



Growing Plants In Space

Investigating cell structure, function
and photosynthesis

Year 8 Unit Teacher 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
Australian Research Council



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

P4S partners include The University of Adelaide, The University of Western Australia, La Trobe University, The University of Melbourne, Flinders University, University of California, Berkeley, University of California Davis, University of Wisconsin-Madison, Rice University, University of Cambridge, University of Nottingham, Research for Agriculture, Food and Environment - INRAE, ETH Zürich, Vertical Future, Space Lab, Gaia Project Australia, Australian Plant Phenomics Network, The Andy Thomas Space Foundation, Dr Joanna McMillan, The Victorian Space Science Education Centre (VSSEC), One Giant Leap Australia Foundation, South Australia Botanic Gardens, South Australian Space Industry Centre (SASIC), Defence Science and Technology Group, Department of Primary Industries and Regions, South Australia (PIRSA), NASA, Australian Space Agency (ASA), Axiom Space, Yuri, Twist Bioscience, BioPlatforms Australia, Australian Genome Research Facility, Saber Astronautics, FOODiQ, National Imaging Facility.

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.

Contact Information

Email: engagement@plants4space.com

Socials:



Creative commons



TABLE OF CONTENTS

Page 4

Curriculum Links

5

About this Unit

6

What Do You Know About Plants Already?

- True or False
- Finish the sentence
- Comparing Plants and Animals

9

Building Understanding

- Setting the scene - a Plants for Space story
- What is Plants For Space ARC Centre of Excellence
- Plant Architecture - Reader, research and activity
- Plant Dissection Activity
- Internal Plant architecture reader
- Plant Cells for Space - videos
- Specialised Cells - Readers, research and activity
- Build a specialised cell model

31

Exploring – Examples of cell structures and function in research

- Root cells in the plant helping the plant survive different environments
- Leaf hairs (trichomes) and altitude

33

Experimenting- Investigations into cell structures and functions in space

- Experiment 1: Is photosynthesis occurring?
- Experiment 2: How do plants respond to light?
- Experiment 3: How do plants roots grow to microgravity?
- Experiment 4. How do plants grow in Space?

42

5. Performance of Understanding

- Designer Plants for Space and Earth: Cell structure, function and photosynthesis
- Student check sheet
- Rubric

Growing Plants in Space- Curriculum

Australian National Curriculum

AC9S8U01 Recognise cells as the basic units of living things, compare plant and animal cells, and describe the functions of specialised cell structures and organelles.

AC9S8U02 Analyse the relationship between structure and function of cells, tissues and organs in a plant and an animal organ system and explain how these systems enable survival of the individual.

Outcomes:

Using the context of Plants for Space research investigating how to grow plants in space (and sustainable farming) students will:

- Explore structure and function of plant cells, organelles and their relationship with photosynthesis
- Investigate examples of plant cell structures and how cells respond to stimuli, illustrating how they help plants survive.
- Investigate how plants might grow in space conditions, how plants respond and how cell structure and function will be essential for plant survival.

Suggested Teaching and Learning Sequence:

1. Activate prior learning

- a. True/False statements
- b. Complete the sentence stems
- c. Plant and animal cell comparison

2. Building understanding

- a. Plants for Space
- b. Plant cell structure and function
- c. Photosynthesis and microgravity

3. Exploring

- a. Examples of cell structures and their functions

4. Experimenting

- a. Photosynthesis, phototropism and gravitropism

5. Assessment / performance of understanding

- a. Report and speculate on plant structure and function for sustainable farming on Mars, space, and Earth.

About this Unit

Design

At Plants for Space, we create practical, engaging teaching resources grounded in contemporary science. Our units are co-designed with teachers to be easy to use in real classrooms, relevant to students' lives, aligned with the Science curriculum, and flexible enough to support diverse learners and school contexts.

Careers in agricultural STEM and space science are rapidly expanding. This unit connects student investigations to authentic research, including work with scientists collaborating with NASA to grow plants beyond Earth. Students experience science as it is practised today – collaborative, applied and impactful.

Easy to use

Resources are classroom-ready, clearly structured and supported with multimodal materials to minimise preparation time and maximise engagement.

The unit's modular design allows you to select and use individual components that best suit your context or implement the full sequence as a cohesive, end-to-end unit of work.

We encourage you to share these resources and would welcome your feedback or examples of how you have used them in your classroom.

Pedagogical approach

This unit deliberately blends explicit teaching and inquiry-based learning. Key concepts and scientific language are introduced through structured instruction, then extended through investigations, experiments and problem-solving. The balance reflects supports conceptual understanding and student agency.

Curriculum and STEM connections

Aligned with the Science curriculum, the unit is also well suited as a STEM program, authentically integrating Technology, Engineering and Mathematics. Students engage in experimental design, data analysis, systems thinking and applied problem-solving, making it ideal for interdisciplinary planning and assessment.

Flexible and inclusive design

The modular structure allows each section to stand alone or form a complete unit of work. Teachers can adapt, differentiate and extend the learning to suit their context, ensuring accessibility and inclusion are embedded rather than added on.

Why space?

Space is a powerful and future-focused context that sparks curiosity and connects science learning to real challenges such as food security, sustainability and human survival in extreme environments. It gives abstract concepts clear purpose and illustrates why such things matter.

1. What Do You Know About Plants Already?

These activities will reveal students' understanding and any misconceptions about how plants function and will serve as stimuli for discussion. Students use the guide to provide, discuss, and reflect on their answers for one or more of the activities.

The activities include:

- True or false
- Complete the sentence stems
- Plant and animal cell comparison

True or False Activity

The questions are intentionally ambiguous to provoke discussion.

Statement	Teacher notes
Plants can move	True - Not exactly running around but plants can move their leaves and flowers to the sun daily - there are time-lapse videos of leaves "flapping throughout the day"
Plants can get sick if they don't have the right nutrients	True - Just as animal need the right nutrients plants do too. For example, this can be seen as yellow spots on the leaves indicate a deficiency of an element e.g. iron or phosphate or as irregular growth.
Plants can grow in the dark	True and False - Seeds and bulbs germinate and grow in the dark however plants will not develop for long in the dark. They need light for photosynthesis to make sugars to fuel their growth.
Watering plants on a schedule is best	False - A watering schedule can be helpful for remembering to water house plants, but it is not essential. Plant water requirements vary widely. For example, the 'resurrection plant' (<i>Bryophyllum pinnatum</i>) can survive for many years in dry conditions and then spring back to life when rain returns. Other plants require regular watering and consistently damp soil, while aquatic plants need to remain in water at all times.
Plants "breathe" in carbon dioxide and "breathe out" oxygen	False - Breathing is an active process that uses muscles and is therefore carried out by animals not plants. Plants do not breathe. Instead, they exchange gases by diffusion. Plants take in carbon dioxide and release oxygen. However, they also take in oxygen and release carbon dioxide, because the air they exchange contains both gases, along with a range of other gases. It is important not to confuse breathing with respiration. Plants do respire, just like animals, but the net effect of plant gas exchange is the uptake of carbon dioxide and the release of oxygen.

True or False Activity (continued)

Statement	Teacher notes
Plants get all their energy from the sun	True – Through photosynthesis, plants convert light energy into chemical energy. There are some rare parasitic plants, including certain orchids, and some trees in declining forests that obtain carbon and energy from neighbouring plants. These are exceptions, as they effectively behave as heterotrophs, similar to animals. However, the carbon and energy they obtain ultimately still originate from photosynthesis carried out by autotrophic plants. As with most food chains, the process begins with photosynthesis.
All plant cells are the same	False – Just like animals, plants have many different types of specialised cells. This variety allows cells to perform specific functions and take on distinct forms.
Plants contain DNA	True – As in animal cells, DNA is found in the plant cell’s nucleus and mitochondria. DNA is also present in chloroplasts and other plastids where it exists as circular molecules within the organelle.
Chloroplasts (where photosynthesis occurs) are only found in leaves	False - Most chloroplasts are found in the leaves, but they can also occur in stems, sepals, and other above-ground plant parts. Chloroplasts are generally absent from underground structures such as roots.
Fertilizer is "plant food"	False - Depending on how you define food, the answer is no. Plants obtain their chemical energy from the sugars produced during photosynthesis, not from soil, substrates, or fertilisers. Minerals such as nitrates and iron, found in fertilisers, are essential for plant health. Plants absorb these minerals through their roots, and they serve as building blocks for compounds like proteins. Without them, plants would become unhealthy or die. In an early experiment, Jan Baptista van Helmont grew a tree in a measured amount of soil. After five years, the tree had gained about 74 kg in mass, while the soil had changed very little. This demonstrates that plants do not “eat” soil like animals eat food. Instead, they produce their own organic compounds from carbon dioxide and water, while absorbing minerals from the soil as nutrients.

Finish The Sentence Activity

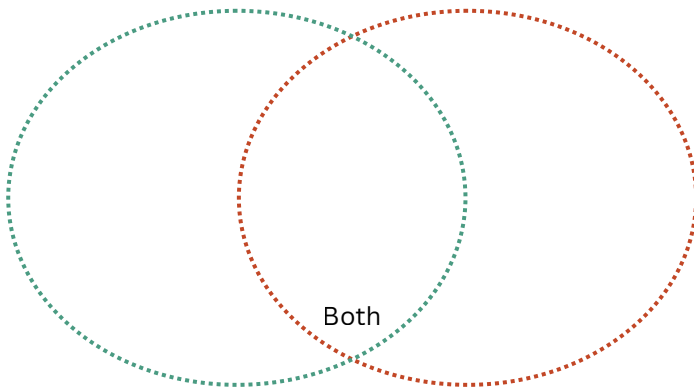
- 1.Plants can provide many useful things for us such as e.g. food, fibre, medicines, joy etc...
- 2.To survive, plants need ... Water, light, nutrients and space
- 3.In biology, cells are... building block that make up living things, or as single cells, that can replicate and contain the instructions for the organism to live.
- 4.Things you can find inside a plant cell ... e.g. nucleus, mitochondria, chloroplasts, vacuole ER, Golgi bodies, ribosomes
- 5.I am similar to plants many ways, for example we both... e.g. cells, DNA, living, energy transforming, ecosystem, respiration...
- 6.Roots grow downwards because... e.g. water and nutrients, gravity, anchor plant

What is Similar, What is Different? Activity

Encourage students to review and discuss the diagrams and their understanding of plants and animals and annotate a Venn diagram to show their understanding of cells, plant needs, and photosynthesis.



Plants

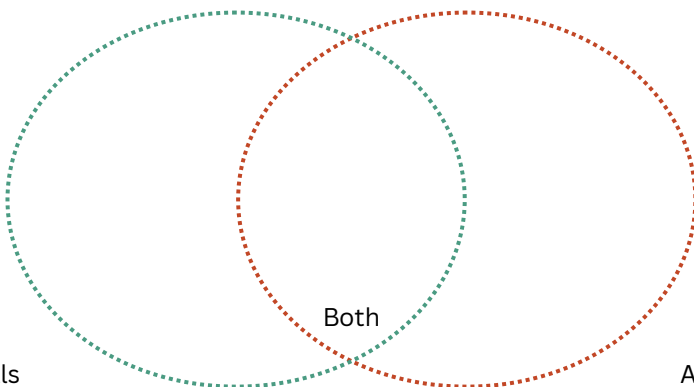


Animals

Plant and cells and animal both do gas exchange and respire and move and reproduce, have colours, have cells, respond to the environment, die etc.. animals eat/digest etc..



Plant cells



Animal cells

Plants cells have the same organelles animal cells. Plant cells have cell walls, chloroplasts, and large vacuoles. (statoliths are a specialised organelles for detecting gravity, these are discussed later in the unit.

2. Building Understanding

These resources and activities provide a range of approaches to engage and build students understanding of the topic.

Resources to support student understanding include:

- The space garden was their sanctuary story
- Videos
- Readers
- Summary questions (these address Plants for Space, Cells organs and tissues, photosynthesis and cell structure and functions)

Guide students through the following text, videos, graphics and activities to answer questions as well as develop and demonstrate their understanding. To support your students read aloud and watch the videos together and encourage questions and connect to their prior understanding and interests.

The Space Garden Was Their Sanctuary (Activity)

This short, near-science fiction story is used as a primer to help students understand the space environment that Plants for Space missions aim to support. Its purpose is to illustrate the challenges faced by living organisms in space and to explain why growing plants may be an important component of future space habitation missions.

Although the narrative is fictional, the concepts embedded within it are grounded in current scientific understanding and planned space missions. Students are encouraged to research these concepts further and explore how real-world space science and plant biology inform the development of sustainable life-support systems beyond Earth.

After reading the story student should attempt to answer and discuss the provided questions. The provided readers, videos and experiments throughout the unit will link the plant cell structure and function to elements within the story.

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? Isolation, artificial environment, air, cramped conditions, water, food, lights etc.
2. What do humans / plants need to survive? Air, water, food/nutrition, lights, sleep, social, green space, etc.
3. Why did Anya and Kai smile at the plants at the end of the story? Plants can provide all the things that they need, air, water, food, medicine (~70% medicines are plant derived), fibres, and green space.
4. How might the space garden be similar to Earth? Earth is floating through space, with plants providing all the things humans need – it is our current sanctuary! There is no Planet B!

Other questions that can be asked, discussed or researched

1. What plants should be grown in space?
2. Why is there pink light?
3. How is Lunar gravity different from earth and does that effect how humans and plants survive.
4. What is the Artemis accord?

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



For a more in-depth activity to inform on the Plants For Space mission and related research consider using the Plants For Space Story Card activity found here:
<https://plants4space.com/resources/plants-for-space-story-cards>



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

How to grow plants in space and sustainable farming by optimising plants and their growth conditions, complete nutrition plants, and plants producing products on demand. Future foods, space laws, etc...

Plant Architecture (Reader)

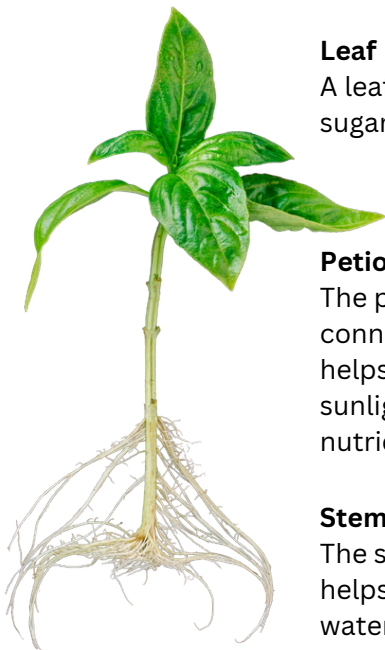
Like animals, plants have different parts, and each part has a specific job. All of these parts together are called a plant's architecture.

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.

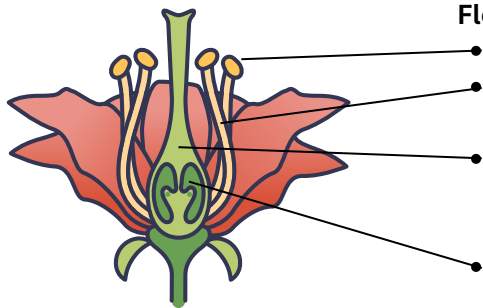
Similarities	Differences

Plant dissection, parts under a microscope and micrographs

Background Guide to Plant Parts:

Students follow the “Plant dissection: Cells, and organs structure and function” guide. Dissect the plant and label parts and functions

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:



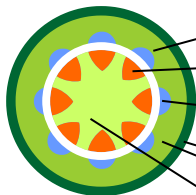
Flower:

- 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.



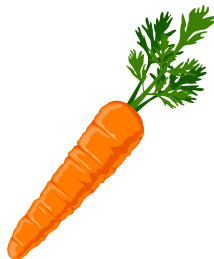
Leaf:

- 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).



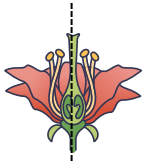
Root and Root Systems:

- 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

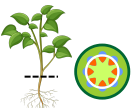
Flowers:

- 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)

Demonstrate, or student use, a USB microscopes/ Fold-a-scope/ smart phone/ tablet camera microscope attachment to view plants parts to identify cells and shapes and functions in difference organ types could highlight using food colouring to stain vasculature of celery.

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

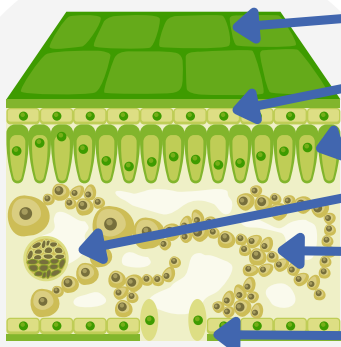
Plant parts	What does it do?	Which organelles do you think are most important in this part to keep the plant alive?	Why so?
Root hairs	to take up water and nutrients	Cell wall and membranes are - shape and stability of the cell. Nucleus to encode proteins to help uptake nutrients. Vacuoles to store nutrient minerals	Increases surface area
Xylem	water and minerals to the rest of the plant	Hollow - cell walls to hold the shape	and acts as a tube to pipe to survive and grow.
Petals	attracts insects and pollinators	Vacuoles store colour Cell wall and membrane shape, size and exude nectar	guide insects to nectar- in the
Stem	Stand upright and harvest light better for photosynthesis	Thick cell walls for strength to stand upright	photosynthesis (and survival)

Internal Plant Architecture (Reader)

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.

Leaf

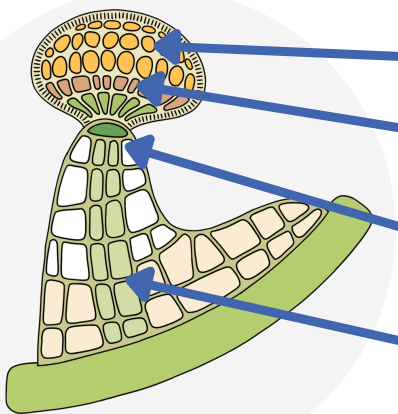
Many cells in a leaf are specialised to aid photosynthesis.



- 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

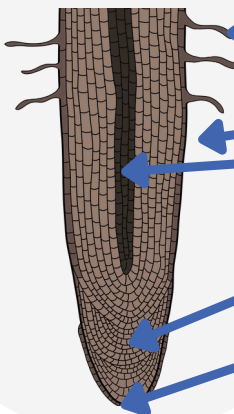
Trichome cells are specialised to make useful chemicals that help protect the plant.



- 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).

Plant Cells for Space

Below are two animated videos that gives an overview of the importance and challenges of light and gravity when growing plants in space, and a flavour of the Plants for space are carrying out to solve some of these problems.

Light recipes to grow plants in Space:



<https://www.youtube.com/watch?v=bywYx8S3TnE>

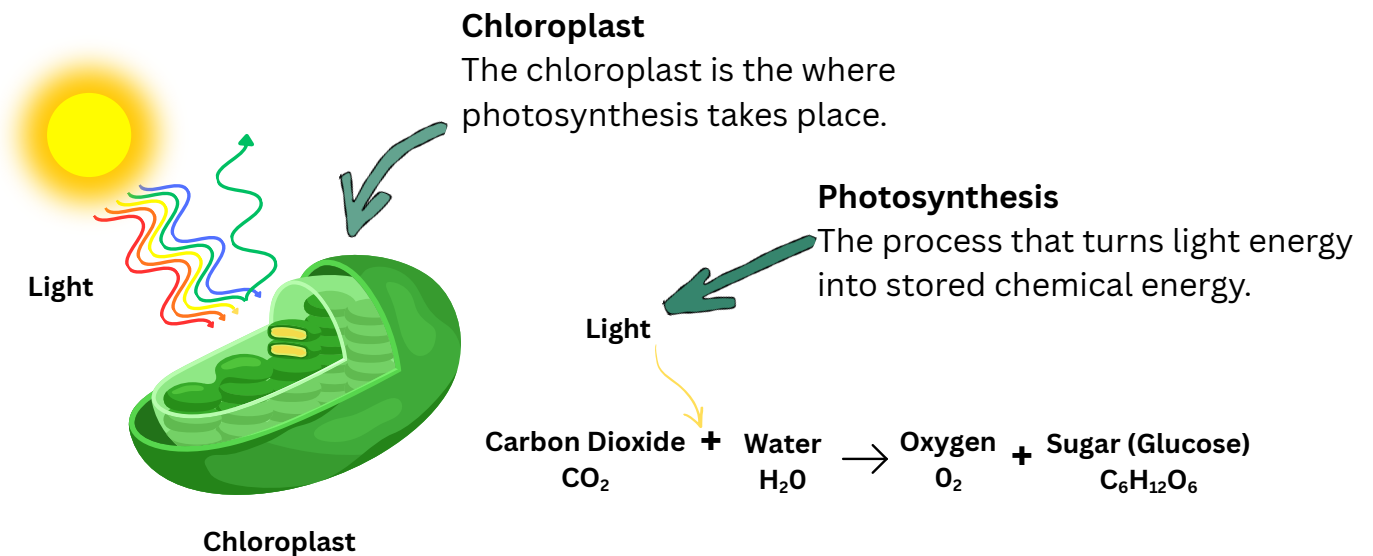
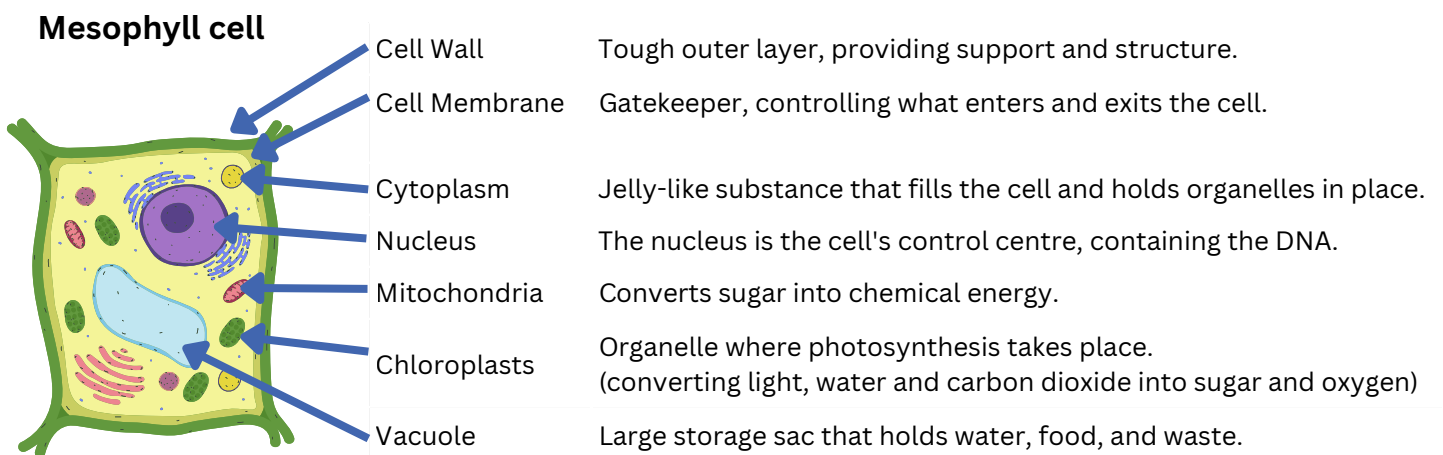
The effect of gravity on plant development:



www.youtube.com/watch?v=YTWUXG3llaA&t=7s

Leaf Cells (Reader)

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.



Without 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 (Reader)

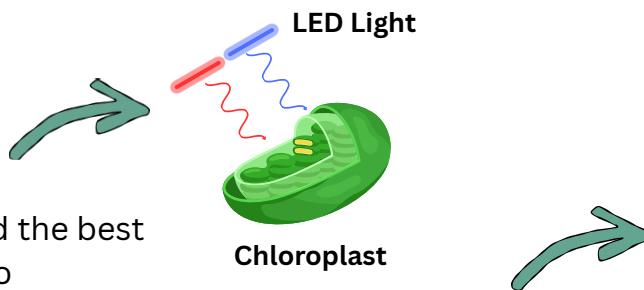
In spacecraft like the International Space Station, astronauts mostly live in a windowless environment. While sunlight is used to generate electricity, the lighting inside is artificial. Light is essential for photosynthesis. In space and indoor farms, where there is no sunlight, scientists use special 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

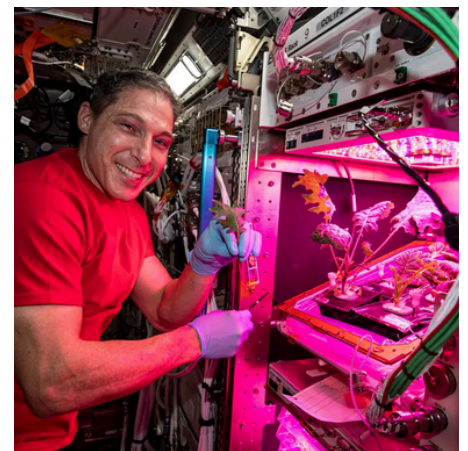
Chlorophyll gives leaves their green colour. Leaves look green because chlorophyll reflects green light rather than absorbing it.

LEDs

P4S researchers are experimenting to find the best mix of light colours to maximise growth. They are finding that different reds 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 (Reader)

Plants for Space Researchers are looking at plant roots to understand how best to help plants thrive in the microgravity 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

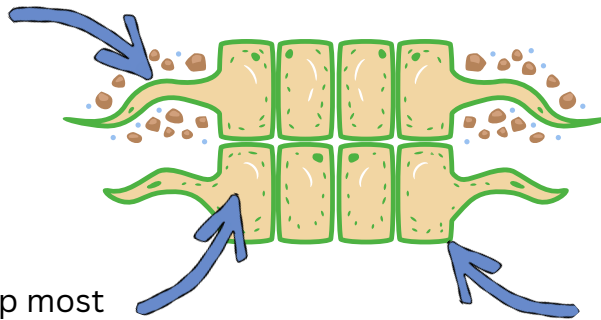
Specialised epidermal cells that increase the surface area of the root that is in contact with the outside environment.

No Cuticle

lacking a waxy layer helps absorb water.

Large Vacuole

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



No Chloroplasts

Root cells do not perform photosynthesis.

Thin Cell Wall

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

Statocytes

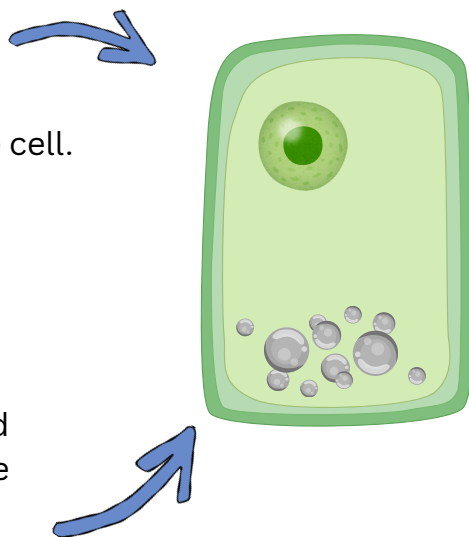
Statocytes are specialised root cells in the root cap that contain statoliths. Statoliths are organelles (starch grains wrapped in a membrane) that are found. They detect gravity and help direct root growth.

Nucleus

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

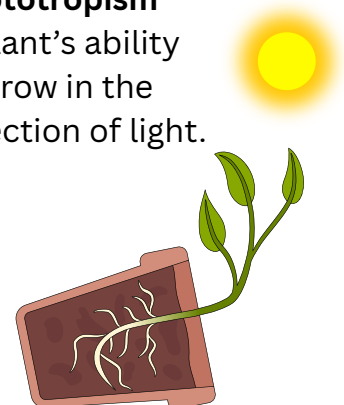
Statoliths

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



Phototropism

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



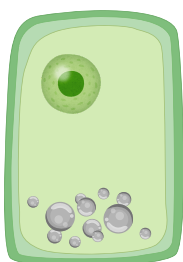
Gravitropism

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

Roots in Space

When plants 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 are investigating are the challenges that plants face when grown in a microgravity environment.

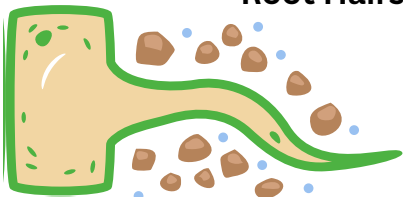
Plant root cell responding to gravity



Statocytes

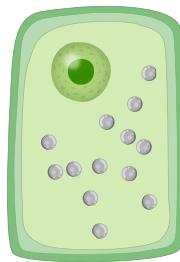
On Earth Statoliths sink to the bottom of the root cell. This tells the root to grow downwards!

Root Hairs



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

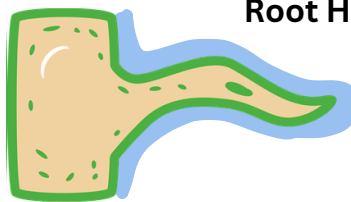
Plant root cell responding to microgravity



Statocytes

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

Root Hairs



In space water clings to roots preventing gas exchange. This will stress the plants similar to what happens when plants 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.



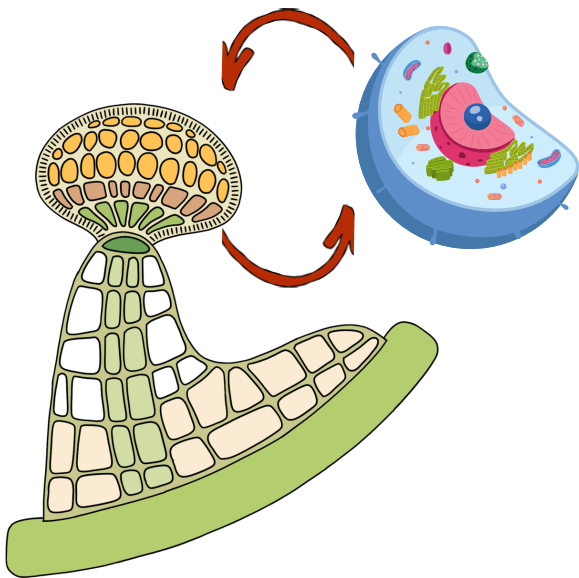
Trichome Cells (Reader)

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! These chemicals are stored in other specialised cells away from the other plant cells.

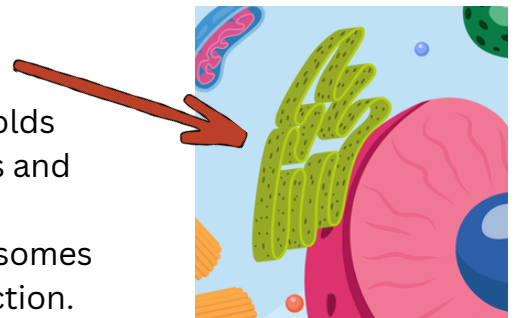
Many organelles, such as endoplasmic reticulum, are important for making these anti-insect chemicals in the secretory cells.



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 embedded 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 happens the chloroplasts lose their green colour. These are called leucoplasts.



Chloroplast



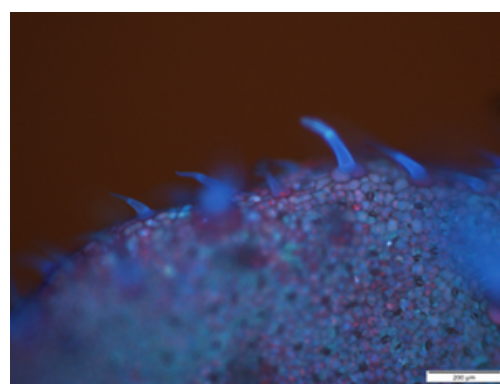
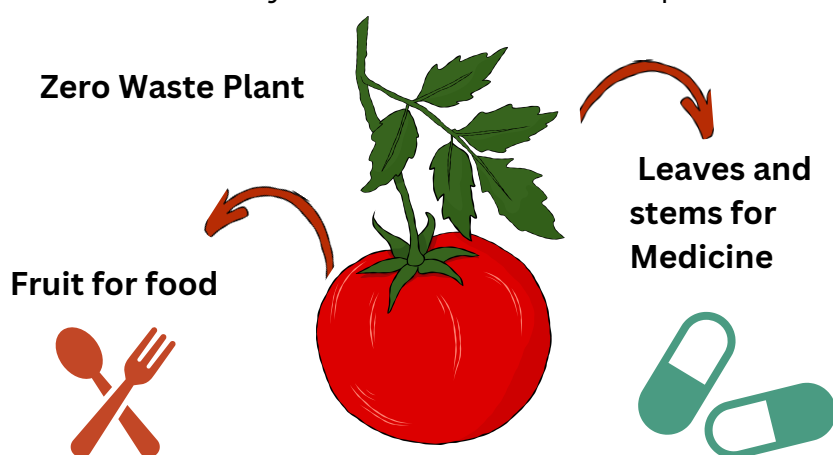
Leucoplast

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? For photosynthesis to make sugar for energy
2. Why are plant chloroplasts important? For photosynthesis to make sugar for energy
3. How do plants grow in response to light? They grow towards it
4. Why is it important to understand how plants respond and grow in LED lights? Light is essential for plant growth and food production! Understanding how well they respond to artificial light, ensures we can grow plants in space without the use of the sun.
5. Why are P4S researchers investigating plant responses to light and how are they investigating it? Investigating how plants respond to different artificial light, to optimise plant growth and efficiently grow of plants in space for astronaut food, as well as indoor sustainable farming on Earth.

Root Cells

1. Why are plant roots important? Anchoring, and water and nutrient absorption
2. What is special about plant cell walls in roots and how does this help the plant survive? They are thinner than normal to help water and nutrient absorption (they are also involved in gravity perception).
3. What specialised part of the plant root cell helps the plant know which way down is? Statoliths
4. Why is it important to understand how plant roots plant grow in microgravity? Cell growth is vital for plant grow and survival and fruit production- understanding the differences of cell grown in Earth vs microgravity and overcoming any challenges is vital to ensure reliable plant and food production.

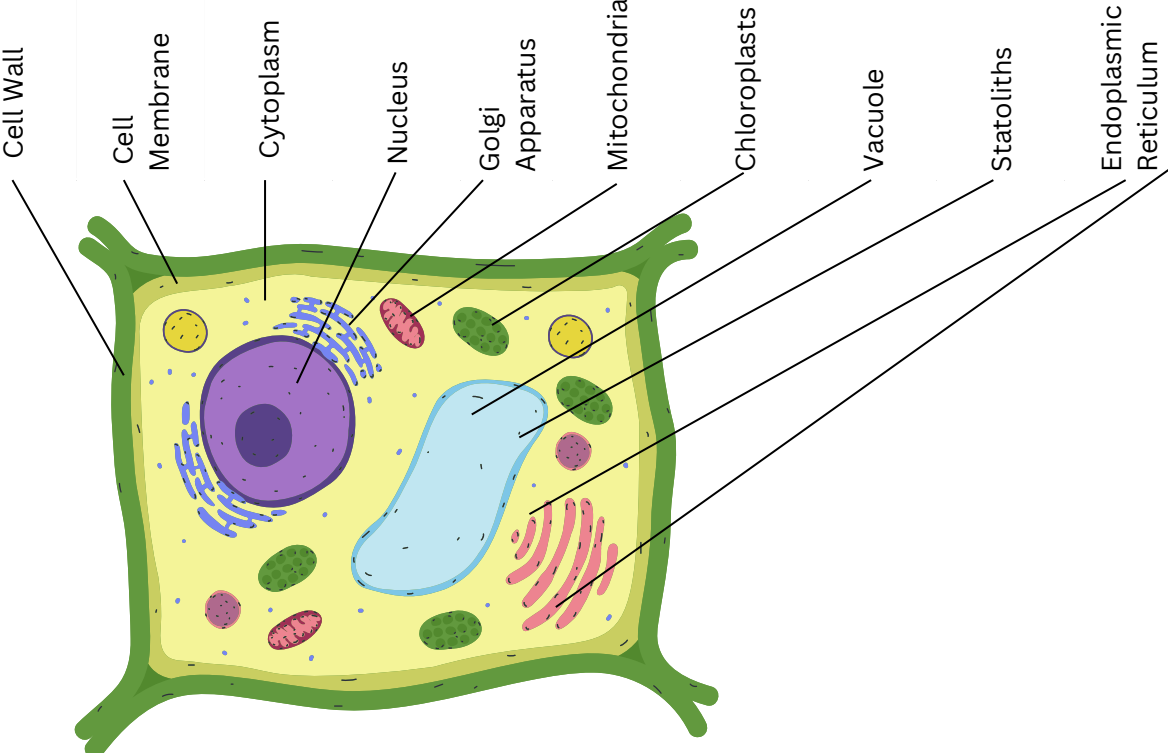
Trichomes Cells

1. Why are trichomes important? Anti-herbivory, UV protection, and produces chemical defences for the plant
2. Which organelles are important for trichomes to work? DNA to have the right shape and structure, ERs to produce the defence chemicals, and cell walls and membranes to contain and release chemicals as needed
3. Why are P4S researchers investigating trichomes? How might it help people? Understand the DNA instructions how they work so we can change it. Using this plant part to produce medicine or other useful chemicals.

Make a specialised Plant Cell model!

Students follow the instructions in their guide to “Build and label a model Plant Cell” to construct an annotated plant cell model. Suggested resources are in “materials”

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!

The cell membrane is the gatekeeper, controlling what enters and exits the cell. It's like a security guard for the cell.

This is a jelly-like substance that fills the cell and holds all the organelles in place. It's like the cell's filling.

The nucleus is the cell's control centre, containing the DNA. It's like the cell's brain.

This is like the cell's post office, packaging and sorting proteins for transport.

These are the powerhouses of the cell, converting food into energy. They're like the cell's energy generators

These are the sites of photosynthesis, where plants make their own food using sunlight. They're what make plants green!

This is a large storage sac that holds water, food, and waste. It's like the cell's pantry and trash can.

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.

A network of tubes that transport materials throughout the cell. It's like the cell's delivery system.

These are the protein-making factories of the cell. They're like the cell's construction workers.

Cell Wall

Cell Membrane

Cytoplasm

Nucleus

Golgi Apparatus

Mitochondria

Chloroplasts

Vacuole

Statoliths

Endoplasmic Reticulum

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 card 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

This is activity that encourages students to think about organelles in the context of specialised cell function to develop student understanding about cells, organisation, structure and function. Students can follow the step-by-step instructions, followed by group presentations and discussion.

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 their “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?
Mesophyll	Photosynthesis, transpiration	Chloroplasts, mitochondria, ribosomes
Root cap	water + nutrient absorption, anchorage, gravity perception	Cell wall, root hairs, and statoliths (less mitochondria)
Trichome	Defence chemical production and storage	Shape, cell walls, ERs mitochondria
Stem	Upright to access light	Cell walls and vacuoles and membranes
Fruit	seed protection and distribution	Mitochondria cell walls, ER and ribosomes
Petal	attract pollinators	cell wall, chloroplasts, mitochondria, ER and ribosomes

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?

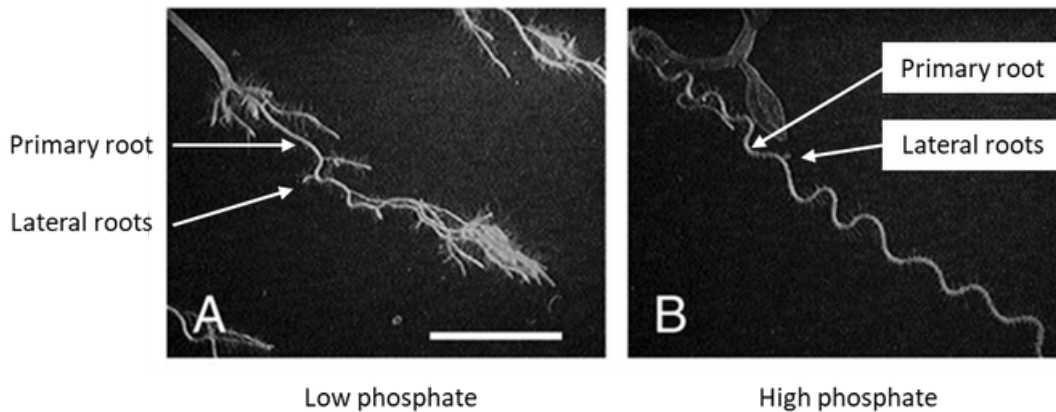
3. Exploring – Examples of cell structures and function in research

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.

Here are two photographs of plant roots grown in:

A: low amounts of Phosphate **B:** high amounts of Phosphate:

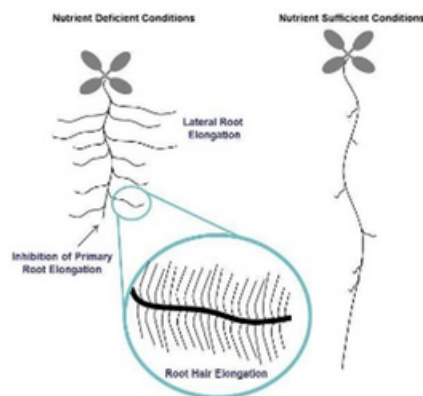


Q: What is different between roots in the low/high phosphate conditions?

High P= long with few lateral roots, Low P -short with lots of lateral roots

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

Extremely Low Phosphate



Extremely High Phosphate



Q: Why might the roots look like that in high phosphate? When there is a lot of phosphate there is less need for lateral roots so doesn't grow them.

Q: Why might the roots look like that in low phosphate? When the plant is growing in phosphate deficient conditions there are increased lateral roots and density to increase the surface area to increase the uptake of phosphate.

Q: Can you suggest why changes in the cells might help the plants survive? The plant is using its cells and its root architecture to ensure phosphate uptake and its own survival- regulating its surface area to fulfill its phosphate needs.

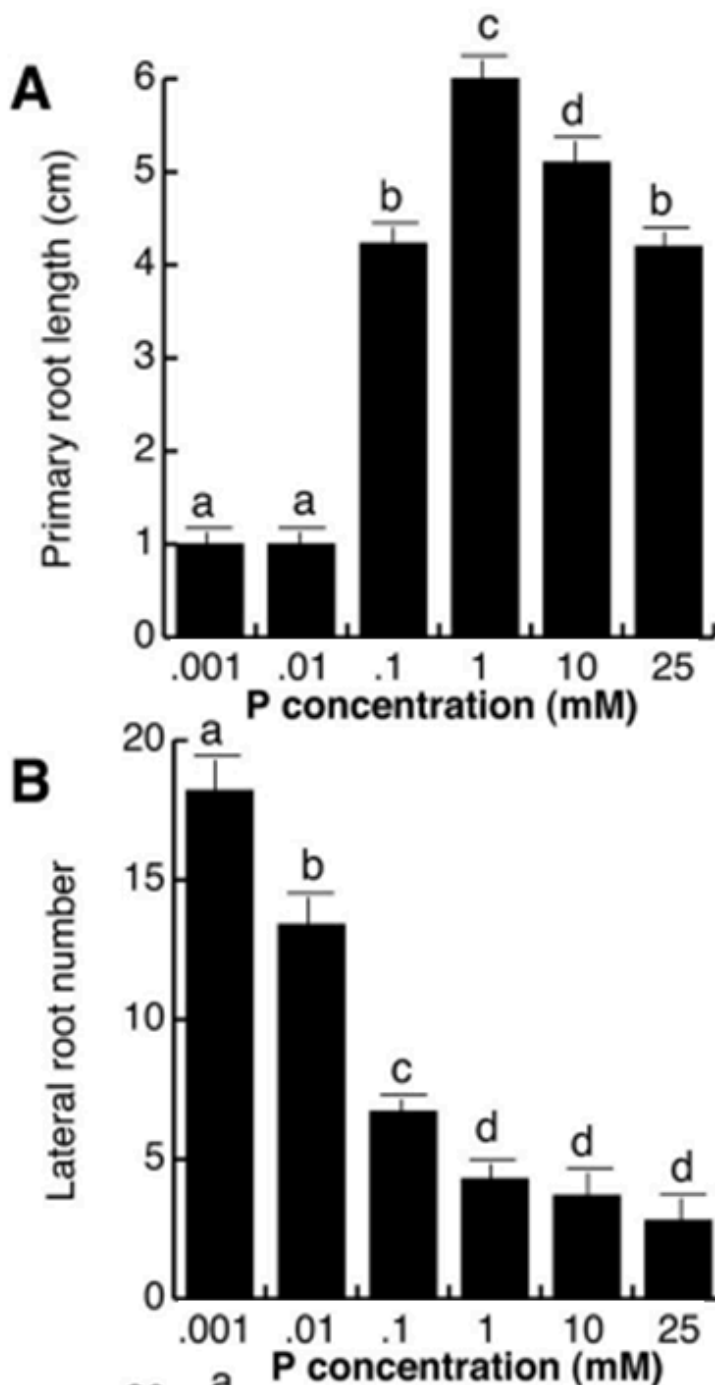
Examples of cell structures and function in research

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? A bell shape or peak. Very low phosphate results in very short roots (1cm), to a peak of 6cm at 1mM and root shortening at very high phosphate.

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

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? Less lateral roots in increasing phosphate

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

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:

Ask the students what they think would be the difference between leaves being covered/uncovered whilst trying to photosynthesise?

Remind them of the inputs and outputs of photosynthesis.

Ask how they might test their hypothesis?

What would be the difference in the leaves of plants are covered/uncovered whilst trying to photosynthesise?... E.G Reduction in Carbon dioxide or water, increasing amounts of oxygen or production of sugar and starch and the requirement for light.

Think about the inputs and outputs of photosynthesis and how you might test it? E.G Reduction in carbon dioxide or water, increasing amounts of oxygen or production of sugar and **STARCH**.

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).

Covered (no light)
= no starch staining
= no starch



Uncovered (exposed to light)
= yes starch staining
= starch

Conclusion:

The parts of the leaf exposed to light turned blue/black the iodine solution was added, demonstrating presence of starch.

The covered part of the leaf showed no staining, indicating no starch was present.

This experiment shows that light... is needed to make starch in the leaves

How can knowing about photosynthesis help us in growing food in space travel? Grow plants effectively and efficiently in controlled environment agriculture/ vertical farming in space!

Food, medicine and materials for astronauts and sustainable farming on Earth!

Extension possibilities: 1. Carry out alongside roots covered and uncovered- testing for the requirement of chloroplasts use a variety of coloured cellophane to see if there is difference in starch production in response to different coloured light.

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 CO₂ 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:



Pot 1 Full light (no box)



Box 1 Complete darkness



Box 2 Cut a small hole in one side



Box 3+ Holes at different positions, hole sizes, or number of holes.



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)
Box 3- Cut hole in different positions from box 2.
You could also test different hole sizes.

3. Placement:

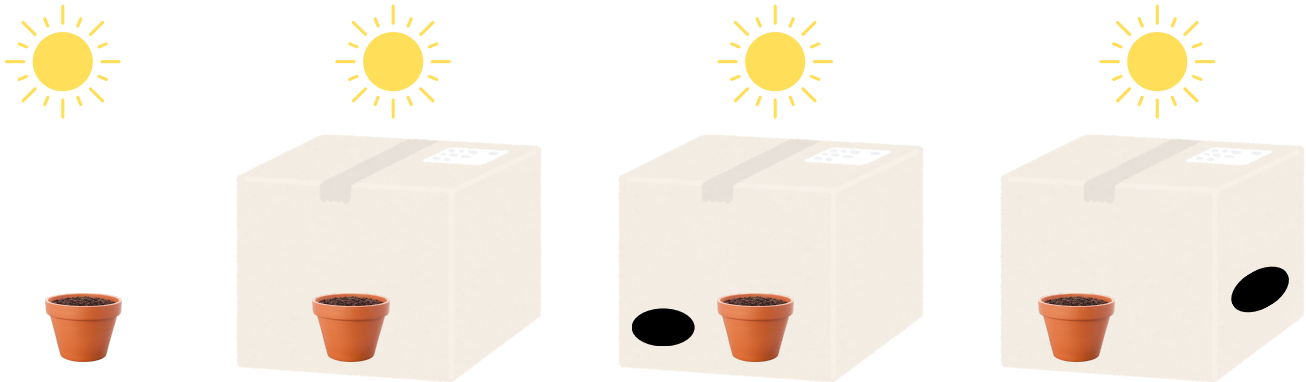
Place all but one pot inside the cardboard boxes

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)? Plants grow straight upwards towards a light source
- How did the plants that were grown in the dark grow (control group) grow? Plants grow straight upwards
- How did the plants that were grown in a box with the light coming in from the side grow (experimental groups)? Plants grow towards the light source even if that light source is not directly up but to the side!
- What (if any) was the difference in growth between plants grown in full light, dark and light, coming in from the side? Plants grown in dark grew faster, but without a cue they up “as a default setting”, but as soon as there was a light source they grow toward that! The light guided the growth direction.

Evaluation

- Why might there be a difference? Light must do something to the cells that make up the stem to direct which way the plant grows. (Light, counter intuitively, inhibits cell division and elongation on the stem facing the light. The cell on the “shaded” side of the stem can divide and elongate. The effect is the shaded side stretches over the side facing the light, causing the tip to face the light. Now the light on the tip is even so no bending /stretching is caused. This is phototropism.
(N.B. The plant hormone auxin is essential in this process. (dipping one side of a stem tip in auxin has similar effect as being in sunlight- inhibiting cell elongation))
- Discuss any potential problems in the experiment. Sneaky light sources. Also, gravity, soils, air etc. could be acting as cue to grow away from
- Suggest ideas for future experiments to further investigate phototropism. Remove or overcome the mentioned limitations, different

Discussion

Why is this knowledge important for growing plants on farms on Earth, or for indoor vertical farms or growing plants on Mars? Understanding how plant need and respond to light can mean we can find ways to help the plants or improve the plants to grow faster and healthier or produce the things people need. And to do so with minimum energy and waste. It will guide how we design and build verticals farms (whether in space, Moon, Mars or on Earth). It will help us chose the right lights, and position them carefully, or use them to direct where and how the plants grow.

What other questions or other experiments would be useful to carry out so can could grow plants in indoor vertical farms or on Mars? Light colour, intensity, duration, species, temperature, nutrients, gas concentrations, gravity, etc...!

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 device called a clinostat to simulate 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:

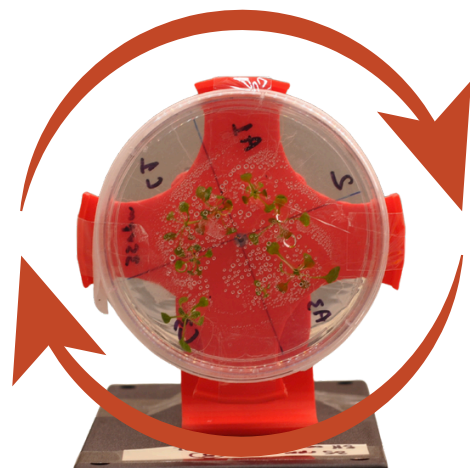
What effect does gravity have on root growth?

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?

Results:

Carry out your observations of root and shoot growth and record them here:

Shoots:

Length: Should be about the same length and health in Earth and microgravity.

Observation: under Earth and microgravity growing away from gravity/ towards light.

Roots:

Length: might be a little shorter in microgravity (might not be detected in this duration of experiment).

Observation: Earth growth towards gravity, in microgravity conditions roots growing all over the place! In circles and quite randomly!

Conclusion:

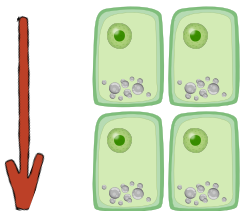
What is the effect of gravity on root growth?

Plant roots grow towards gravity!

Without gravity roots are unable to direct which way to grow, but the length appears unaffected.

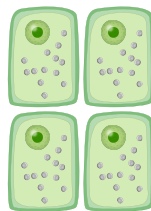
This the current understanding of how plants sense gravity and the how clinostats “confuse” the plants sense of gravity.

Earth - Gravity



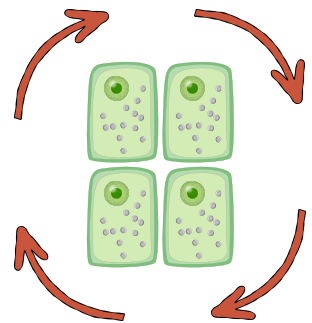
The statoliths at the bottom of the cell signals for the roots to grow down

In Space - Microgravity



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

On Earth Clinostat - Simulated Microgravity



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? Yes

Explain why you think it does or does not. Without gravity the statoliths do not fall to base of root cells– resulting in no gravity perception and stimuli to grow down towards gravity and instead growing in random directions!

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.

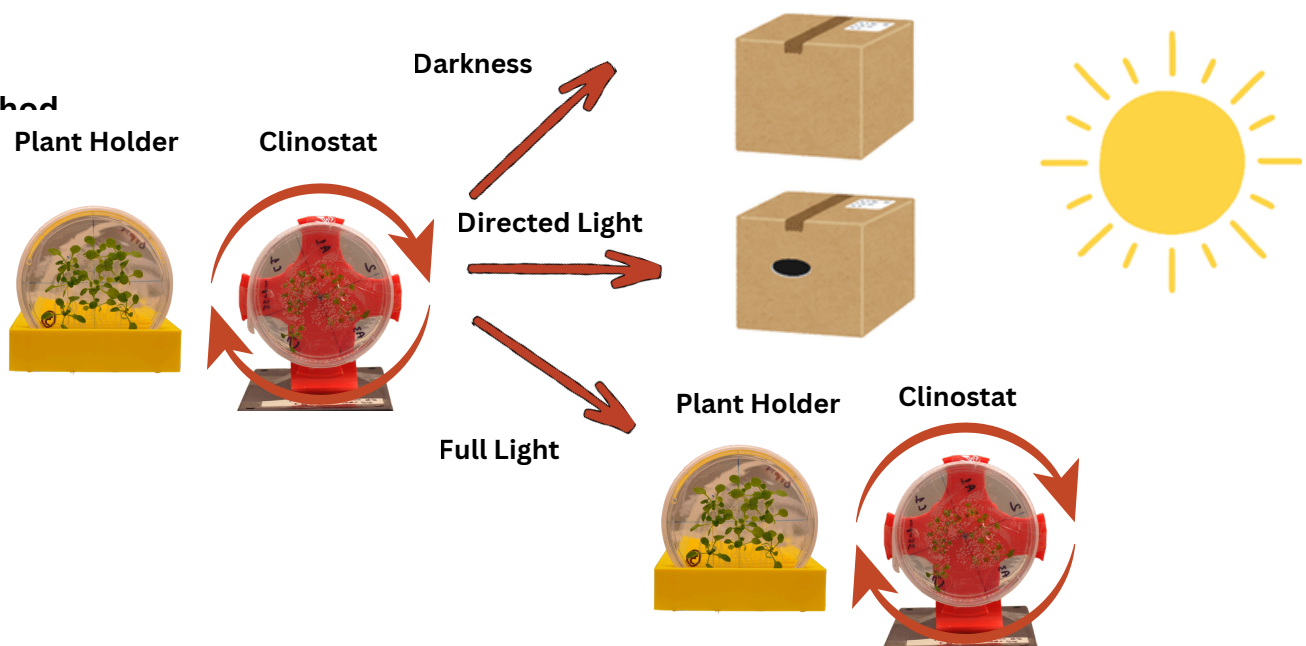
In earlier experiments, you explored how plants respond to the direction of light and to microgravity. Both of these conditions affect how plants grow in space. By combining these conditions, you can simulate a space environment. How will plants grow under these simulated space conditions?

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.... *Student response might be roots will go everywhere and shoot will grow towards the light.*

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).
- 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.

Optional: Additional clinostats can be covered with boxes with holes at different positions or hole sizes or multiple holes.

Optional: Taking photographs of the plants at beginning and end of the experiment is great way to collect evidence.

Results

Table of results showing the shoot and root length and direction in Earth gravity or microgravity in dark or light or directional light.

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 **Many factors might be suggested including:** Light seeping in, clinostat wrong speed to simulate microgravity, seeds not in centre of the clinostat, range of directed light, not in soil, age of the plants, species of plants, temperature, gas concentrations, amount of light plants received, type of lights, ...
- How could the experiment have been fairer or more accurate or reliable? **Increasing sample number, repeating experiment, taken mass /dry mass measurements, better (accurate) measurement equipment, quality of dark covering, standardizing experimental procedure and measurement across the class/group, ...**
- How could the conditions we grew the plants in have been more like ISS? **Controlling conditions e.g.: gas concentration, lighting, microbiome, nutrients, growth media, temperatures, day-night length, fans (microgravity need fans to move the air (and heat) around, human contact**
- What other questions might you have now? Or suggest ideas for future experiments to grow plants in space. **E.G Effects of: gas concentration, lighting (type intensity and duration), species of plants, reproducibility, replicants, speed of clinostat, nutrients, and growth media, temperature, speed of clinostat, comparing clinostat with reduced gravity e.g. Moon and Mars, would size of growth conditions make a difference? Could automation help? Does flavour change? Would it be more or less appealing to eat? How to nutritional value change in differing gravity? Etc..**

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.