Growing Plants In Space

Investigating cell structure, function and photosynthesis

Year 8

Unit

Student Guide

Let your imagination fly freely into the vastness of space. Get ready for a plant adventure like you've never experienced before.

Australian Government
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PLANTS FOR SPACE
ARC CENTRE OF EXCELLENCE

@Plants4Space

Acknowledgments

Plants for Space acknowledges the Traditional Custodians of Country and their deep ongoing relationship with the Land. We pay respect to Elders past, present and future.

Plants for Space (**P4S**) is funded through the Australian Research Council and

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These materials have been developed by the P4S Education and Engagement team with consultation with the P4S researchers, education providers and classroom teachers. LISAF and Melbourne Uni Botany Foundation.

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What Do You Know About Plants Already?

True or False: Indicate which of the following statements about plants and cells you think are true or false:

Statement	True	False
Plants can move		
Plants can get sick if they don't have the right nutrients		
Plants can grow in the dark		
Watering plants on a schedule is best		
Plants "breathe" in carbon dioxide and "breathe out" oxygen		
Plants get all their energy from the sun		
All plant cells are the same		
Plants contain DNA		
Chloroplasts (where photosynthesis occurs) are only found in leaves		
Fertilizer is "plant food"		

Finish the sentences...

Plants can provide many useful things for us, such as ....

To survive, plants need ...

In biology, cells are...

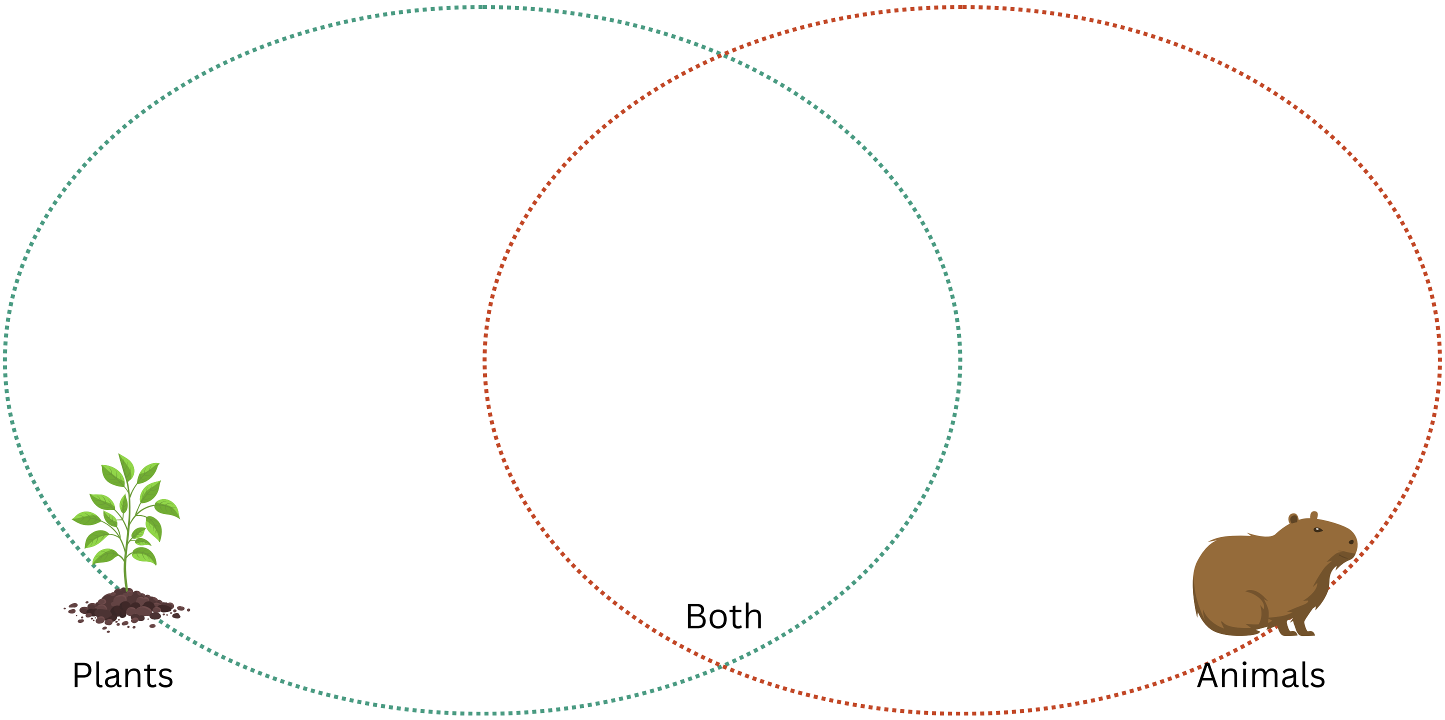
Things you can find inside a plant cell...

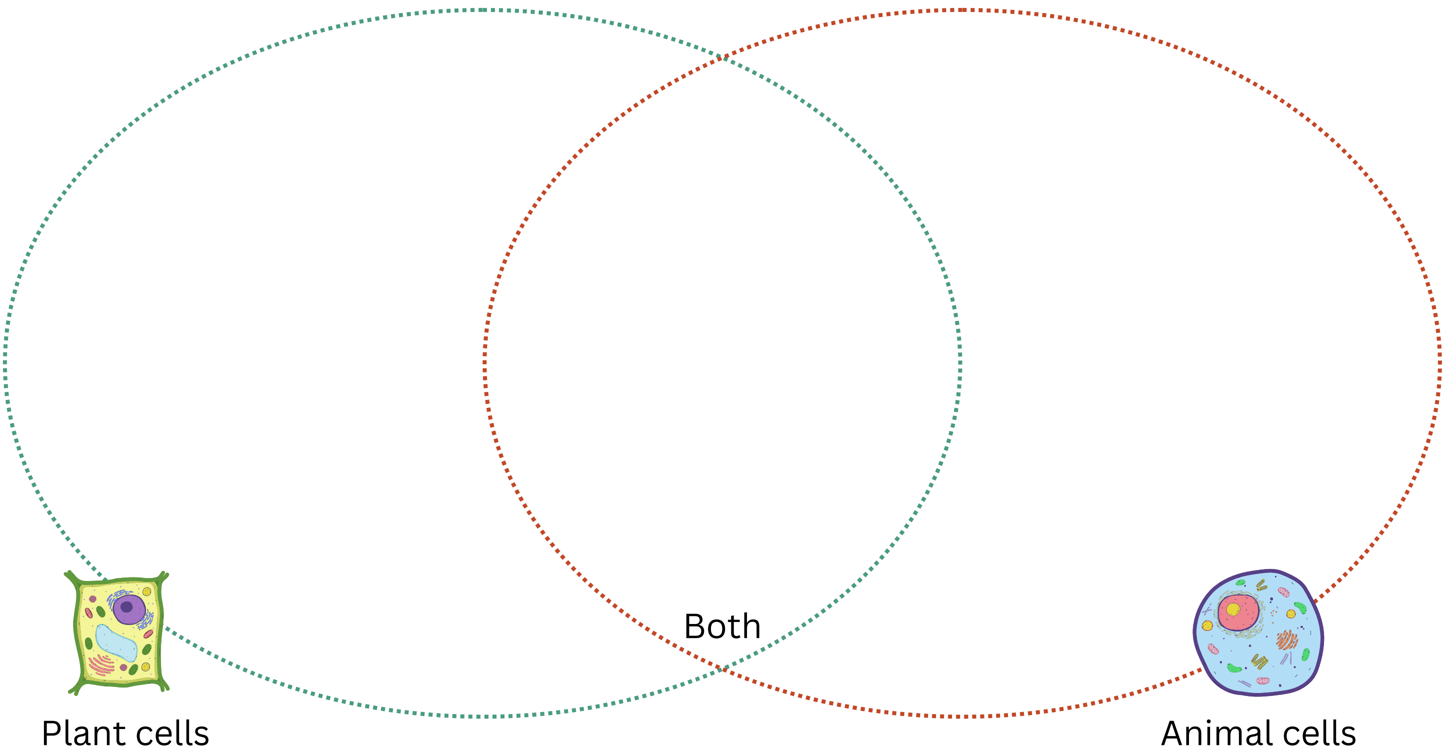
I am similar to plants many ways, for example we both...

Roots grow downwards because...

What is similar, what is different?

Can you identify any similarities, differences, or things only found in plants or animals?





The Space Garden Was Their Sanctuary

Alarms screamed. Red lights flashed everywhere.
Air hissed as metal twisted and broke. The Moon base shook, and everyone was confused and scared.
A meteor shower was hitting the Moon.
On Earth, small space rocks burn up in the atmosphere and do not cause harm. But the Moon has no atmosphere. Nothing slowed the rocks down. Tiny pieces of rock and ice slammed into the base at very high speed.
The hits were strong. Metal ripped apart. Air rushed out into space.
Anya and Kai were thrown to the floor. The air pressure dropped quickly, and it started getting very cold. Without air, a person can only survive for a short time.
"Garden module. Now!" Anya shouted.
They ran.
They raced through shaking hallways. Air rushed past them as they moved. When they reached the space garden, they hit the emergency controls. The heavy doors began to close. For a moment, they thought they would not make it.
Then the doors sealed shut.
Everything went quiet. The shaking stopped. The air was still again.
They fell to the floor, breathing hard.
"We're alive," Kai said softly.
Anya did not answer right away. She held her arm. A sharp piece of metal had cut through her suit and skin. Blood slowly drifted in the Moon's low gravity.
She took a deep breath and moved to the control panel.
"Crew quarters offline," she read. "Research lab offline. Command module offline."
The base was badly damaged. But the main power was still working. Emergency power had been sent to the garden module, keeping it alive.
Rows of plants filled the room. Tomatoes, lettuce, and beans grew under soft pink lights. Some leaves were damaged, but most of the plants were still alive.
And that was very important.
The plants were making oxygen. They were cleaning the air. They helped control the temperature. Without them, Anya and Kai would not survive.
Outside, the Sun was setting.
On the Moon, night lasts for fourteen Earth days. That means fourteen days of darkness and freezing cold. No one could come to help quickly.
Anya carefully cleaned and wrapped her wound. Getting sick in space could be very dangerous.
"Fourteen days," Kai said, looking around the glowing garden. "Just us, the plants, and the dark."
Anya nodded.
Space is a harsh place. To survive, humans need air, water, food, and protection.
Anya and Kai looked at the plants, then at each other, and smiled.
The space garden was no longer just an experiment.
It was their safe place.

The Space Garden Was Their Sanctuary

Alarms screamed. Red warning lights flashed.
The sound of hissing air and twisting metal echoed across the Lunar outpost as confusion filled the crew quarters.
A meteorite shower was hitting the Moon.
On Earth, something this small would pose no danger. Space rocks usually burn up in the atmosphere before they ever reach the ground. The Moon has no protective atmosphere. Nothing slowed the meteorites down. Tiny pieces of ice and rock slammed straight into the outpost at incredible speed.
The impact was violent. Metal tore apart. Air rushed out into space.
Anya and Kai were thrown to the floor as the pressure dropped and the temperature began to fall fast. Without air, a human could only survive for seconds.
“Garden module. Now!” Anya shouted.
The two astronauts ran.
They raced through shaking corridors, their boots barely touching the floor as air escaped around them. When they reached the space garden, they slammed their hands onto the emergency controls. The bulkhead doors began to close.
For one terrifying moment, they thought they were too late.
Then the doors sealed shut.
The shaking stopped. The roaring rush of air was gone.
They collapsed onto the floor of the garden module, gasping.
“We’re alive,” Kai said quietly.
Anya did not answer right away. She was gripping her arm, where a sharp piece of metal had torn through her suit and skin. Blood seeped through the fabric and drifted slightly in the Moon’s low gravity.
She forced herself to focus and pulled herself toward the systems terminal.
“Crew quarters offline,” she read. “Research lab offline. Command module offline.”
The outpost was badly damaged. Somehow, the meteorite had missed the main power reactor. Emergency power had automatically been redirected to the garden module, keeping its life-support systems running.
Rows of plants filled the room. Tomatoes, lettuce, and beans grew under soft pink lights. Some leaves were torn, but most of the plants were still alive.
And that mattered more than anything.
The plants were producing oxygen. They were cleaning the air. They were helping control humidity and temperature. Without them, Anya and Kai would not survive long.

Outside, the Sun was setting.
On the Moon, night lasts fourteen Earth days. Fourteen days of darkness. Fourteen days of freezing cold. There was no chance of immediate rescue. Under the Artemis Accords, agreements between spacefaring nations, emergency support missions existed, but reaching the Moon took time.
Too much time.
Anya carefully cleaned and wrapped her wound. Infection could be deadly this far from Earth.
"Fourteen days," Kai said softly, looking around the glowing garden. "Just us, the plants, and the dark."
Anya nodded.
Space was hostile. It did not care if you were brave or clever. To survive, humans needed air, water, food, and protection. Anya and Kai looked at the plants and then each other and smiled.
The space garden was no longer just an experiment.
It was their sanctuary.

Discussion // Analysis:

1. Why is space difficult for living things?

2. What do humans / plants need to survive?

3. Why did Anya and Kai smile at the plants at the end of the story?

4. How might the space garden be similar to Earth?

What is Plants For Space ARC Centre of Excellence

Plants for Space is a big team of scientists from five Australian Universities, plus space companies, farming experts, the Australian Space Agency, and even NASA!

Together the team aims to figure out how to grow plants for food, medicine and materials so people can live in space for a long time without needing so many deliveries from Earth. What we learn can help make better food, and farming friendlier to the planet, here on Earth.

The Plants for Space team studies lots of things, like ways of growing plants without soil, how food affects our health and feelings, and even the rules about growing food in space.

P4S Missions

1. Making medicine in plants when we need them
2. Designing new plants that grow well inside sustainably
3. Making healthy, tasty, plant-based food for astronauts and for people on Earth
4. Helping kids and adults learn skills to get ready for jobs of the future

Q: What are the Plants for Space researchers trying to achieve?

Plant Architecture (Reader)

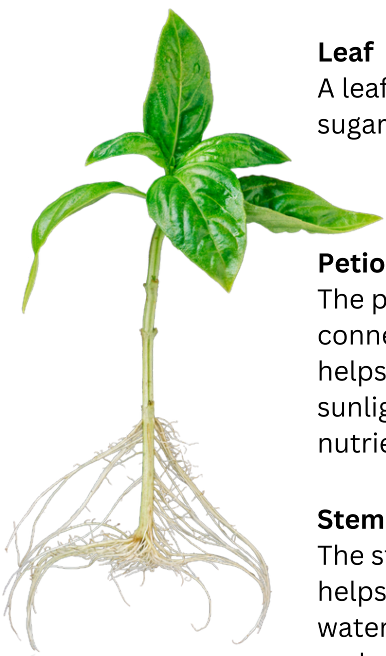
Like animals, plants have different parts, and each part has a specific job. All of these parts together are called a plant's architecture.

While there are many different types of plants with a wide range of shapes and sizes, most plants share the same basic parts. A plant's architecture is species-specific and is mostly determined by its genetics. However, it can also be influenced by the environment the plant grows in.

Conditions such as temperature, water, light, and nutrient levels can change how a plant looks and grows. For example, these conditions can affect stem length, leaf size, or fruit development.

By understanding how each plant part works and how they function together, Plants for Space researchers can design plants for specific environments and purposes. This might include plants with shorter stems, smaller leaves, larger fruits, or other useful traits.

Read about the common parts of a plant and think about how these parts can look different across plant species.



Leaf
A leaf captures sunlight to make sugar for the plant to use as energy.

Petiole
The petiole is the stalk that connects a leaf to the stem. It helps position the leaf to capture sunlight and transports water, nutrients, and sugars.

Stem
The stem supports the plant and helps it reach sunlight. It transports water and minerals from the roots and sugars from the leaves to the rest of the plant

Roots
Roots anchor the plant in the soil, absorb water and nutrients, and in some plants store excess sugars use.

Flowers
Flowers are the reproductive part of the plant. They produce seeds after fertilisation.

Fruit
Fruits protect the seeds and often help with seed dispersal. They often develop from flowers after pollination.

Seeds
Seeds contain a young plant and store food. They allow new plants to grow when conditions are right.

Plant Architecture for Space

In space, plants are grown in controlled environments using LED light instead of sunlight, and hydroponic systems instead of soil. To maximise limited space, vertical farming may be used in space habitats like the Moon. With limited resources, plants must be selected and designed to grow efficiently in these conditions. Plant architecture is a key focus of Plants for Space research, including developing compact plants that still produce enough food for astronauts.

A vertical farm growing lettuce for P4S research

The Research

Micro-Tom Dwarf Tomato plant

This is a tomato plant called a Micro-Tom. It has the same parts as a regular tomato plant, but everything is smaller. It typically, only grows to about 30 cm tall, with smaller fruit. Plants for Space researchers, including Dr Gunya, are studying how to keep the plant small while still growing larger and more nutritious fruit. Other P4S scientists are also exploring changes to features like root length and overall plant structure.

The Researcher

Dr Gunya Malhotra is a plant scientist at La Trobe University working with the Plants for Space team. She studies how plant cells make decisions about when to grow and how to defend themselves from disease. Gunya looks closely at plant hormones and genes to understand how these signals work inside each cell. Her research helps scientists create crops that grow well in small, indoor spaces like vertical farms or space stations. By learning how plant cells function, Gunya is helping design strong, efficient plants that can feed astronauts in space – and improve farming back here on Earth

Dr Gunya Malhotra

Plant Architecture Activity

In the boxes below, list how we use the different parts of plants in our everyday lives.

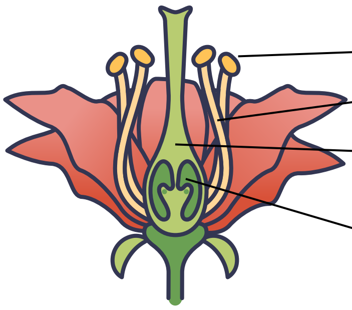
Leaf	
Stem	
Roots	
Fruit/Seeds	

Draw two different types of plants and label their similarities and differences in plant architecture.

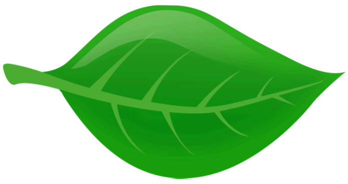
Similarities	Differences

Plant dissection, parts under a microscope and micrographs
Background Guide to Plant Parts:

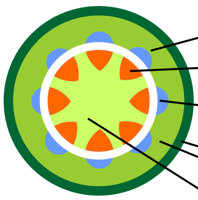
Whether on Earth or in Space, plants will have the same parts that carry out particular roles to help the plant survive and reproduce. Let's have a look at some of the most common features:



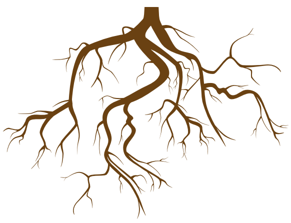
Flower:
- Pollen: Male gametes contained within pollen grains.
- Stamens: Male reproductive organs consisting of anther (produces pollen top) and filament (stalk).
- Pistil: Female reproductive organ consisting of stigma (receives pollen), style (connects stigma to ovary), and ovary (contains ovules).
- Ovules: Structures within the ovary that develop into seeds after fertilization.

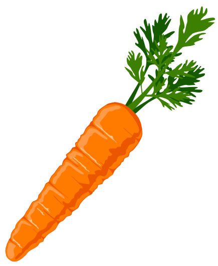


Leaf:
- Shape: Can vary widely (e.g., oval, heart-shaped, needle-like).
- Margins: Edge of the leaf (e.g., smooth, toothed, lobed).
- Venation: Pattern of veins (e.g., parallel, net-like).



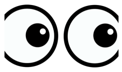
Stem:
- Vascular Bundles: veins that transports water and transports sugars through the stem.
- Xylem: Transports water and minerals from roots to leaves.
- Phloem: Transports sugars produced by photosynthesis from leaves to other parts of the plant.
- Epidermis: Outer layer that protects the plant.
- Cortex: Layer between the epidermis and vascular bundles.
- Pith: Central region of the stem (may be hollow).



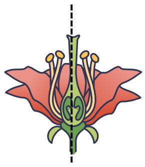


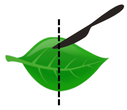
Root and Root Systems:
- Taproot: A single main root with smaller lateral roots (e.g., carrot).
- Fibrous Root System: Many thin, branching roots (e.g., grass).
- Root Hairs: Tiny hair-like extensions that increase surface area for water and mineral absorption.

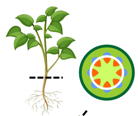
Plant Dissection Protocol:



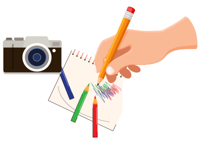
1. External Examination: Carefully observe the external features of the plant: Shapes, sizes, colours, textures, symmetry







2. Dissection
Flowers:
· Remove sepals and petals to expose the reproductive structures.
· Identify and examine the stamens (male) and pistil (female).
· Make a cross-section (cut length ways) of the ovary to view ovules.
Leaves:
· Examine the leaf shape, margins, and venation patterns.
· Make a cross-section to observe internal tissues.
Stems:
· Note the stem's shape, thickness, and any specialized features (e.g. hairs).
· Make a cross-section to observe vascular bundles.
Roots:
· Note the type of root system (taproot, fibrous).
· Examine root hairs if present.



3. Document your observations
· Take photos or draw diagrams of each dissected part or sticky tape down and label all identified structures

Leaf sample on a slide in water under a coverslip

4. Microscopic Examination (Optional)

Draw/stick in and label four plant parts and complete the table:

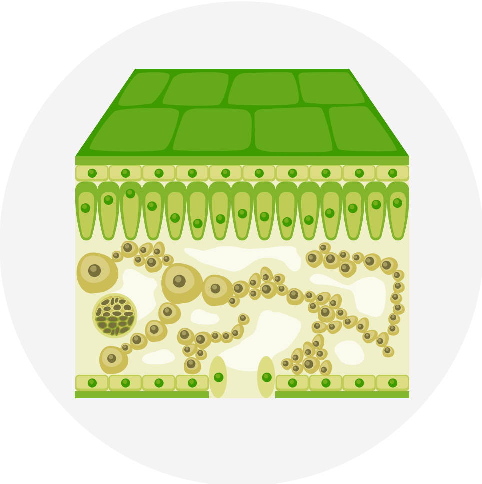
Plant parts	What does it do?	Which organelles do you think are most important in this part to keep the plant alive?	Why so?

Internal Plant Architecture

Three plant structures of interest to P4S are leaves, trichomes, and roots. Investigating the internal structure of the specialised cells within these parts helps researchers better understand their functions and identify ways to optimise them.

Draw an arrow from the cell names to the diagram.

Leaf



Many cells in a leaf are specialised to aid photosynthesis.

Waxy surface for protection

Epidermis ("skin") cells for protection

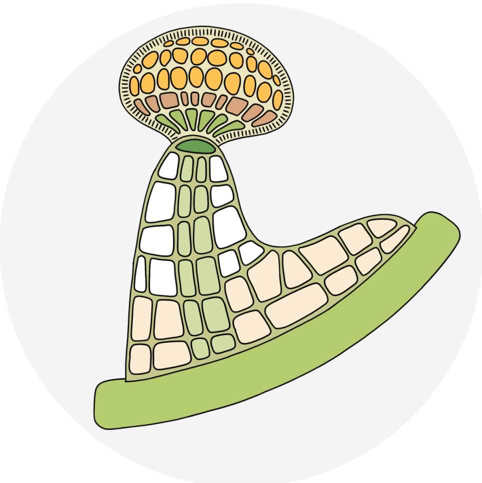
Palisade mesophyll cells are tightly packed at the top to help collect the light.

Vascular cells transports water and nutrients to the leaves and to take sugar away

Spongy mesophyll cells are loosely packed to help exchange gases with the surrounding air.

Guard cells create holes that control gas exchange and water loss by opening or closing

Trichome



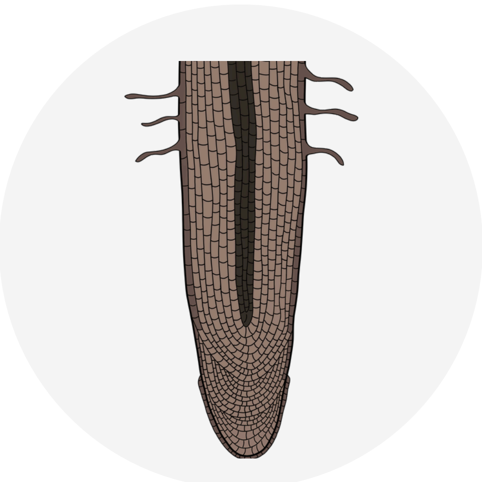
Trichome cells are specialised to make useful chemicals that help protect the plant.

Secretory Vesicles acts as a reservoir for chemicals produced by the secretory cells
Secretory Cells produce chemicals that can act as defensive chemicals

Basal Cell at the top of the stalk holds onto the head of the trichome called the gland

Hypodermal Cells Transports nutrients to the trichome head

Root



Root cells are specialised to absorb water and nutrients, to store energy and anchor the plant.

Root Hairs Modified epidermis cells that increase surface area to aid water and nutrient absorption
Epidermis cells are the outer layer and used for protection

Vasculature cells to take water and nutrients to the leaves and to take sugar to the root.

Root tip where the cells multiply, divide and stretch out (root meristem and extension zones).

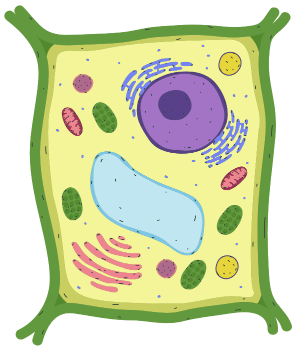
Root cap cells protect root cells as they grow through the soil (it gets stripped away by friction).

Leaf Cells

All living things are made of cells, including plants and animals. While they share some basic structures, plant cells have different organelles that give them unique abilities. These organelles allow plants to make their own food, store water, and maintain a strong shape. Plants also have specialised cells for different roles. Root cells absorb water and store nutrients, leaf cells carry out photosynthesis, stem cells transport water and nutrients, and fruiting cells produce seeds and food. These specialised cells are essential for the plant and useful to humans for food, fibres, and everyday products.
Mesophyll leaf cells contain organelles called chloroplasts that act like tiny food factories. They use sunlight, water, and carbon dioxide to produce sugar and oxygen in a process called photosynthesis.

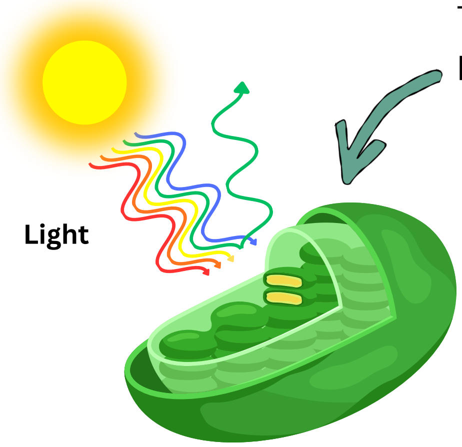
Draw an arrow from the cell organelle to the diagram.

Mesophyll cell



Cell Wall	Tough outer layer, providing support and structure.
Cell Membrane	Gatekeeper, controlling what enters and exits the cell.
Cytoplasm	Jelly-like substance that fills the cell and holds organelles in place.
Nucleus	The nucleus is the cell's control centre, containing the DNA.
Mitochondria	Converts sugar into chemical energy.
Chloroplasts	Organelle where photosynthesis takes place. (converting light, water and carbon dioxide into sugar and oxygen)
Vacuole	Large storage sac that holds water, food, and waste.

Chloroplast
The chloroplast is the where photosynthesis takes place.



Chloroplast

Photosynthesis
The process that turns light energy into stored chemical energy.

Light

Carbon Dioxide CO_2 **+ Water** H_2O → **Oxygen** O_2 **+ Sugar (Glucose)** $C_6H_{12}O_6$

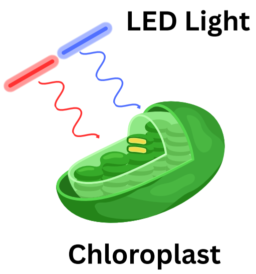
With out chloroplast the energy from the sun would not be turned into stored chemical energy in the form of sugar. This process is the foundation of virtually all life on earth.

Leaves in space

In spacecraft like the International Space Station, astronauts mostly live in a windowless environment. While sunlight is used to generate electricity, the lighting inside is artificial.
Light is essential for photosynthesis. In space and indoor farms, where there is no sunlight, scientists use special lights called LEDs to grow plants.
Plants for Space scientists are testing different colours of light and how long plants are exposed to it to find the best conditions for growth.

The Research

Chlorophyll gives leaves their green colour. Leaves look green because chlorophyll reflects green light rather than absorbing it.



LEDs
P4S researchers are experimenting with light. This is finding the best mix of light colours to maximise growth. they are finding that different red and blues produce the best results. The future of space farming looks purple.

Red + Blue = Purple
with no green light to reflect plants grown under red and blue light will look black.

NASA astronaut Mike Hopkins has tended to multiple plant experiments on the International Space Station (ISS). NASA

The Researcher

Robert Rintoul is a joint PhD student at the University of Nottingham and the University of Adelaide and is working alongside the Plants for Space team. He studies duckweed, a tiny, fast-growing aquatic plant packed with nutrients that could be a great food source for astronauts on long space missions. Robert experiments with different LED lights – using red, blue, and white colours – to see how they affect duckweed's growth, nutrition, and flavour. By finding the best light conditions, his work helps us grow fresh, healthy food in space and improve vertical farms on Earth. This means we can grow crops more efficiently all year round, using less water and space, which supports sustainable and reliable food production for everyone.

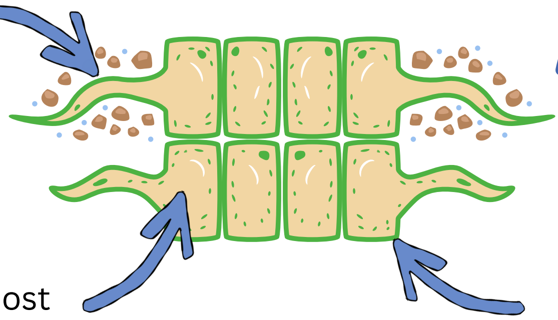
Root Cells

Plants for Space Researchers are looking at plant roots to understand how best to help plants thrive in the mircogravity environment of space. The specialised cells found in the plants roots work together to help penetrate into soil and absorb and transport nutrients and water.

Root Hair Cells

Specialised epidermal cells that increase the surface area of the root that is in contact with the outside environment.

No Cuticle
lacking a waxy layer helps absorb water.



No Chloroplasts
Root cells do not perform photosynthesis.

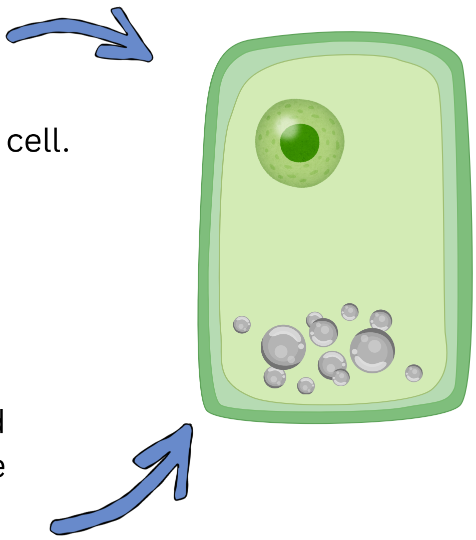
Large Vacuole
The Vacuole takes up most of the room in the cell and helps with water absorption and storage.

Thin Cell Wall
Thin cell walls are less of a barrier for faster water, nutrient absorption, and gas exchange.

Statocytes

Statocytes are specialised root cells in the root cap that contain statoliths. Statoliths are organelles (starch grains wrapped in a membrane) that found are found. They detect gravity and help direct root growth.

Nucleus
The nucleus is usually oriented to the top of the cell.



Phototropism
A plant's ability to grow in the direction of light.

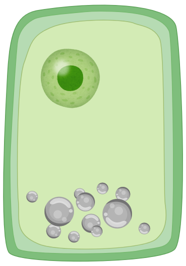
Statoliths
Statoliths are starch filled organelles that sink to the bottom of the root cell. This tells the root to grow downwards (Gravitropism)!

Gravitropism
A plant's ability to grow in the direction of gravity.

Roots in Space

When plant are grown in Space they have to survive in an environment that they did not evolve to grow in. One aspect that Plants for space researches a investigating are the challanges that plants face when grown in an microgravity environment.

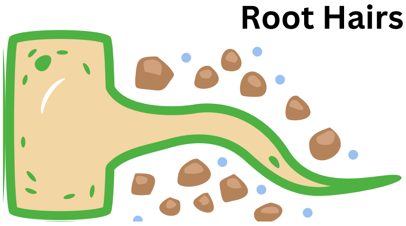
Plant root cell responding to gravity



Statocytes

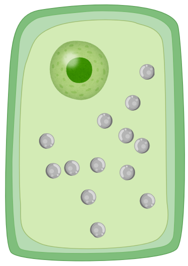
On Earth Statoliths sink to the bottom of the root cell. This tells the root to grow downwards!

Root Hairs



On earth, water is pulled down through he soil and away from roots. This enable roots to perform gas exchange.

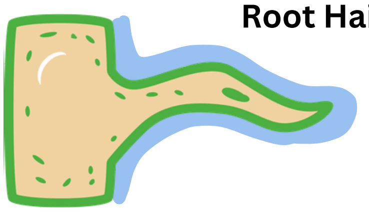
Plant root cell responding to microgravity



Statocytes

In space Statoliths are not pulled down by gravity and don't sink. This will make roots grown in all directions.

Root Hairs



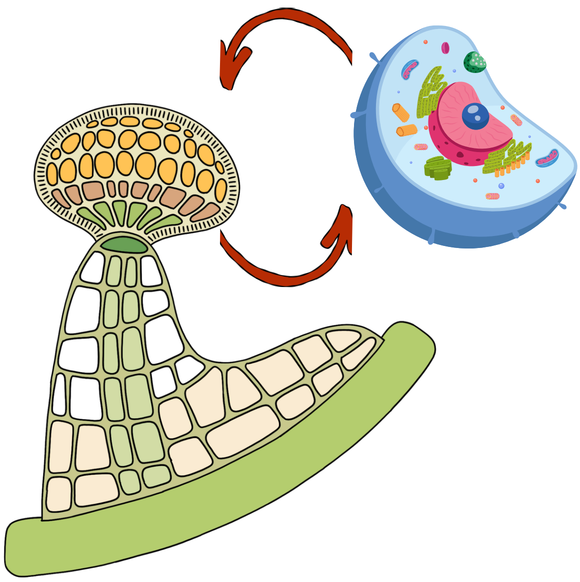
In space water clings to roots preventing gas exchange. This will stress the plants similar to what happens when plans are over watered or flooded.

The Researcher

Dr Troy Miller is a plant scientist at the University of Western Australia, working with the Plants for Space team. He studies how plant roots respond to different environments – including what happens when you grow a plant in space, where there's no gravity to help water move through the soil. Without gravity, roots can experience low oxygen (hypoxia) stress. Troy's research focuses on how cells in the roots grow, sense gravity, and transport oxygen. His work helps scientists design plants that can survive in space – and also supports better farming on Earth, especially in areas where heavy rainfall or flooding affects crop growth.

Trichome Cells

Trichome cells are found on the epidermis of plant leaves, stems, flowers, seeds, and fruits. Trichomes protect plants from UV light, frost, insects and disease. They have different shapes and structures to do different jobs. Trichomes can be long and thin like a hair or like a ball on a stick (glandular Trichomes). The glandular trichome is important for making chemicals that could be harmful to plant eating pests.



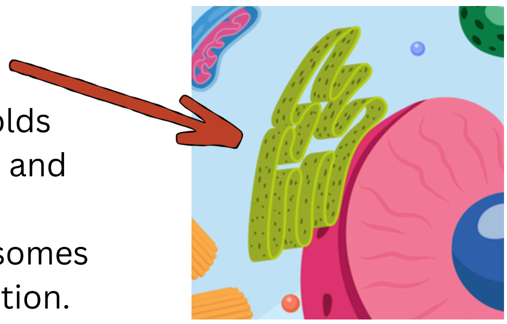
Trichome Secretory Cells

Trichome secretory cells are located toward the base of glandular trichomes. These specialized cells make chemicals that can be harmful to insect pests and the plant itself and so are stored in other specilised cells away from the other plant cells.

Many organelles, such as endoplasmic reticulum, are important for making these anti-insect chemicals in the secetory cells.

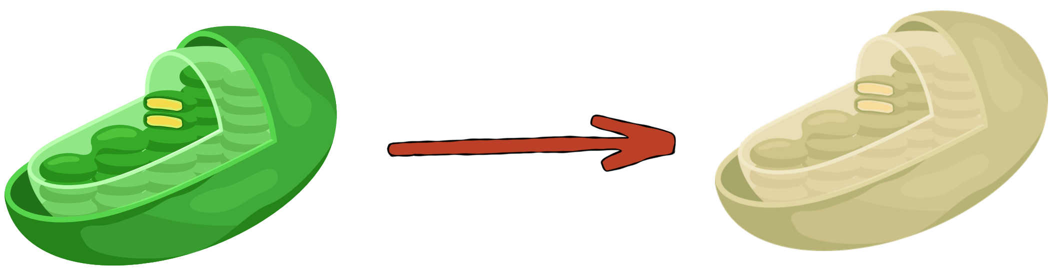
Endoplasmic Reticulum and Ribosomes

The Endoplasmic Reticulum (ER) is a membrane with many folds often surrounding the nucleus of the cell they make, process and transport fats and proteins.
Some ER's have ribosomes embeded in the membrane. Ribosomes make proteins that are important for the cell to live and function.



Changing Chloroplast

In some trichomes chloroplasts lose their ability to photosynthesize and instead make chemicals used to defend the plant against stresses. When this happen the chloroplasts lose their green colour. These are called leucoplasts.



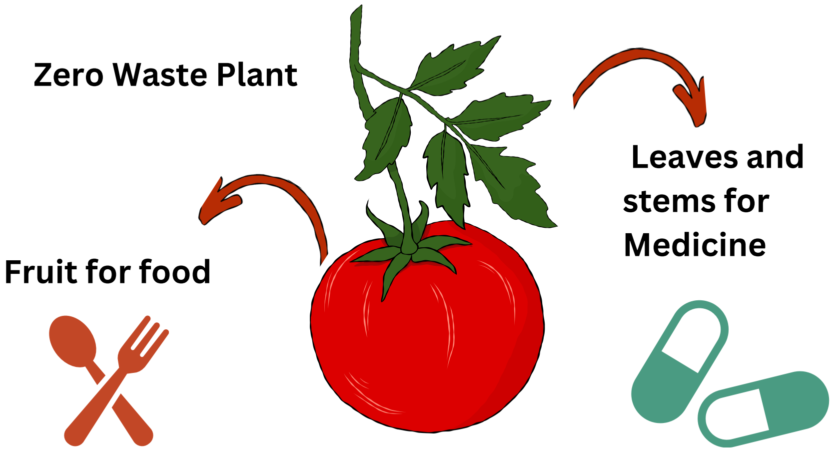
Chloroplast **Leucoplast**

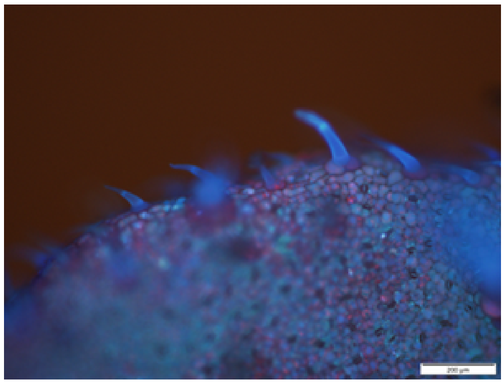
Trichomes in space (Reader)

Trichomes are an important plant structures for Plants for Space. Trichomes make chemicals that can be very useful for humans e.g. in pharmaceuticals (medicines), flavours and fragrances (rosemary and mint), and pesticides (to kill insects). Plants for Space are looking at the how the DNA controls how tomato trichomes to grow and which medicines we could engineer trichomes to make that could help astronauts.

The Research

By being able to control what is made in trichomes Plants for Space wants the entire tomato plant to be used by astronauts. This is a step closer to creating a zero-waste plant.





A microscopic image of Tomato Trichomes. Lee J. Conneely.

The Researcher

Lee Conneely is a molecular biologist from La Trobe University who studies glandular trichomes using cutting-edge genetic techniques to understand how these specialised cells regulate gene activity and produce valuable chemical compounds like medicines. Lee uses big data sets to understand how these cells work and is working on a project to reprogram tomato plants to make vital medicines for astronauts on long space missions. Because astronauts can't carry all their medicines into space, growing them in plants is a clever solution. Understanding trichomes and their functions also helps us learn how plants protect themselves and adapt to different environments, such as high altitudes on Earth or the challenges of growing in space. Lee's work alongside the Plants for Space team, supports growing plants that can thrive in tough conditions, benefiting space missions and sustainable farming on Earth.

Reader questions

Leaf Cells

1. Why are plant leaves important?

2. Why are plant chloroplasts important?

3. How do plants grow in response to light?

4. Why is it important to understand how plants respond and grow in LED lights?

5. Why are P4S researchers investigating plant responses to light and how are they investigating it?

Root Cells

1. Why are plant roots important?

2. What is special about plant cell walls in roots and how does this help the plant survive?

4. What specialised part of the plant root cell helps the plant know which way down is?

5. Why is it important to understand how plant roots plant grow in microgravity?

Trichomes Cells

1. Why are trichomes important?

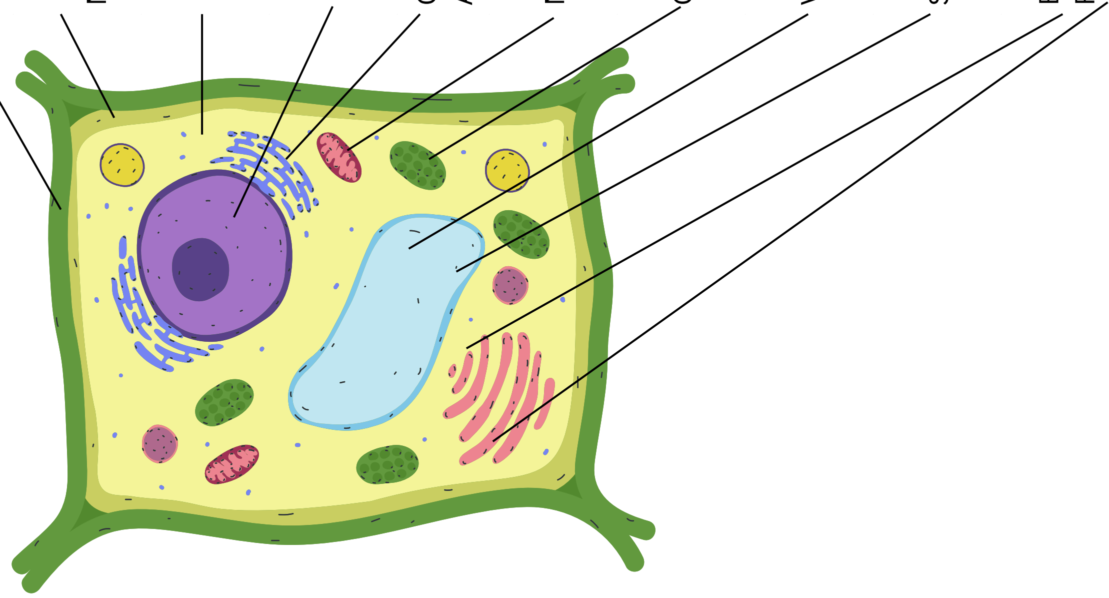
2. Which organelles are important for trichomes to work?

3. Why are P4S researchers investigating trichomes? How might is help people?

Make a specialised Plant Cell model!

Plant cells are eukaryotic, meaning they have a nucleus and other membrane-bound organelles. Plant cells are different from animal cells in that they have a cell wall, chloroplasts, and a large central vacuole. The organelles in a plant cell work together to carry out the functions of life, such as growth, reproduction, and responding to their environment. Let’s have a closer look at those cell parts...

This is like the plant cell's tough outer coat, providing support and structure. It's what makes plant stems stand upright!	Cell Wall
The cell membrane is the gatekeeper, controlling what enters and exits the cell. It's like a security guard for the cell.	Cell Membrane
This is a jelly-like substance that fills the cell and holds all the organelles in place. It's like the cell's filling.	Cytoplasm
The nucleus is the cell's control centre, containing the DNA. It's like the cell's brain.	Nucleus
This is like the cell's post office, packaging and sorting proteins for transport.	Golgi Apparatus
These are the powerhouses of the cell, converting food into energy. They're like the cell's energy generators	Mitochondria
These are the sites of photosynthesis, where plants make their own food using sunlight. They're what make plants green!	Chloroplasts
This is a large storage sac that holds water, food, and waste. It's like the cell's pantry and trash can.	Vacuole
Only found in root tip cells. They detect gravity and tell the root to grow downwards. They are starch grains bound in a membrane layer.	Statoliths
A network of tubes that transport materials throughout the cell. It's like the cell's delivery system.	Endoplasmic Reticulum
These are the protein-making factories of the cell. They're like the cell's construction workers.	Ribosome



Make a Plant Cell Model!

Materials

Base: You can use a variety of materials, such as cardboard/box, foam board, a large paper square plate, a clear plastic container lid.
Cell Wall: Green construction paper, green craft foam, green felt.
Cell Membrane: A thinner material than the cell wall, such as clear plastic wrap.
Organelles: You can get creative with the materials you use to represent the different organelles:
Nucleus: A small ball of playdough or a pom-pom or balloon (any colour you like).
Chloroplasts: Green candies (like M&Ms or jellybeans), green pom-poms, or green craft foam cut into small oval shapes.
Mitochondria: Red candies (e.g. M&Ms or jellybeans), pom-poms, or craft foam cut into bean shapes.
Vacuole: A large blue or purple candy, pom-pom, or blue or purple craft foam cut into a large circle or oval.
Endoplasmic Reticulum: Pieces of red liquorice, yarn, or car cut into wavy strips
Golgi Apparatus: Pieces of yellow liquorice, yarn, or craft foam cut into thin, curved strips.
Ribosomes: Small sprinkles, small beads, or small pom-poms (any colour you like).
Statolith: Small sprinkles beads, or small pom-poms wrapped in cell membranes (cling wrap)
Other Supplies: Glue or tape, scissors, markers or coloured pencils for labelling

Instructions

1. **Create the Cell Wall**: Cut out a large square or rectangle of your material. This will represent the rigid cell wall that surrounds the plant cell.
2. **Place the cell membrane material inside the cell wall**. It should be slightly smaller than the cell wall so that it fits inside. If you're using plastic wrap, you may need to tape it to the cell wall.
3. **Place the vacuole** (large blue or purple pom-pom, balloon etc.) in a large open space within the cell. It's often the largest organelles.
4. **Place the nucleus** (playdough, pom-pom, etc.) in the centre of the cell.
5. **Scatter the Chloroplasts** (green candies, pom-poms, etc.) throughout the cell.
6. **Place the mitochondria** (red candies, pom-poms, etc.) throughout the cell.
7. **Place the ER and Golgi** material (liquorice, yarn, etc.) near the nucleus.
8. **Scatter the ribosomes** (sprinkles, beads, etc.) throughout the cell. They can be on the ER or floating freely.
9. **Label Your Model**:
Label each part of the cell using markers, coloured pencils.

Make and discuss a specialise Plant Cell model

Different specialised cells have different functions, to help them do different jobs they can have different shapes, and more or less organelles.

1. After building your "model" plant cell model.
2. Divide into small groups.
3. Each group allocated a specialised plant cell type e.g:
    a. Mesophyll b. Root cap c. Trichome d. Stem, e. Fruit f. Flower
4. Use the "specialised cell readers", and to use the craft materials to modify your cell models to make it into a specialised cell type - i.e. change the cell shape and add/remove the organelles for the cell type.
5. Groups present the revisited model to the class showing which cell type it is, how it is specialised, and why they think it is important for survival and growing in space.

Cell Type	**Cell Function**	**Which organelles/ cell part are important to do its do? Which are not?**

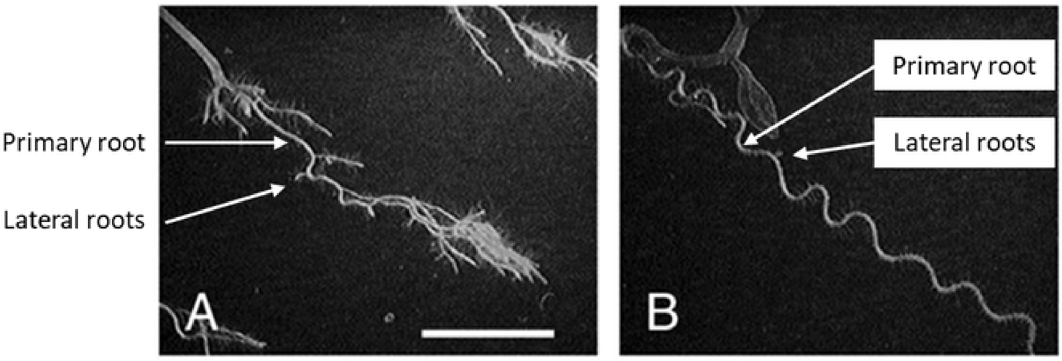
Follow up questions for the student's discussion might include:

1. What is different between the cell types?
2. Why is cell specialisation important?
3. Which is the most important organelle for that cell type? Is that always the case?
4. Which is the most important cell type/ organelle?
5. How might their cell type help people?
6. How might their cell type be important for space/astronauts?

3. Exploring –
Examples of cell structures and functionin research

Root cells help the plant survive different environments
Plant roots have many different roles including anchoring in the ground, absorbing water and nutrients such as phosphate from the soil to stay healthy.

Here are two photographs of plant roots grown in:
A: low amounts of Phosphate **B:** high amounts of Phosphate:

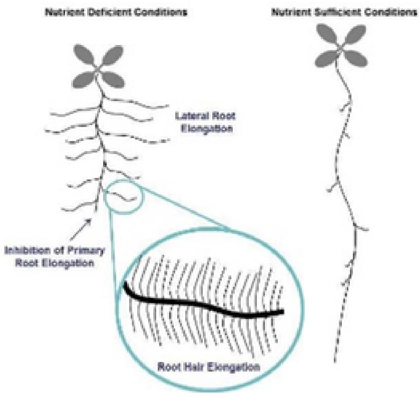


Low phosphate High phosphate

Q: What is different between roots in the low/high phosphate conditions?

Q: Can you draw what you think roots would look like in very high and very low phosphate conditions:

Extremeyl Low Phosphate



Extremely High Phosphate

Q: Why might the roots look like that in high phosphate?

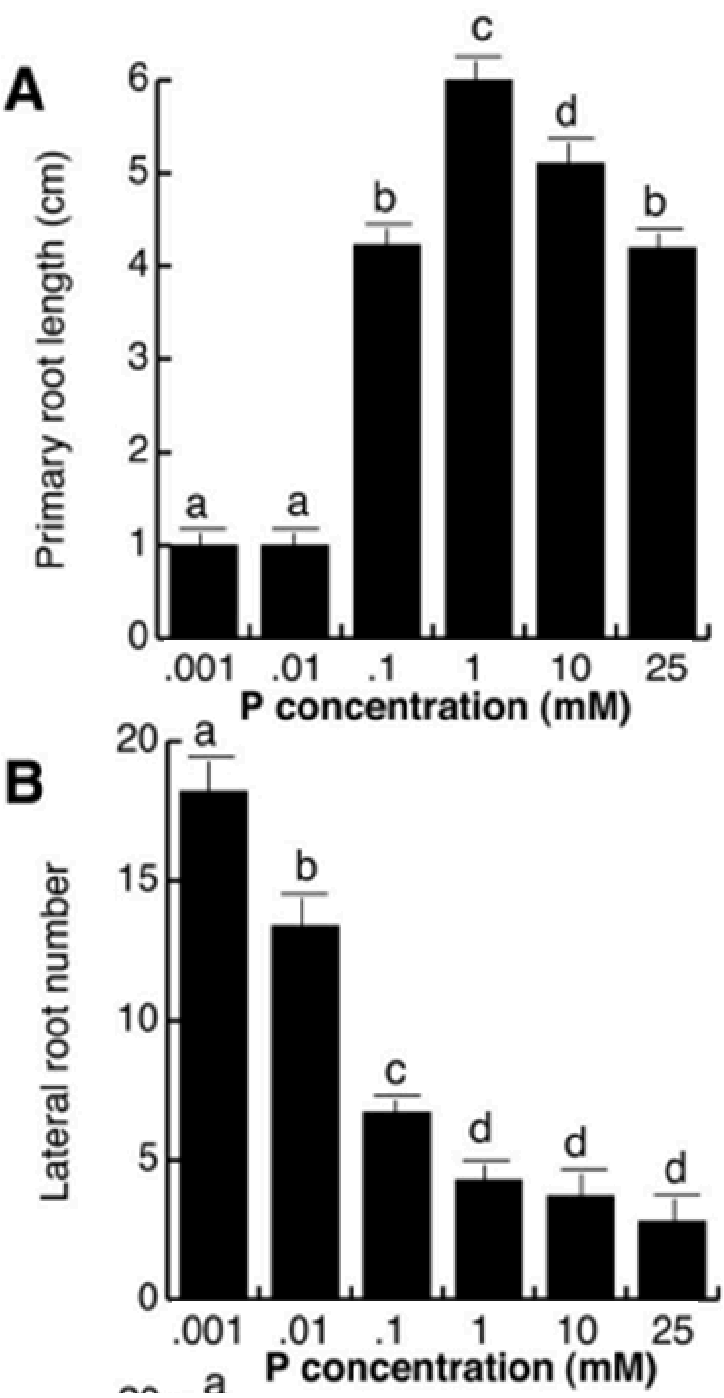
Q: Why might the roots look like that in low phosphate?

Q: Can you suggest why changes in the cells might help the plants survive?

Examples of cell structures and function in research

Root cells help the plant survive different environments
Plant roots have many different roles including anchoring in the ground, absorbing water and nutrients such as phosphate from the soil to stay healthy.

Below are two graphs showing the roots of plants grown in soils with different nutrients (phosphate) levels after 17 days.
Questions:



Root length
Q: How does root length change when grown in different amounts of phosphate?

Q: What root length would you predict if there was less phosphate than 0.001 mM?

Lateral (side) roots. Roots branching off the main root
Q: What change in lateral roots do you see then grown in different amounts of phosphate?

Q: What number of lateral roots would you predict if there was less phosphate than 0.001mM?

José López-Bucio, Esmeralda Hernández-Abreu, Lenin Sánchez-Calderón, María Fernanda Nieto-Jacobo, June Simpson, Luis Herrera-Estrella, Phosphate Availability Alters Architecture and Causes Changes in Hormone Sensitivity in the Arabidopsis Root System, *Plant Physiology*, Volume 129, Issue 1, May 2002, Pages 244–256, https://doi.org/10.1104/pp.010934

4. Experimenting
Investigations into cell structures and their functions in space

Experiment 1: Is photosynthesis occurring?

Research Questions:
Is light necessary for photosynthesis - how can we prove it?

Are leaves and the chloroplasts they contain necessary?

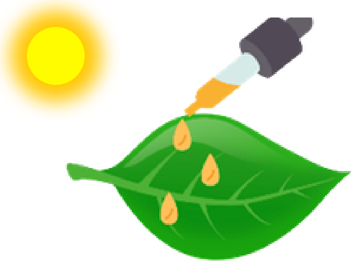
How can knowing about photosynthesis help us grow food for space travel?

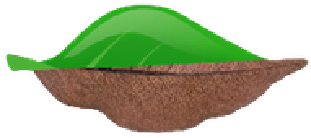
Hypothesis:

What would be the difference in the leaves of plants are covered/uncovered whilst trying to photosynthesise?...

Think about the inputs and outputs of photosynthesis and how you might test it?

Method:





1. De-starch the plant: Place the plant in the dark for 24-48 hours to remove starch in the leaves.

2.Prepare the leaf: Cover a half a healthy leaf with aluminium foil securing it with paper clips.

3.Expose to light: Place the plant in a well-lit area for at least 4 hours -sunlight or lamp.
NB: You could compare different light conditions e.g. bright vs dim.

4.Starch test: Remove foil and place the leaf on a white tile or dish. Using a dropper add a few drops of iodine solution onto to both the covered and uncovered portions of the leaf.

5.Observe and Record:
Dark blue-black colour indicates the presence of starch.
Note any colour changes in the leaf immediately after applying the iodine and then again after a few minutes.

Results:
Draw your leaf, label which was the covered and uncovered halves, and show where the iodine stained the starch (i.e. where the starch was found in the leaf).

Conclusion:
The parts of the leaf exposed to light turned ________________ the iodine solution was added, demonstrating ________________.
The covered part of the leaf showed________________, indicating________________.

This experiment shows that light...

How can knowing about photosynthesis help us in growing food in space travel?

Experiment 2:
How does plant growth respond to light? On Earth or Vertical Farm in Space...

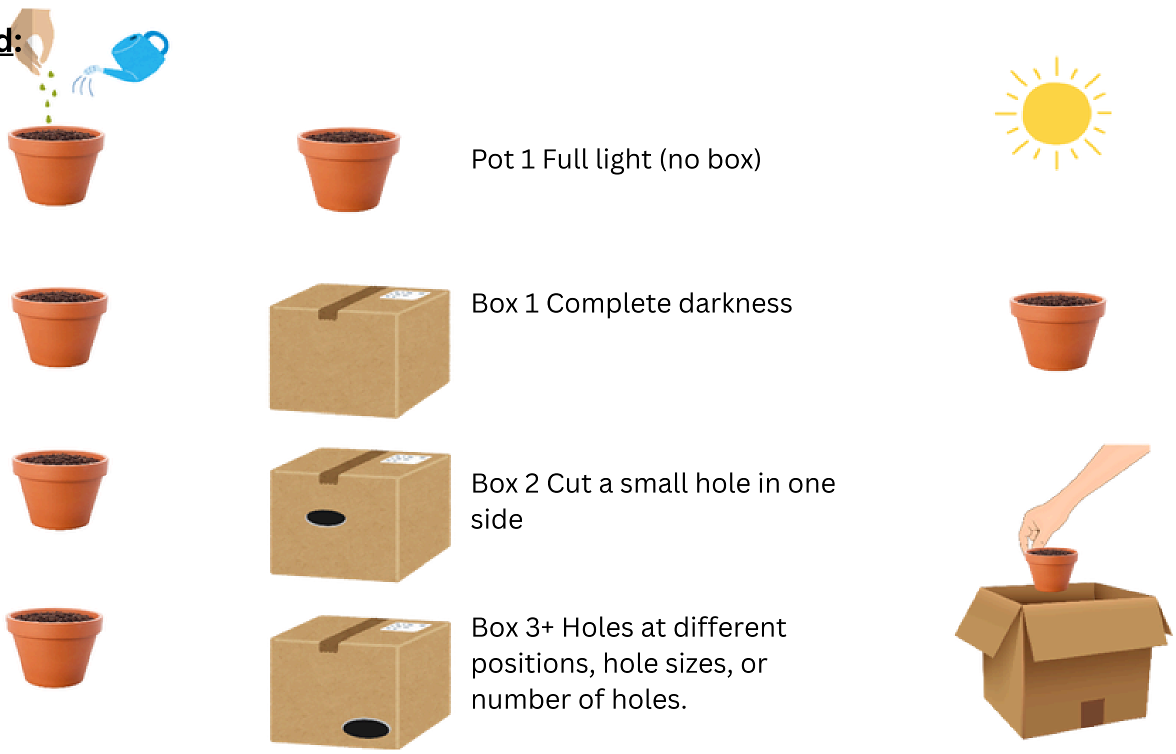
Research Question: How does plant growth respond to light? How can knowing about photosynthesis help us in growing food for space travel?

Introduction:

Vertical farms on Earth act as testbeds for space agriculture. Using stacked growing layers and hydroponics, they precisely control light, temperature, humidity and CO_2 to produce high yields in confined spaces, similar to conditions in space habitats.

Plants for Space researchers study how plants respond to different light environments to help produce sustainable food for astronauts and improve indoor farming on Earth. Their work includes controlled experiments, measuring plant growth and light use, studying plant cells, and even sending plants into space.

Method:



1.Plant seeds.
Several seeds per pot (minimum 3 pots) filled with potting soil.
Add water and keep it moist but not waterlogged.

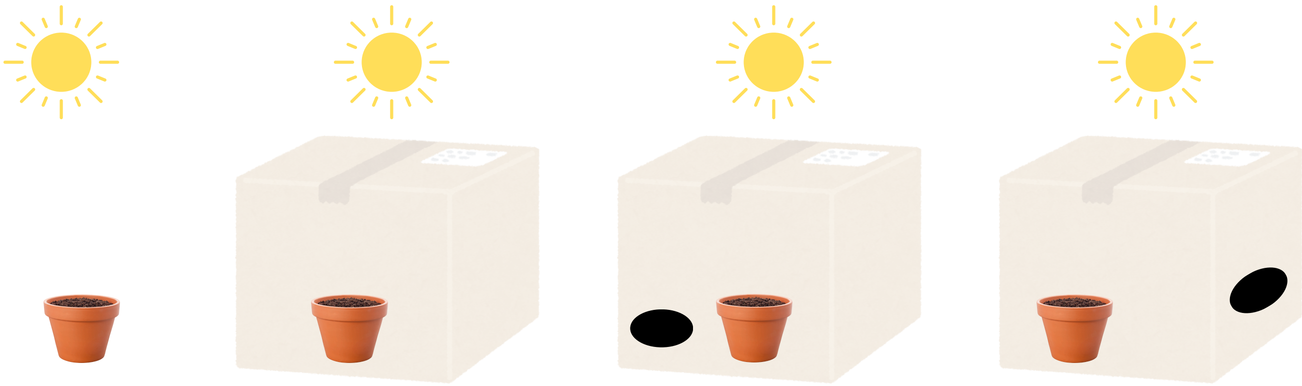
2. Experiment design:
Pot- Full light- control group
Box 1- Complete darkness - control group (tape down edges to ensure no gaps)
Box 2- Cut a small hole in one side (experimental group group)
Box 3- Cut hole in different positions from box 2.
You could also test different hole sizes.

3.Placement:
Place all but one pot inside the cardboard boxes

4. Light source:
Place all pots and boxes near a good light source (window/lamp).
Observe after several days / a week
When observing BE QUICK! (Less than 30 seconds!) As you will introduce light into the experiment!)
Make and record your observations, noting the direction of growth, stem length, and any other relevant changes.

Hypothesis:

Plants will respond to the direction of the light source.
Draw how the plants predict the plants will grow:



Q: I think they will respond by...

Results:
Diagram illustrating growth of plants

	Plants grown in full light			Plants grown in darkness			Plants grown with hole in box		
	Height (mm)	Angle of growth (°)	Observations and diagram	Hight (mm)	Angle of growth (°)	Observations and diagram	Hight (mm)	Angle of growth (°)	Observations and diagram
0 Days growth									
5 Days growth									
10 Days growth									
15 Days growth									

Conclusions

Summarise your findings- What did you see?
How did the plants that were grown in full light grow (control group)?
How did the plants that were grow in the dark grow (control group) grow?
How did the plants that were grown in a box with the light coming in from the side grow (experimental groups)?
What (if any) was the difference in growth between plants grown in full light, dark and light, coming in from the side?

Evaluation
Why might there be a difference?
Discuss any potential problems in the experiment.
Suggest ideas for future experiments to further investigate phototropism.

Discussion

Why is this knowledge important for growing plants on farms on Earth, or for indoor vertical farms or growing plants on Mars?
What other questions or other experiments would be useful to carry out so can could grow plants in indoor vertical farms or on Mars?

Experiment 3:
How do plants roots grow to microgravity?

Introduction:
Lunar Effects on Agricultural Flora (LEAF) is a NASA project part of the Artemis III mission in which Plants for Space researchers will be growing plant on the moon. They will compare plant growth in reduced gravity on the Moon compared to Earth.

In preparation for this Plant for Space researchers are growing and testing plants in microgravity on Earth! Researchers use a clever devise called a clinostat to simulates microgravity. Clinostats rotate objects giving them the feeling of “floating“ or constantly “falling” just like microgravity compared to plants not rotated.

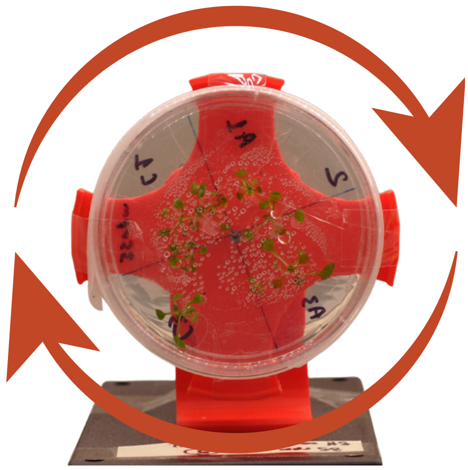
To build your own clinostat use the build guide found here:
https://plants4space.com/resources/clinostat-build-guide

For detail clinostat experiment protocols:
https://plants4space.com/resources/plant-growth-in-microgravity

Research Question:
What effect does gravity have on root growth?

Method:
Plants grown on in Earth conditions compared to plants grown in simulated microgravity on a rotating clinostat.

Earth condition control



Simulated microgravity

Recording data:
What data and observations will you collect to measure root growth?

NB You may like to consider length and direction of growth comparing in Earth and microgravity. How will you show the data collect observations collected of root growth? A table or graph? What sort of graph would be best?

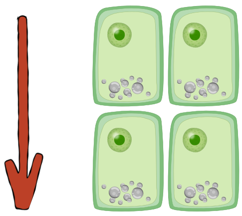
How do plants roots grow to microgravity?

<u>Results</u>:
Carry out your observations of root and shoot growth and record them here:

<u>Conclusion</u>:

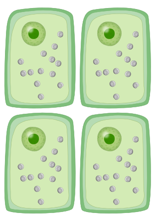
This the current understanding of how plants sense gravity and the how clinostats “confuse’ the plants sense of gravity.

Earth - Gravity



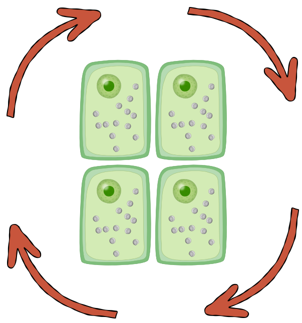
The statoliths at the bottom of the cell signals for the roots to grow down

In Space - Microravity



The statoliths don’t sink to the bottom of the cell so there is not signal to grow down

On Earth Clinostat - Simulated Microravity



When turned by a clinostat the statoliths cannot sink to the bottom of the cell preventing a signal to grow down

Using your data, does it agree with the current theory?

Explain why you think it does or does not.

Experiment 4:
How do plants grow in Space?

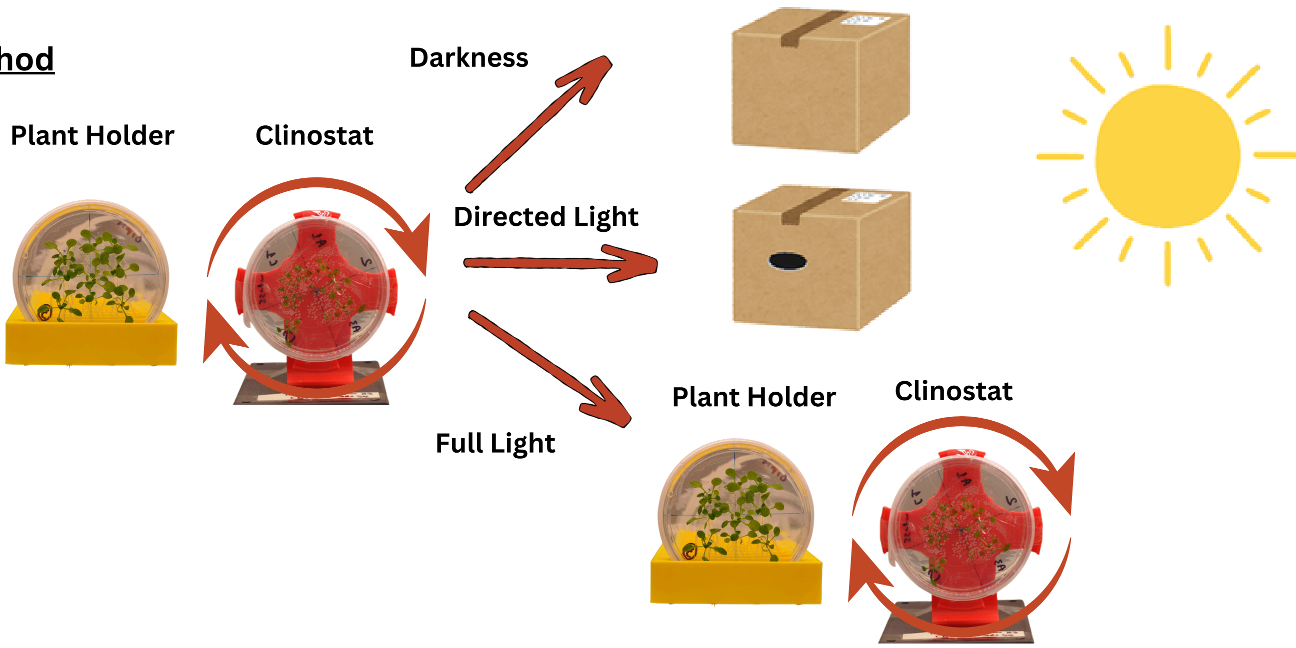
Introduction:
Growing plants in space is challenging. Space habitats are closed environments with microgravity, and there is no natural sunlight. Everything plants need must be provided, including water, nutrients, gases, light, and room to grow. In the future astronauts will need plants for food, medicine and materials.

In earlier experiments, you explored how plants respond to the direction of light and to microgravity. Both of these conditions affect how plants grow in space. By combining these conditions, you can simulate a space environment. How will plants grow under these simulated space conditions?

Research Question: How do plants grow under space conditions such as microgravity and a directional artificial light source?

Hypothesis:
What I think will happen is....

Method



1. Set up a minimum of 6 seeds in plates/Ziploc bags.
Add several seeds per plant/ziplock bag

2. Place plants in the clinostats and holders.
Add 3 plates into in clinostats
Add 3 plates into plant holders.

3. Place a clinostat + a plant holder (with plates) in:
1. **Complete darkness** -covered with box (no hole)(control group).
2. **Directed light** - Cut a small hole in one side (experimental group group).
3. **Full light** - no box (control group)

4. Place the light source.
lamp or near a window.
Leave seeds to germinate and grow for at least 4 days.

5. Decide what to record and observations to make

6. Observe and record plant growth.

Results / Data Analysis

- Measure the stem and root length of the plants in both the experimental and control groups.
- Calculate the average stem and root length and direction for each condition.
- Create a graph to compare the growth of the plants in the two groups over time.
- Analyse the direction of growth in the experimental group.

Conclusion

- Summarize your findings:
- What did you observe? Your data shows?
- How did the experimental groups plants respond to light source and micro gravity?
- How did their growth compare to the control group?

Limitations and improvements

- Discuss any potential sources of error in the experiment
- How could the experiment have been fairer or more accurate or reliable?
- How could the conditions we grew the plants in have been more like ISS?
- What other questions might you have now? Or suggest ideas for future experiments to grow plants in space.

5. Assessment//Application of knowledge//Performance of understanding

Can we grow Plants in Space?
This is an illustration of what a vertical farm on Mars might look like:
With a focus on cell structure and functions, Student report on the combine phototropism and gravitropism experiment and speculate / advise for using cell structure and function in sustainably growing plant in vertical farms on Mars.

Task: Use your knowledge of plant cell structure and function, and photosynthesis to design a plant and vertical farm for the journey to Mars (similar to moon) that is incredibly sustainable, meaning the plants don't waste any water, nutrients, light. Think about how you might modify the plants.

Resources: Your experiments, Space sanctuary story, P4S diagrams, P4S readers, Videos, Story cards, and independent research, Plants for Space researchers.

Points to think about:
1.**How do plants photosynthesise or collect water and nutrients?** What parts? How could you change plant cells to make them even better and more efficient in a vertical space farm?

2.How do plants respond to gravity? What parts detect gravity? How could you change the plant's cells to make them even better and more efficient at growing in microgravity in in a vertical farm in space?

3.How do plants reproduce? What parts make fruits? How could you change the plant's cells to make them even better and more efficient at growing in microgravity in in a vertical farm in space?

4.What would be the same and different in vertical farm in space and on Earth farm?

5.What other ways could we change the cells of the plants to make them more sustainable in space vertical farm and on Earth farms?

Student Checklist – Can We Grow Plants in Space?

Task: Design a sustainable vertical farm for Mars using your knowledge of plant cells, functions, and photosynthesis.

Knowledge of Cells & Organelles

- ☐ Have I named the important parts of a plant cell (like chloroplasts, vacuoles, nucleus)?
- ☐ Have I explained what these parts do for the plant?
- ☐ Have I shown how these parts help plants survive in space farms?

Structure–Function Relationships

- ☐ Have I explained how plant structures (roots, stems, leaves) help the plant live?
- ☐ Have I shown how these structures might change or be used differently in space?
- ☐ Have I linked cell functions to whole plant survival?

Application to Space Context

- ☐ Have I thought about how plants would grow in space or on Mars?
- ☐ Have I suggested changes to help plants grow in microgravity or with limited resources?
- ☐ Have I designed ideas that save water, nutrients, or light?

Using Experiments & Evidence

- ☐ Have I used what I learned from the phototropism and gravitropism experiments?
- ☐ Have I explained how this experiment helps me make decisions about my design?
- ☐ Have I used other diagrams, videos, or research to support my ideas?

Sustainability Thinking

- ☐ Have I thought about how plants use water, nutrients, and light in a vertical farm?
- ☐ Have I compared space farming to Earth farming?
- ☐ Have I suggested ways to reduce waste or recycle resources in both?

Communication & Design

- ☐ Have I drawn and labelled my vertical farm design?
- ☐ Have I explained my design choices in writing or notes?
- ☐ Have I made my ideas clear, creative, and based on science?

Tip for students: Before handing in, check off as many boxes as you can — the more you tick, the stronger your project will be!

Can We Grow Plants in Space? - Rubric

Task: Use knowledge of plant cell structure, function, and photosynthesis to design a sustainable vertical farm for Mars. Include experiment reflections and recommendations.

Knowledge of Cells & Organelles (AC9S8U01)

1. **Developing:** Identifies some cell structures (e.g. chloroplast, nucleus) with limited explanation of function.
2. **Proficient:** Accurately describes key organelles and links them to plant processes such as photosynthesis and water transport.
3. **Advanced:** Demonstrates deep understanding by comparing plant and animal cells, and explains specialised roles of organelles with clear connections to space farming context.

Structure–Function Relationships (AC9S8U02)

1. **Developing:** Provides simple statements about plant systems (e.g. roots take water).
2. **Proficient:** Explains how cell, tissue, and organ structures support plant survival (e.g. roots, stems, leaves in photosynthesis/transport).
3. **Advanced:** Analyses how altered cell functions (e.g. enhanced chloroplasts, gravitropism sensors) could support plants in microgravity or resource-limited conditions.

Application to Space Context

1. **Developing:** Limited or general ideas about plants in space.
2. **Proficient:** Suggests realistic adaptations for plants or farm design (e.g. recycling water, controlled light).
3. **Advanced:** Proposes creative, evidence-based designs and modifications for plants in vertical farms on Mars, making explicit links to sustainability.

Use of Experimental Evidence

1. **Developing**: Mentions experiments or observations without clear link to design.
2. **Proficient:** Incorporates findings from phototropism/gravitropism experiments to justify farm/plant design choices.
3. **Advanced:** Integrates experimental results and wider research to speculate, advise, and critically evaluate solutions for space farming.

Sustainability Thinking

1. **Developing:** Identifies basic needs (water, light, nutrients).
2. **Proficient:** Explains how resources could be conserved in space farms compared to Earth farms.
3. **Advanced:** Proposes innovative cell-level or design solutions that minimise waste, reuse resources, and connect ideas to sustainable Earth farming.

Communication & Design Presentation

1. **Developing:** Provides a simple description or drawing with limited detail.
2. **Proficient:** Produces a clear design/report with labelled diagrams and explanations of key choices.
3. **Advanced:** Communicates a detailed, logical, and imaginative farm design using multiple formats (illustrations, report, annotations) with clear scientific reasoning.