?



## Introduction

This activity serves as an introduction to the wider scope of automation and discusses the ethics of such a mission to Mars.

## Exercise

1) Many of the resources a plant needs could be monitored in a similar fashion to how we have monitored the moisture levels of the soil. You should check to make sure that the students have covered the resources that they identified in activity 0.

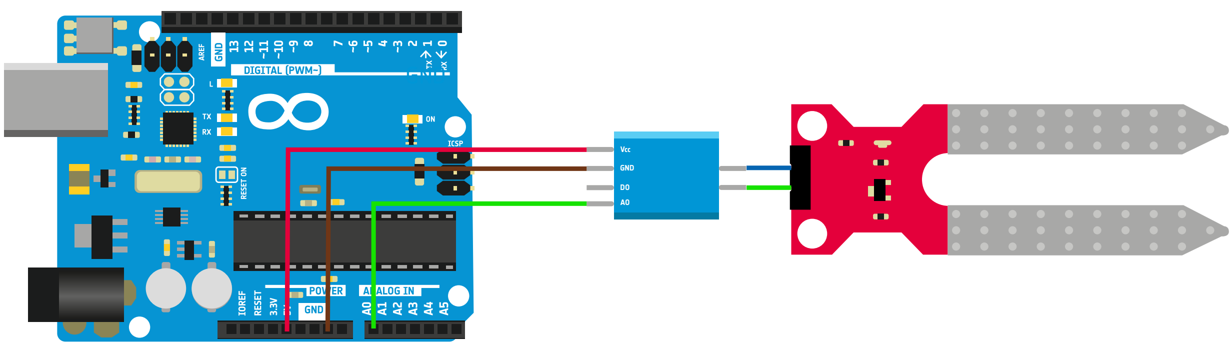
2) This exercise can be used to create an interesting discussion about the ethics of a manned mission to Mars. Whilst the laws involved are complicated, it can be used to give a context to discussions about space exploration in general.

# → ANNEX 1: DIFFERENCES BETWEEN MOISTURE SENSORS

The moisture sensor discussed in the activities contained an onboard controller and can be connected directly to the pins of the Arduino. Some moisture sensors have an external controller board and must first be connected to this before it can interface with the Arduino.

The exact setup will vary between moisture sensors. However, often the pins will be labelled Vcc, GND, AO (analog output) and DO (digital output). If this is the case for the sensor you are using, then a suitable circuit diagram is shown in the figure below. If your sensor is different from both of the sensors we have discussed, then you should look at the manufacturer's manual for further instructions.

Figure A1



↑ The configuration for a moisture sensor with an external controller board.

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