PLANTS FOR SPACE

ARC CENTRE OF EXCELLENCE

Student Guide

Can we grow Plants in Space?

Investigating cell structure, function and photosynthesis

Year 8

Australian Government
Australian Research Council

PLANTS FOR SPACE
ARC CENTRE OF EXCELLENCE

What do you know already?

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

Commented [LVDH1]: I don't understand this sentence. Should it just be 'indicate which of the following statements about plants and (plant?) cells you think are true or false?'

Statement	True	False
Plants can move		
Plants can grow in the dark		
Plants can get sick if they don't have the right nutrients		
Watering plants on a schedule is best		
Plants "breathe" in carbon dioxide and "breathe out" oxygen		
Plants get all their energy from the sun		
Plants contain DNA		
All plant cells are the same		
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...

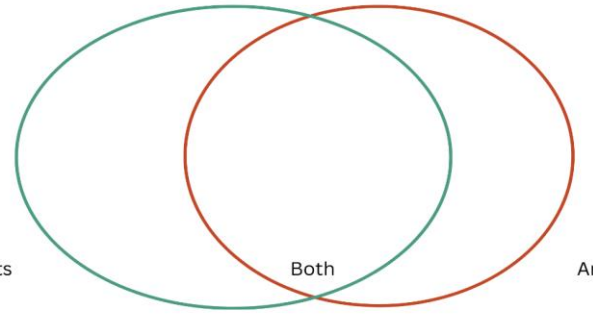
Roots grow downwards because…

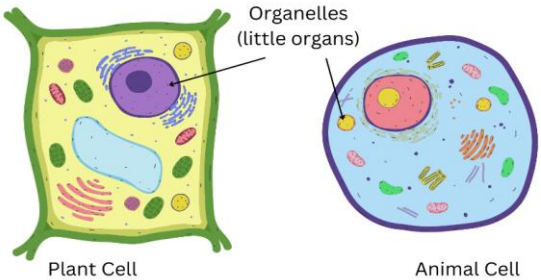
Plants and Animals:
What is similar, what is different?

Can you identify any similarities or differences, perhaps things only found in Plants or Animals?

Plants

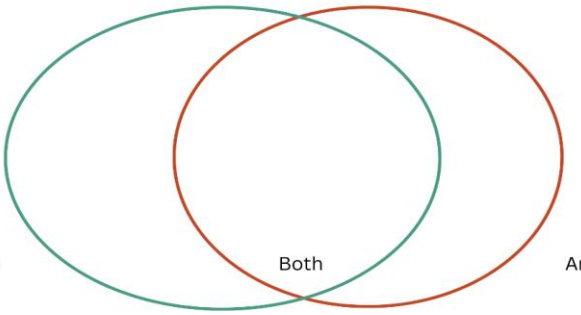
Animals





Plant Cell

Animal Cell



Developing understanding:

Plants in Space! Why?

1.Story: *The space garden was their sanctuary*

"The Argos VI shuddered, a death rattle echoing through its metal bones. Alarms screamed, red lights flashing a frantic warning. The rogue asteroid, a dark behemoth, had struck. The impact was catastrophic, shearing off a large section of the ship, sending debris tumbling into the void.

The ship groaned, a symphony of tearing metal and hissing air. The pressure plummeted, the temperature dropping with terrifying speed. Anya and Kai, battling to seal the garden's emergency bulkheads, finally they slammed shut, a fraction of a second before the vacuum claimed them. The space garden module, now violently shaking, was their only sanctuary.

The impact had ripped through multiple sections but somehow missed primary reactor and continued to power the garden's LED, and water recycling pumps.

"We're alive," Kai whispered, his voice hoarse. "But for how long?" doubted Anya dusting shrapnel and blood from her shoulder.

They were safe and relatively unharmed. The ship was a wreck. But inside the Space garden, they had air, recycled water, and a semblance of protection. The plants, though damaged, were still producing oxygen and the tomato flowers and early fruits were still mostly fine. They were trapped, adrift, but alive.

They rationed the emergency food packs, took stock of the medicines in the first aid kits and fertilizer and materials in the stores - they were not looking good. They looked at each other and turned to the green plants under pinkish flickering light. They nearly smiled.

This space garden was their sanctuary. It was all they had."

Discussion // Analysis:

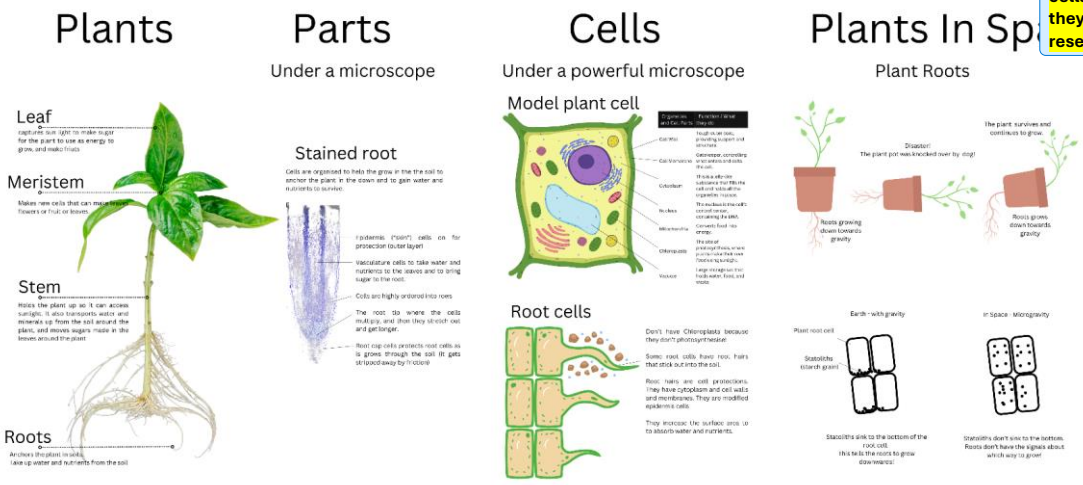
- Why is space difficult for living things?
- What do humans / plants need to survive
- Why did Anya and Kai nearly smile at the plants at the end of the story?
- How might the space garden be similar to Earth?

Plants for space and understanding plant cell structure and function

1.Plants for Space Intro video – What are the Plants for Space researchers trying to achieve?

In the video Prof Jenny Mortimer describes the below diagram:

2.Cells to Plant Responses in Space Knowledge organisers: LINK



Commented [FT2]: Who we are and what we're doing - Video - Edit it to include Jen Mortimer talk about plants being made of specialised organs, and specialized cells and plant specific parts - cell walls and function they play including the root. And her microgravity research into cell wells LINK

Q's: Why are plant roots important?

Why are plant cell walls important?

How do plant roots grow in microgravity?

Why is it important to understand how plant roots, cell walls, and plant grow in microgravity?

How are they investigating it?

3.Read the following P4S cells functions in Space Reader LINK (5min read)

Imagine growing your own salad on Mars or inside a tall building in the middle of a city! That's what scientists are working on, and it all starts with understanding how plants work.

Let's Talk Plant Cells

Just like our bodies are made of tiny building blocks called cells, plants are too. Plant cells have special parts:

- Cell Wall: This is like a strong, outer shell that helps the plant stand tall.
- Chloroplasts: These are like tiny green food factories inside the cell. They use sunlight, water, and air (carbon dioxide) to make sugar (glucose) and oxygen. This process is called photosynthesis, and it's how plants get their energy. In most plants this happens in the leaves.
- Vacuole: This is like a storage room for water and nutrients. It helps keep the plant plump and healthy.

How Plants Grow

Photosynthesis is super important! It's the plant's way of making food. In places like space or indoor farms, scientists use special lights called LEDs. These lights give plants the right kind of light they need to grow, even without sunlight.

Plants are really good at adapting. They can:

- Bend towards light: This is called phototropism, and it helps them get more energy.
- Grow roots down and stems up: This is called gravitropism, and it's how they know which way is up and down. But in space, there's not much gravity, so scientists are trying to figure out how to help plants grow the right way.

Growing Plants in Space

Growing plants in space is important for astronauts on long trips. Plants give them fresh food, oxygen to breathe, and clean water. Scientists are doing experiments on the International Space Station and the Moon to learn how plants grow in space.

Vertical Farms on Earth

Back on Earth, we have vertical farms. These are like indoor gardens stacked on top of each other. They use special lights and water systems to grow plants in a small space. This is similar to what they need to do in space.

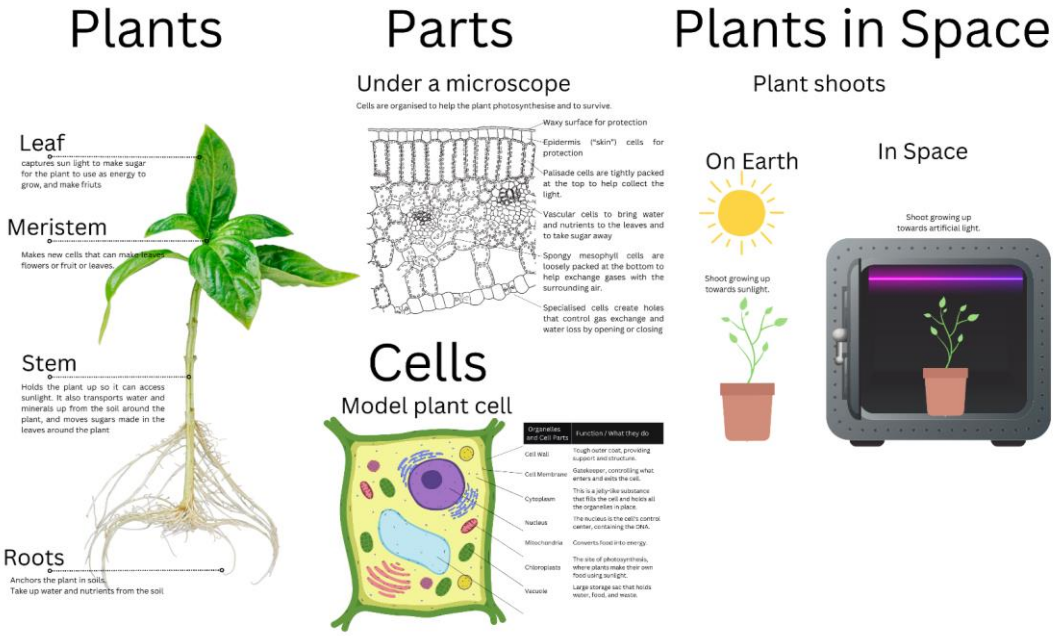
Plants for Space (P4S) Researchers

P4S researchers are working hard to learn all about how plants grow in different places. They do experiments with special lights replicating the light conditions in space! They are comparing plants grown in different colours and how much time the plants get light and

light, and brightness! Their work will help us grow food in space and make better indoor farms on Earth.

Connecting Earth and Space

By learning about plant cells and building vertical farms, we are getting closer to growing plants anywhere, whether it's on Earth or in space. This means we can have fresh food and clean air, no matter where we are!



Q's: Why are plant leaves important?

Why are plant chloroplasts important?

How do plant grow in response to light?

Why is it important to understand how plant leaves shoots response and grow in LED lights?

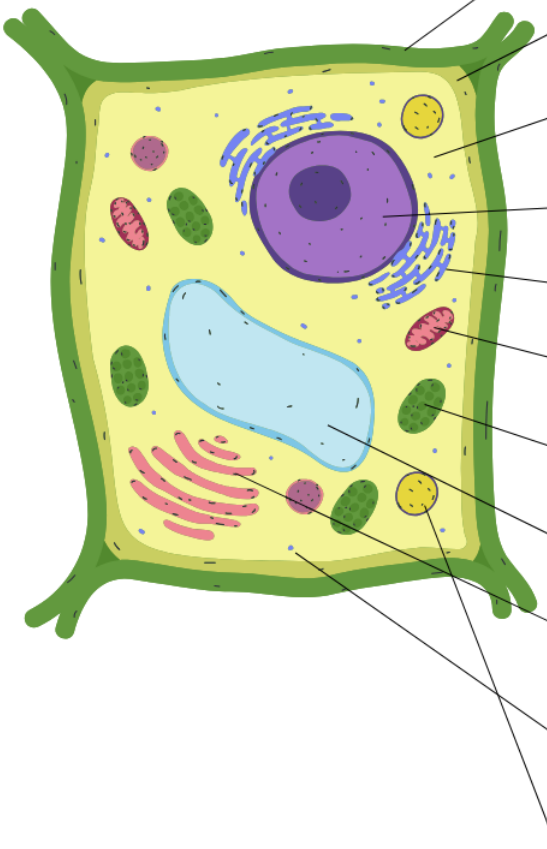
Identify why P4S researchers are investigating responses of light

How are they investigating it?

Make a Model Plant Cell!

Commented [FT3]: Needed?

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 response to stimuli.



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

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 (ER): Pieces of red or pink liquorice, yarn, or craft foam cut into thin, wavy strips
Golgi Apparatus: Pieces of yellow or orange 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 or "Key parts and Functions" table (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 or orange candies, pom-poms, etc.) throughout the cell.
7. **Place the ER and Golgi materia**l (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:**

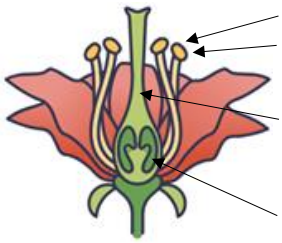
Label each part of the cell using markers, coloured pencils or cut and stick the table of "Key parts and Functions" found in this guide with glue or tape.

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:

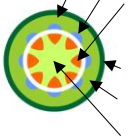


Pollen: Male gametes contained within pollen grains.
Stamens: Male reproductive organs consisting of anther (produces pollen top) and filament (stalk).
Pistil: Female reproductive organ consisting of stigma (receives pollen), style (connects stigma to ovary), and ovary (contains ovules).
Ovules: Structures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



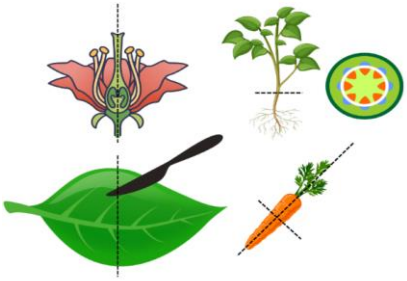
Vascular Bundles: veins that transports water and transports sugars through the stem.
Xylem: Transports water and minerals from roots to leaves.
Phloem: Transports sugars produced by photosynthesis from leaves to other parts of the plant.
Epidermis: Outer layer that protects the plant.
Cortex: Layer 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: Observe the plant parts and see how they might help the plant survive

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.
· Label all identified structures)

Leaf sample on a slide in water under a coverslip

4. Microscopic Examination (Optional)
Use a microscope to examine cells, tissues, and specialized structures.

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

Plant parts and description	What does it do?	What organelles do you think are most important in this part to keep the plant alive?	What environments or conditions might different organelles be super helpful and even more might be needed?
1.			
2.			
3.			
4.			

Commented [LVDH4]: Is super helpful the description that would get the best answer here? Might need to think of further questions and better descriptions here

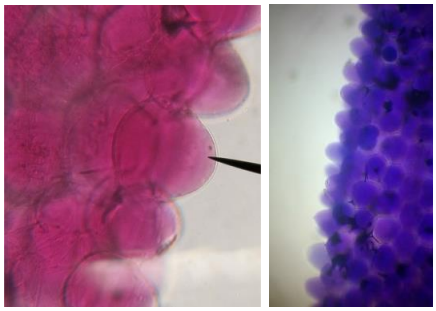
Commented [FT5R4]: I added some examples- just trying to get them to think about the cell structure and function and link that to organelles.. Better?

How plant cells can help the plant survive – Investigating examples of cell structures and their functions

1.The shape of petal cells and their functions

View the pictures of flower petal cells below, what do you notice and can do they help the plant survive:

Cells of petals on flowers



Q: What do you notice about the shape of the flower cells?

Many flowers need insects to climb inside the flower to pollinate them.
Pollination ins when pollen gets onto the stigma and can fertilise the plant and make seeds.

Q: Using the pictures, which part of the insect helps them climb get into the flower to pollinate them?

Q: How might the shape of the cells help the insects?

Q: Why might the flower cell shape help the plant?

2.Petals under UV light and microscope

Can you identify what these cells might do and how they might help the plants?

View the pictures of a flower below under white light and UV light, and a powerful microscope, what do you notice and what can do they help the plant survive:

In Sunlight

A *Rudbeckia fulgida* flower under white light/sun light. Flowers are bright and colourful to human eyes.

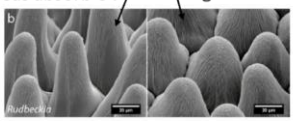
Under UV light

Insects can see ultraviolet (UV) light which humans cannot. Under UV light *Rudbeckia fulgida* flower look a very different.

Dark areas absorb UV

Light areas reflect UV

Cells seen under Electron microscope



Black under UV lights (absorbs UV light)

White under UV light (reflects UV light)

Cells of *Rudbeckia* flowers under a powerful electron microscope. It shows what the cells look like from the dark area under UV light (absorbing) and White area under UV light (reflecting)

Q: For this insect-pollinated plant, what do you notice about the light-dark areas under UV light?

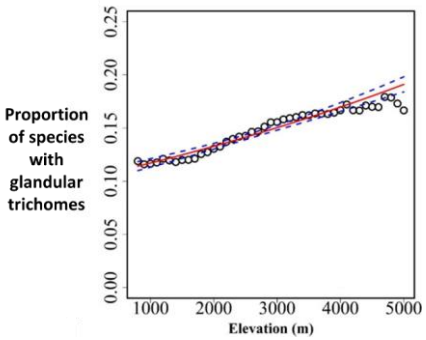
Q: What is different about the cell shape in the light/dark areas under UV light?

Q: Thinking about the location of the dark patch, pollination, and insects, how might cell shape in the dark areas help the plant to survive?

3.Leaf hairs (trichomes) and altitude

Trichomes are hairs on leaves, scientists are trying to figure out what they do, some believe they give protect the plants from being eaten by herbivores.

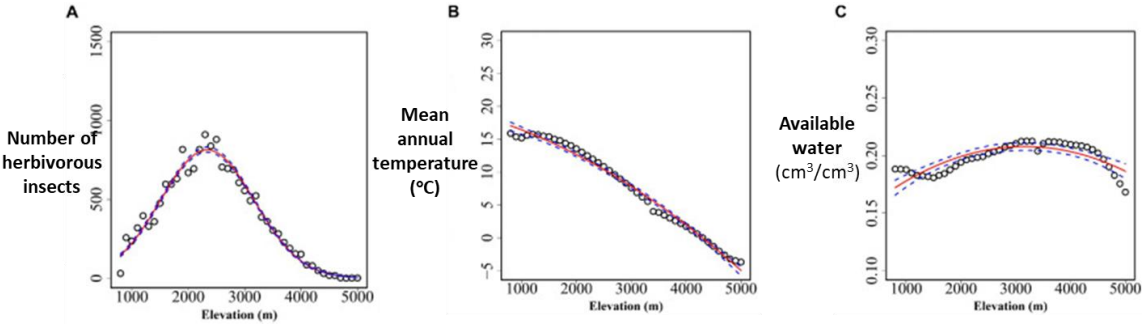
View the graph below that shows the proportion of 6,262 plant species that have leaf hairs (a.k.a. trichomes) at different altitudes in the Chinese Hengduan Mountains:



Wu R, Lev-Yadun S, Sun L, Sun H, Song B. Higher Elevations Tend to Have Higher Proportion of Plant Species with Glandular Trichomes. Front Plant Sci. 2021 Apr.

Q: What do you notice about the proportion of species with glandular trichomes (sticky leaf hairs) with increasing altitude?

The three graphs below show, (A) the number of herbivorous insects (insects that eat plants), (B) the temperature, and (C) the amount of available water in the same locations as the plants the looked at.



Q: What is the trend of herbivorous insects with increasing altitude?	Q: What is the trend in temperature with increasing altitude?	Q: What is the trend of available water with increasing altitude?

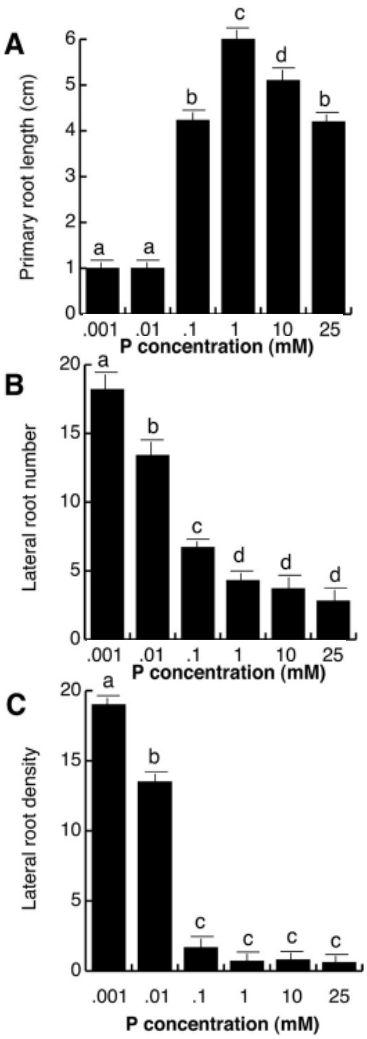
Q: Thinking about the trend in leaf hairs with increasing altitude, which one of these conditions might have something to do with leaf trichome

Q: What might the leaf hairs be doing to help the plant survive?

Root cells in the plant helping the plant survive different environments

Plant roots have many different roles in including anchoring in the ground and absorbing water and nutrients such as phosphate from the soil to stay healthy.

Below are three graphs and an image 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?

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 0.001?

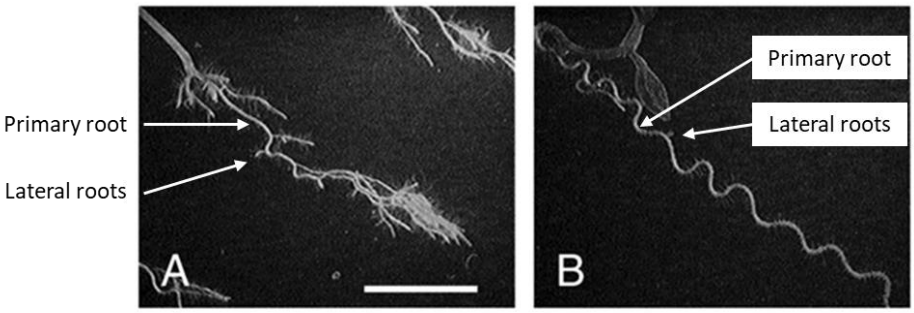
Root density. Calculated by dividing the number of lateral roots by the length of the primary roots.

Q: What change in root density do you see when grown in different amounts of Phosphate?

Q: What density of root density would you predict if there was less phosphate than 0.001?

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

Below are two photographs of plant roots grown in A low amounts of Phosphate. B in high amounts of Phosphate:

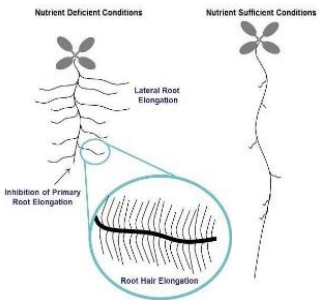


Low phosphate High phosphate

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:

Very Low Phosphate



Very 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?

How plant cells can help the plant survive – Experiments into cell structures and their functions and space

1. Researching Photosynthesis and phototropic responses in space

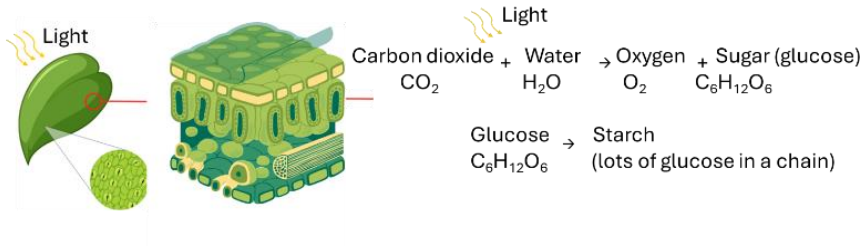
Background:

Plants for Space scientists are helping to create a vertical farm in space for research and for food. P4S are collaborating with a company called Axiom who are building a new Space Station that will grow plants together with United Kingdom Space Agency, Vertical farm company Vertical Futures and a communications company called Sabre.
Plants for Space are growing plants in a vertical farm using LED lights and using video to monitor how the plant grow the colour and direction of the leaves, measuring plant health and photosynthesis. In the future this will help direct automated robots to care for the plants. Link to Video

Experiment 1: Where is photosynthesis occurring?

Research Question: Is light necessary for photosynthesis - can we prove it? How can knowing about photosynthesis help us in growing food for space travel?

Introduction: Leaf and chloroplast cell are believed to be essential for photosynthesis:



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

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

Method:

1. Destarch the plant:
Place the plant in a dark cupboard or room for 24-48 hours before the experiment.
This will ensure present starch in the leaves is used up.

2.Prepare the leaf:
Select a healthy leaf on the plant. Cover a half of the leaf with aluminium foil or dark paper, securing it with paper clips.

3.Expose to light:
Place the plant in a well-lit area (sunlight or lamp) for 4-6 hours. (You can put plants in different light conditions (bright vs dim) to compare.

4.Starch test:
Detach the leaf.
Place the leaf on a white tile or dish.
Add a few drops of iodine solution directly to the leaf to both the covered and uncovered portions using a dropper.

5.Observe:
Dark blue-black colour indicates the presence of starch.

6.Record:
Note any colour changes in the leaf immediately 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…

This experiment shows that photosynthesis…

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

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?

Background: Vertical farms on Earth serve as valuable testbeds for space agriculture. These indoor farms use stacked layers and hydroponics to optimize growing conditions. Precise control of light, temperature, humidity, and CO2 levels, along with LED lights and direct nutrient delivery through hydroponics, allows for high-yield, resource-efficient agriculture in confined spaces, mirroring the challenges of space habitats.
P4S (Plants for Space) researchers are crucial to this effort. They investigate how plants respond to different light conditions, particularly in space, to provide a sustainable food for astronauts and improve indoor farming on Earth. They conduct controlled experiments, utilize advanced tools to measure light utilization and growth rates, examine cellular processes, and even send plants into space.

Method:

1.Plant seeds. Several seeds per pot (minimum 3 pots) filled with potting soil.

2.Place the pots inside the cardboard boxes with holes.

3.Experiment design:
1 Full light (control group)
2 Complete darkness (control group) (no gaps- tape down the edge to make sure!))

Pot 1 Full light (no box)

Pot 2 Complete darkness

Pot 3 Cut a small hole in one side

Optional: Holes at different positions, hole sizes, or number of holes.

4. Light source: Place the lamp near the hole in the boxes or near a well-lit window.

Observe after several days or weeks (BE QUICK! Less than 30 seconds! As you will introduce light into the experiment!)

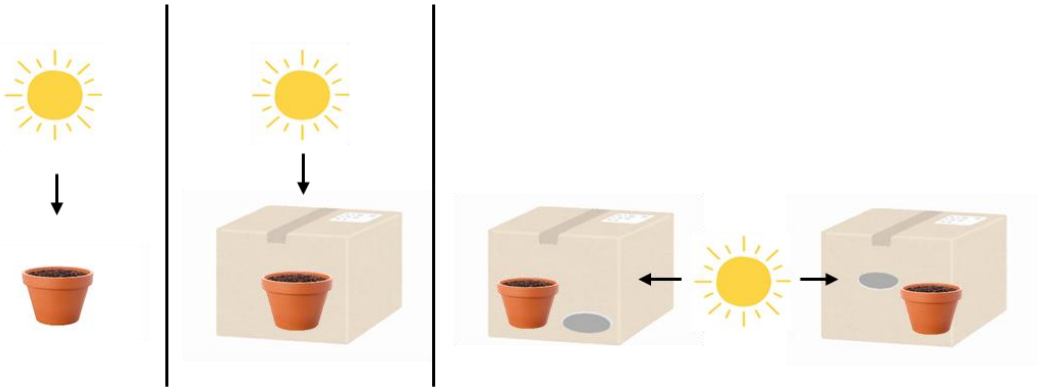
Add water and keep it moist but not waterlogged.

Pot 3 Cut a small hole in one side (experimental group group)

Optional additions pots can be covered with boxes with holes at different positions or hole sizes or multiple holes.

Decide an appropriate method to record your observations, noting the direction of growth, stem length, and any other relevant changes.

Hypothesis: Plants need light so will respond to the direction of the light source. Please draw in the way you predict the plants will grow:



Q: I think they will respond by…

Results:

Plants grown in:	Full light			Darkness			Light coming in from the side		
Diagram illustrating growth of plants									
Measure-ments: Days growth:	Height (mm)	Angle of plant growth (°)	Observations	Hight (mm)	Angle of plant growth (°)	Observations	Hight (mm)	Angle of plant growth (°)	Observations

Conclusion

- Summarize 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 difference in growth of 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?

3.How do plants roots grow to microgravity?

Introduction:

International Space Station (image on right) is a laboratory in low Earth orbit (travelling around the Earth like the moon). Plants will be needed to sustain human life providing food, medicine, materials and for enjoyment and mental health. Plants on board will experience microgravity.

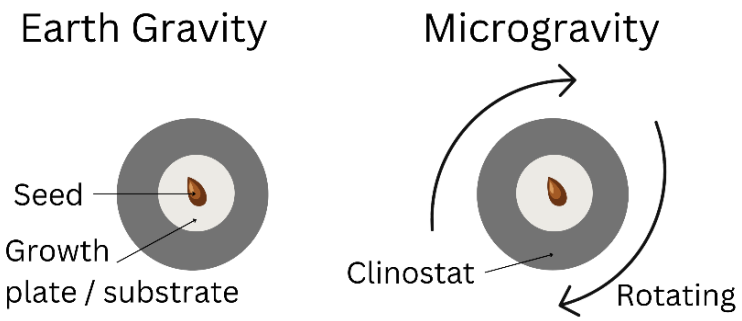
how do plants and plant roots cells respond to microgravity on the ISS? To test how plants grow in microgravity this we need to compare plants grown in gravity on Earth and those grown in microgravity.

There is a clever devise that simulates microgravity called a clinostats. Clinostats rotate objects giving them the feeling of constantly "falling" but never actually moving downwards or hitting the bottom. Lunar Effects on Agriculutural 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 in reduced gravity and compared them to Earth gravity. In preparation for this Plant for Space researchers are growing plants testing them in microgravity by rotating them in a clinostat and comparing them to plants not rotated. LINK TO VID + reader earlier.

Build a Clinostat build guide + Clinostat Experiment include plate turning alternative

Research Question: What is the effect does gravity on root growth?

Method: Plants grown on compared to plants grown in simulated microgravity (on a rotating clinostat).



Recording data:

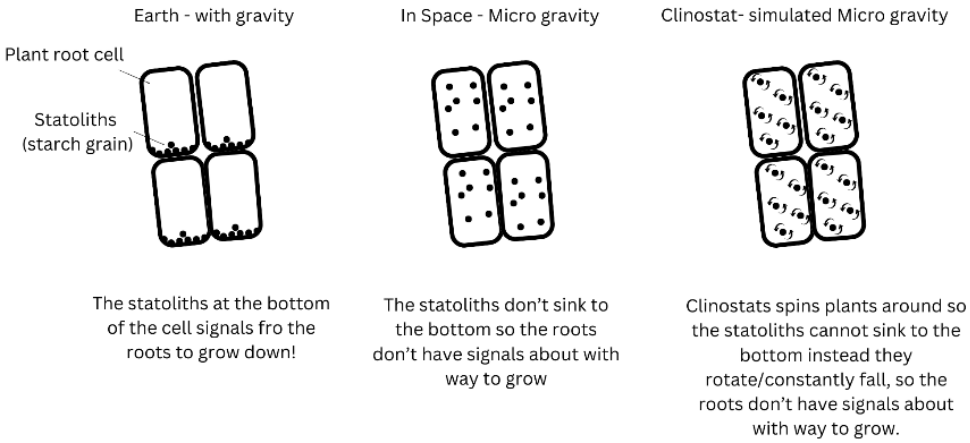
What data and observations will you collect to measure root growth? Perhaps length and direction of growth in Earth gravity (1G and Microgravity gravity (~0G)).
How will you show the data collect observations collected of root growth? Perhaps a table or graph? What sort of graph would be best?

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

Conclusion:
What is the effect of gravity on root growth?

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

Space and Plant Roots



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

Explain why you think it does or does not.

4.How do plants grow in Space?

Introduction:

It is difficult to grow plants in the ISS it is a dark metal box with microgravity. We will have to provide all the things plants need to produce the food, materials and medicines we need, proving the plants with gases, water, nutrients, substrate, space to grow and light.

Plants for Space are working out the best, or optimum conditions to be able to sustainably grow plants in space, factors like the amount of light.

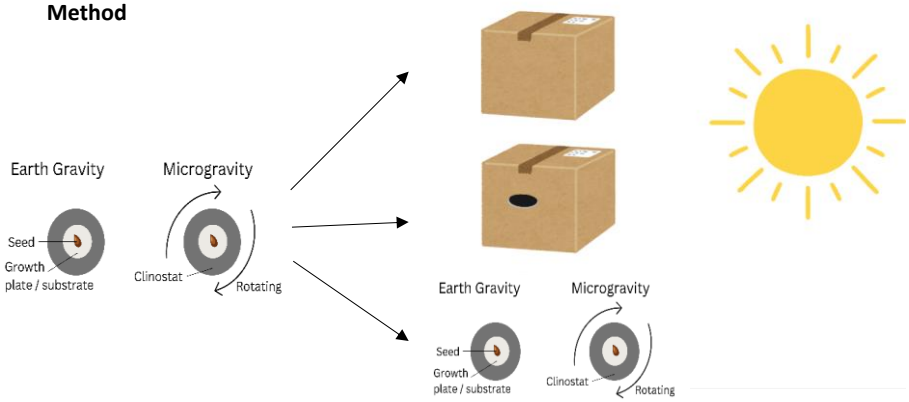
The light provided to the plants is from an artificial light source e.g. LED lights, directed to the plants on the ISS in vertical farms, as there will not be enough sunlight or enough space to for "horizonal farming". Plants will experience microgravity.

Our previous experiments separately tested how plants response to light direction and microgravity, conditions that are both found on the ISS. Combining these conditions/our previous experiments we can simulate conditions on the ISS. How will plants grow under simulated space conditions?

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

Hypothesis: What I think will happen is….

Method



Step 1. Set up 6 minimum plants in plates/ziplock bags (as before): 3 for clinostats and 3 Plant holders (1 each per condition)	**Step 2.** Place plants in the clinostats and holders. Place one clinostat and one holder in the different conditions	**Step 3.** Place clinostat 1 + No spinning clinostat plant in the Three conditions: 1. Complete darkness (covered with box (no hole)) (control group). 2. Cut a small hole in one side (experimental group group)	**Step 4.** Place the light source (lamp) near the hole in the boxes or near a well-lit window. Leave seeds to germinate and grow for at least 4 days. **Step 5.** Decide what to record and observations to make, (these might include

	(minimum three as shown above)	3. Full light - no box (control group) and turn on the clinostats!	direction of growth, stem length, and any other relevant changes. **Step 6.** Observe and record plant plants 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.

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 graphs 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 show?
- 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.

Can we grow Plants in Space?

Designer Plants for Space and Earth: Cell structure, function and photosynthesis

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 ISS) that is incredibly sustainable, meaning the plants don't waste any water, nutrients, light. Think about how you might modify the plants.
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 in SPACE/ Moon/Mars.

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

Check list of things 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?