PLANTS FOR SPACE

ARC CENTRE OF EXCELLENCE

Teacher 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

Can we grow plants in space?

Cell structure, function and photosynthesis

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** (True/False statements and/or complete the sentence stems and/or Plant and animal cell comparison)
2. **Developing understanding** (Plants for Space, plant cell structure and function, photosynthesis and microgravity)
3. **Investigation and experiment** (examples of plant cell functions, phototropism and gravitropism)
4. **Assessment** / performance of understanding (report and speculate on plant structure and function for sustainable farming on Mars, space, and Earth).

Indicative duration	Suggested Learning sequence	Resources found
15 mins	**Activate prior learning** In the student guide: Students respond to 'True or false statements", and "Complete the sentence stems". This activity will reveal student understanding and misconceptions and stimuli for discussion about how plants work.	**Student workbook:** "True or false statements", "Complete the sentence stems" And "Plant and animal cell comparison"

Statement	Teacher notes
Plants can move	Not exactly running around but they can move their leaves and flowers to the sun daily - there are videos of leaves "flapping throughout the day"
Plants can grow in the dark	Seeds and bulbs germinate and grow in the in the dark. Plants do not develop for long in the dark. They need light for photosynthesis to make sugars to fuel their growth.
Plants can get sick if they don't have the right nutrients	Yes – often yellow spots on the leaves indicate a deficiency of an element e.g. iron or phosphate.
Watering plants on a schedule is best	A watering schedule is probably best to remember to water your house plants, but it is not essential. An example is he 'resurrection plant' (Bryophyllum pinnatum), which can last

	many years in the desert without water and spring back to life when the rains come. Other plants need regular and constant damp - there is very high variation of water needs for plants.
Plants "breathe" in carbon dioxide and "breathe out" oxygen	Breathing is an active processed achieved by using muscles, so something done by animals. Plants have gas exchange only by diffusion. Plants take in carbon dioxide and give out oxygen. However, as they also take in oxygen and give out carbon dioxide, as the gas atmosphere they take in and out contain oxygen and carbon dioxide and a range of other gases. Do not confuse breathing and respiration: plants do respire like animals, but the net plant output is oxygen and intake of carbon dioxide.
Plants get all their energy to grow from the sun	Yes. Through photosynthesis. There are some very rare parasitic orchids, and some species of trees dying in forests, that obtain the carbon source/energy from neighbouring plants. This is an exception, they are effectively acting as heterotrophs like animals, but the still that carbon/energy they obtain is derived from photosynthesis (autotrophic). Like most food chains it begins with photosynthesis.
Plants contain DNA	Yep, in the nucleus, mitochondria, chloroplasts and even some free-floating plastids (DNA loops).
All plant cells are the same	No, there is a lot of variety among plant cells, which is needed to ensure cells can carry out different functions and give different appearances.
Chloroplasts (where photosynthesis occurs) are only found in leaves	The most chloroplasts are found in the leaves. They can also be found in stems and sepals and other plant parts. Chloroplasts are not usually in the (underground) roots
Fertilizer is "plant food"	Depending on your definition of food. No, plant chemical energy comes from the sugars created in photosynthesis, not soils or substrates, or fertilisers. Yet, minerals like Nitrates and iron are found in fertilizers. Minerals are very important to plants. They are absorbed through the roots and are used as the building blocks of things like proteins, and they would die or be sick without them. Baptista van Helmont grew a tree in a weighed amount of soil. After five years the tree weighed about 74 kg and the soil had hardly changed. Plants don’t consume soil like animals do food, they “make their own” from the gas they take in, yet the minerals are up-taken as nutrients.

Finish the sentences…

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 "**Plant and animal cell comparison**" Student booklet 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. Model 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.. Model plants cells have the same organelles as animal cells AND cell walls, and chloroplasts, and large vacuoles. (statoliths are a specialised organelles for detecting gravity, not discussed in the simplified cell model but is later.	
45 min	**Developing understanding activities** **Plants in Space! Why?** 1. Students read the **Story**: "*The space garden was their sanctuary*". The story outlines a spaceship disaster and finding sanctuary in a Space garden. It illustrates the challenges for living things in space, and why growing plants in space might be a worthwhile endeavour. Discuss the following points: Why is space difficult for living things? Isolation, artificial environment, air, cramped conditions, water, food, lights etc.. What do humans / plants need to survive? Social, green space, air, water, food/nutrition, lights, sleep etc.. Why did Anya and Kai nearly 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. 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 Plan-et B! 1. Show students the "**P4S introduction video** **https://www.youtube.com/watch?v=xTo063Y0roY&list=PL7xKXnJ29**	**Student workbook**: "P4S introduction video", and Links to P4S yr8 Explainers: video, and text, graphics "Build a model Plant Cell" and Craft materials **Student workbook**: "Plant dissection: Cells, and organs structure and function" **Teacher notes**: "Viewing Plant Cells guide" **Teacher notes**:

	VzUA77xuaLNXYWG9A0k_INEm&index=3- "Why plants in space?" And growing plants in microgravity"" Students respond to "What are the Plants for Space researchers trying to achieve?" How to grow plants in Space and sustainable farming - Optimising plants and their growth conditions, complete nutrition plants, and plants producing products on demand. Future foods, space laws, etc… 2. Show students and discuss the "**P4S yr8 Explainer – Cells to Plant responses in space**" in student workbook illustrates the ideas of plants cells, roots and their growth responses in space using the work of P4S researchers. Students answer the following: -Why are plant roots important? Anchoring, and water and nutrient absorption -Why are plant cell walls important? Give the plant structural support- helps plant stand up, and water and nutrient absorption, gravity perception. -How do plant roots grow in microgravity? They grow in random directions. No gravity can't grow towards gravity! -Why is it important to understand how plant roots, cell walls, and plant grow in microgravity? Cell walls are vital for plant grow and survival and fruit production- so understanding the differences of cell walls in plants grown in Earth vs microgravity and overcoming any challenges is vital to ensure reliable plant and food production. -How are they investigating it? Investigating the differences of cell walls in plants grown in Earth vs microgravity using clinostats and eventually on the moon in reduced gravity! 3. Students read the Read **P4S cells functions in Space Reader and graphic organiser** in the student guide. Outlining the growing plants in space with a focus on plant parts and cells and using artificial light o grow plants in space. Why are plant leaves important? For photosynthesis making sugar for energy Why are plant chloroplasts important? For photosynthesis making sugar for energy How do plant grow in response to light? They grow towards it Why is it important to understand how plant leaves shoots response and grow in LED lights? Light is essential for plant growth and food production! So understanding how they respond to artificial light, to make sure we can do it will determine if we can grow plants in space Why P4S researchers are investigating responses of light and how are they investigating it? Investigating the how plants respond to artificial lights differences, so we can optimise plant growth and so support growing plants in space for astronaut food, and in door sustainable farming on Earth.	"Viewing Plant Cells guide"

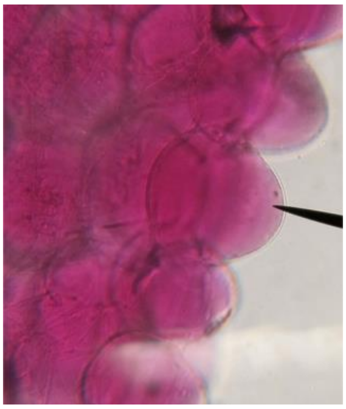
	Students follow the instructions in their guide to "**Build and label a model Plant Cell"** to construct an annotated plant cell model. Students follow the "**Plant dissection: Cells, and organs structure and function**" guide. Dissect the plant and label parts and functions Optional - Demonstrate, or student use, a USB microscopes/ Fold-a-scope/ smart phone/ tablet camera microscope attachment to view food and plants parts to identify cells and shapes and functions in difference organ types could including celery stained with food colouring (teacher notes in "**Viewing Plant cells guide**"). Show students different microscope imagines zooming into cell parts (Micrographs in teacher notes in "**Viewing Plant cells guide**"). In the student guide, students select four plant parts and ask student to describe the cellular structure and its function including the organelles and asking questions, such as: -What organelles are important in this part to keep the plant alive? E.g. **root hairs**- the cell wall and cell membranes are essential for the shape and stability of the cell and to increase surface area to up take nutrients. **Nucleus** to encode proteins to help uptake nutrients. **Vacuoles** to store nutrient minerals, the **xylem** is hollow and acts as a tube to pipe water and minerals to the rest of the plant to survive and grow. **Petals** - Shape and size guide insects to nectar- colour stored in the vacuoles **Stem** - thick cell walls for strength to stand upright and harvest light better for photosynthesis (and survival) -What environments or conditions might different organelles be super helpful and even more might be needed? E.g. **Drought**...nucleus to make proteins to protect it **Poor nutrients**... cell wall, membrane, ribosomes, DNA, Vesicles to required for sensing and activating root hair growth **Windy**... Mitochondria- to breakdown sugars for energy to make repairs! Cell walls, DNA golgi, ER, rough ER **Wet** ...Xylem- hollow out! **Hot**... Epidermis- chloroplasts top regulate stomata opening and closing, and vacuole can help prevent wilting	
15mins	**Investigations and Experiments** **How plant cells can help the plant survive – Investigating examples of cell structures and their functions** In the students guide Students will investigate *How plant cells can help the plant survive – investigating examples of cell structures and their*	**Student workbook**: 1 Petal cells and pollinators. 2 Petal cells, UV light and pollinators 3 Leaf hairiness and altitude

functions. Students investigate data, identify patterns and draw conclusions about how plant cells help the plant to survive

1. **The shape of petal cells and their function**.

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?

They are

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?

Legs and feet - They walk/climb into the flower.

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

Bumpy petal cells make it easier for the insects to gain purchase/grip/hold on the petal to assist in climbing into the flower to obtain the nectar and inadvertently pollinate the plant.

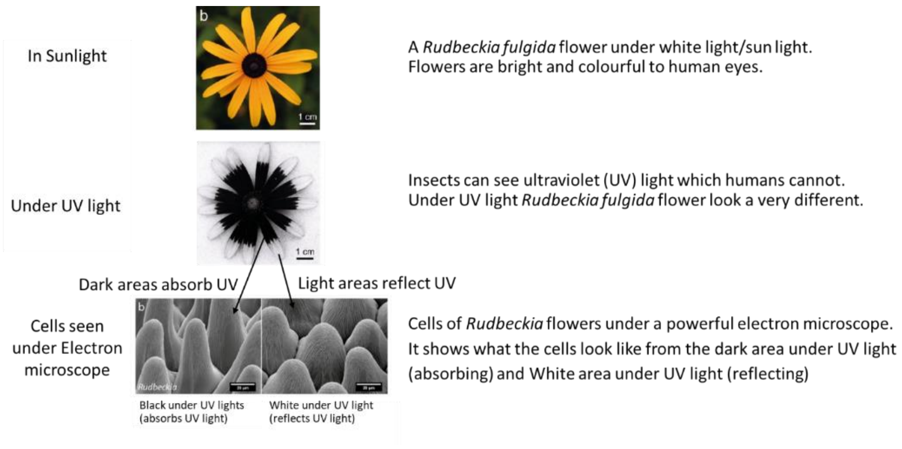
Q: Why might the flower cell shape help the plant?

The cells help the insect get into the flower. The insect is then able to pollinate the flower, Pollination is the movement of pollen to the stigma, enables the nuclei of the pollen and flower's egg to fertilise and grow into an embryo and seeds. So the cells help the plant to reproduce.

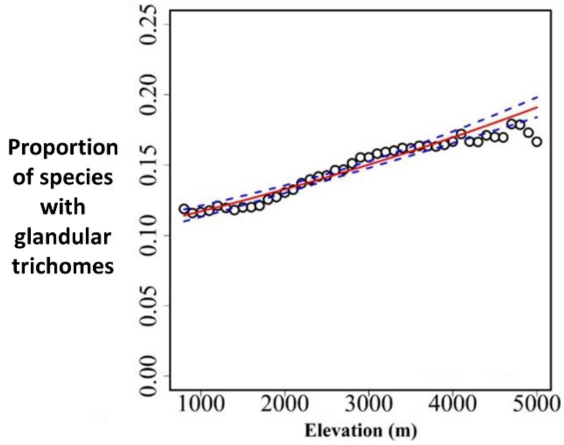
2.Petals under UV light and microscope

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

4 root length and nutrient conditions

30 min	light, and a powerful microscope, what do you notice and what can do they help the plant survive:  **Q: For this insect-pollinated plant, what do you notice about the light-dark areas under UV light?** Insect can see UV light and the dark areas (UV absorbing) is found it the centre of the flower. Acting like a 'landing pad' directing insects to the nectar and pollen and stigma in the flower. **Q: What is different about the cell shape in the light/dark areas under UV light?** The petals cells have different cell shapes. The cells on the out of the flower i.e. the white areas under UV light (reflect UV light) are flatter and have blunter tips compared to the cells in the dark areas (absorb UV light) which are are taller and pointier. The UV reflecting cells help to guide the insect into the centre of the flower. **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?** In UV light, the cells in the dark areas are specialised to absorb UV light creating a dark patch that acts to guide insects to the centre of the flower. Also the increased pointiness of the cells in the dark areas would also help the insect to climb to the flower to pollinate it, so increasing chances of pollination and producing seeds and offspring. 2. **Leaf hairs** 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.	**Teacher notes:** Plant experiment guides: 1.Block light on half of leaf with foil. 2.Light direction and dark 3.Microgravity-clinostat 4.Light and microgravity **Student guide**: "1. Block light on half of leaf with foil.

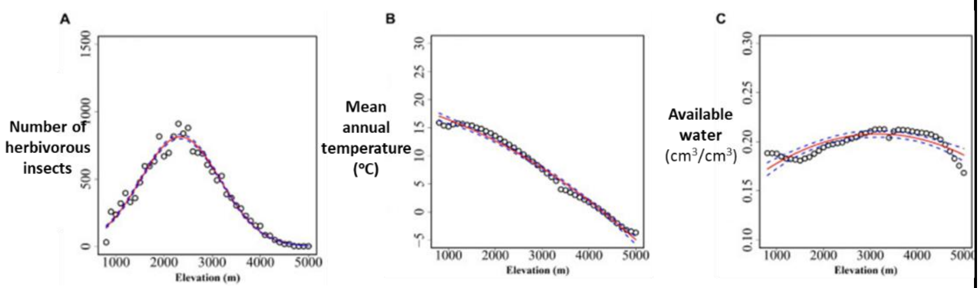
View the graph below that shows the proportion of 6,262 plant species that have leaf hairs (a.k.a. trichomes) at different altitudes in the Chinese Hengduan Mountains:



Song B. Higher Elevations Tend to Have Higher 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?
As altitude increase more species have globular trichomes.

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?
Bell shape- low then peaks and returns low numbers
Q: What is the trend in temperature with increasing altitude?
Annual temperature decreases with increasing altitude
Q: What is the trend of available water with increasing altitude?
Relatively flat or a shallow bell curve

Q: Thinking about the trend in leaf hairs with increasing altitude, which one of these conditions might have something to do with leaf trichome
Temperature decrease as altitude increases - maybe trichomes keep plants warm. The opposite effect with increase altitude but both constant, so the only condition with a logical (negative) relationship.
Q: What might the leaf hairs be doing to help the plant survive?
Temperature decrease as altitude increases and as the temperature decrease the number of Plants with trichomes increase...maybe trichomes keep plants warm.
Also, UV increase with altitude - so may play a role in UV protection.

2.Light direction and dark
3.Microgravity-clinostat
4.Light and microgravity”

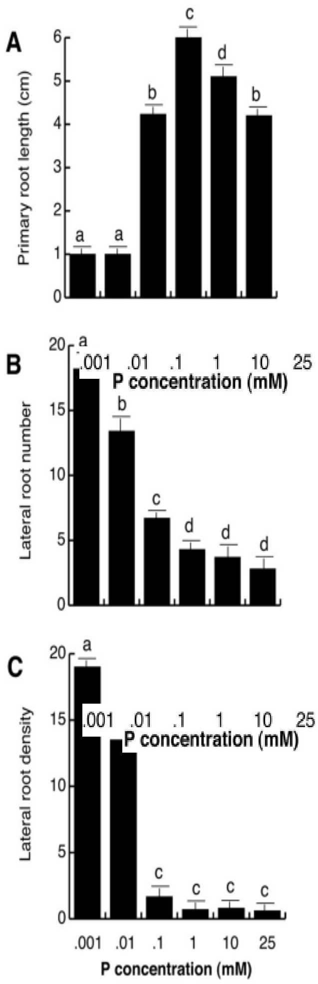
30mins

Etc.. could be something else if students can think of and rationalise other ideas! The researchers are unclear on this point too!

3. **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??

A bell shape or peak.

Very low phosphate results in very short roots, to a peak at 0.1 an 1 and at very high phosphate results in the roots reducing in length.

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

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

Even more lateral roots!

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

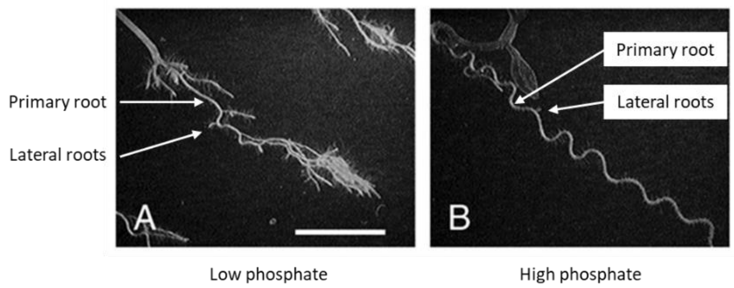
Q: What change in root density do you see when grown in different amounts of Phosphate?

Less root density with increasing phosphate

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

Even less root density

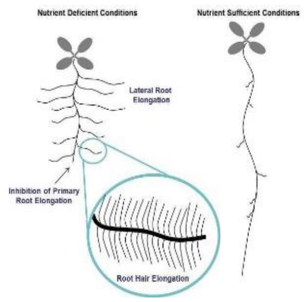
Below are two photographs of plant roots grown in A low amounts of Phosphate. B in high amounts of Phosphate:



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:

Very low Phosphate



Very High Phosphate

Q: Why might the roots look like that in high phosphate?
When there is ample phosphate the root there is less need for lateral roots so doesn't produce them
Q: Why might the roots look like that in low phosphate?
When the plant is growing in phosphate deficient conditions it increases its lateral roots and density to increase the surface area to increase the uptake of phosphate.

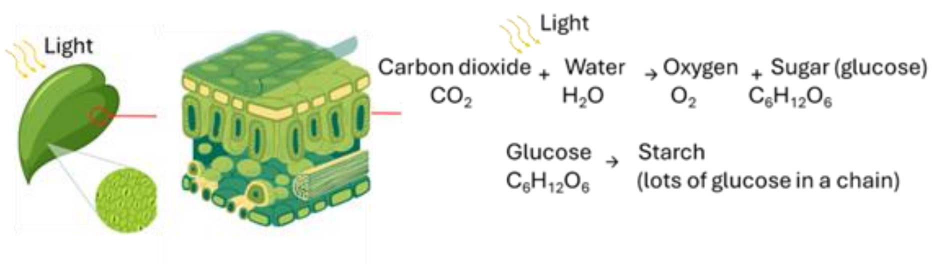
Q: Can you suggest why changes in the cells might help the plants survive?
The plant is using its cells or its root architecture to ensure phosphate uptake and its own survival- regulating its surface area to fulfill its phosphate needs.

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

40 min	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. **Experiment 1: Where is photosynthesis occurring?** **Objective**: To demonstrate that light is necessary for photosynthesis and the subsequent production of starch in plants. Follow the below protocol of this experiment. **Introduction:** Leaf and chloroplast cell are believed to be essential for photosynthesis. Using the diagram remind students of the cellular structure of leaves, chloroplasts and their roles in photosynthesis.  **Research Question:** Is light necessary for photosynthesis - can we prove it? How can knowing about photosynthesis help us in growing 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. And how they might test that? **Materials:** • Potted plant (e.g., geranium or bean plant) with large, relatively thin leaves. A plant that has been actively growing is best. • Aluminium foil or dark paper • Paper clips • Iodine solution (weak solution, diluted with water if necessary) • Dropper • White tile or dish **Method:**	

1 2 + 3 + 4 5 6

1. **De-starch the plant:** Place the plant in a dark cupboard or room for 24 to 48 hours before the experiment. This will ensure starch already present in the leaves is used up before the start of the experiment.
2. **Prepare the leaf:** Select a healthy leaf on the plant. Cover a portion of the leaf with aluminium foil or dark paper, securing it with paper clips. Ensure a significant portion of the leaf remains exposed to light.
3. **Expose to light:** Place the plant in a well-lit area (sunlight or under a grow lamp) for several hours (4 to 6 hours).
4. **Detach the leaf:** Carefully remove the leaf from the plant. This makes handling and observation easier. If you do not detach the leaf, you will be applying the iodine solution directly to the leaf while it is still on the plant. Try not to get iodine on other parts of the plant.
5. **Starch test:**
   - Place the leaf on a white tile or dish (if detached). If the leaf is still attached to the plant, make sure you can lay it down on a stable surface for testing.
   - Add a few drops of iodine solution directly to the leaf using a dropper. Apply the iodine to both the covered and uncovered portions of the leaf. Dark blue-black colour indicates the presence of starch, whereas areas without starch will remain the colour of iodine.
     Potato, flour, and rice are excellent positive controls to demonstrate what iodine starch staining looks like.
6. **Observe and 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).

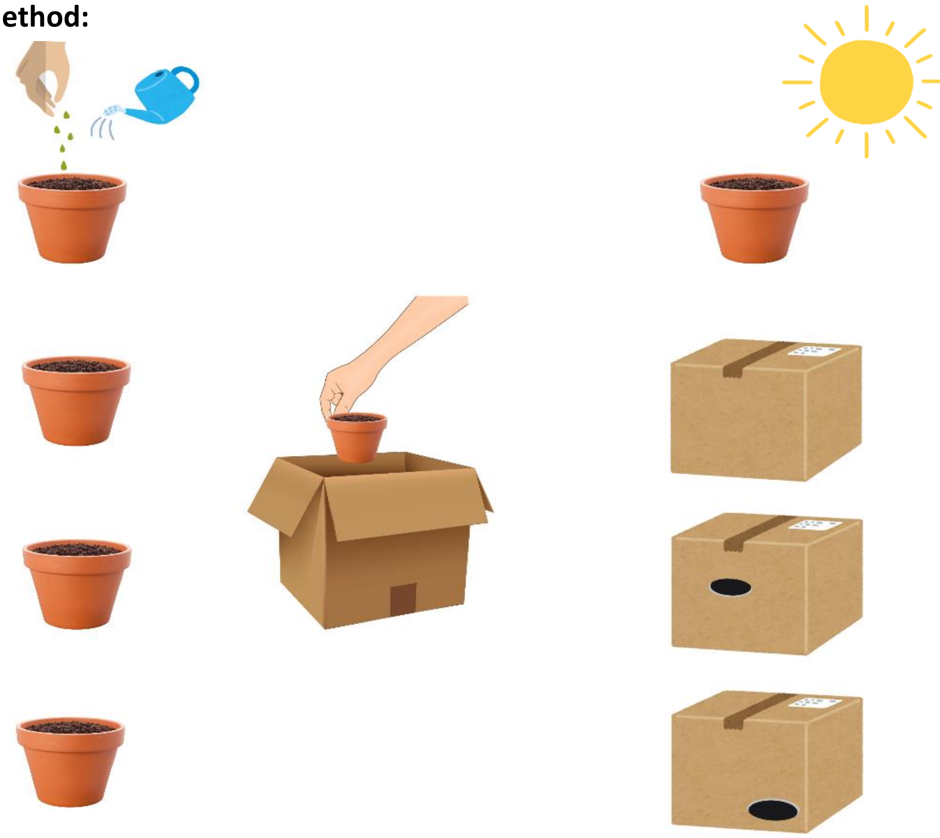
Covered (no light)
= no starch staining
= no starch

Uncovered (exposed to light)
= starch staining
=Starch present

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! **Safety Precautions:** • Wear safety goggles, gloves and a lab coat or apron when working with iodine solution. Iodine can stain skin and clothing. • Avoid getting iodine on your clothes or the work surface. **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 develop sustainable food production 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. **Question:** How does plant growth respond to light? How can knowing about photosynthesis help us in growing food for space travel? **Hypothesis:** Plants need light so will respond to the direction of the light source. They will respond by… **Materials** • Seeds (e.g., bean, pea, or mustard seeds) • Small pots or containers • Potting soil • Water • Cardboard boxes (shoeboxes or similar) • Light source (Optional e.g., a lamp with a fluorescent bulb, alternatively place experiments near a well-lit window • Ruler/protractor/ Camera (optional) (Optional) Take photographs of the plants at regular intervals to document their growth. **<u>BE QUICK</u>! Less than 30 seconds! As you will introduce light into the experiment!)**	

Method:



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.

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

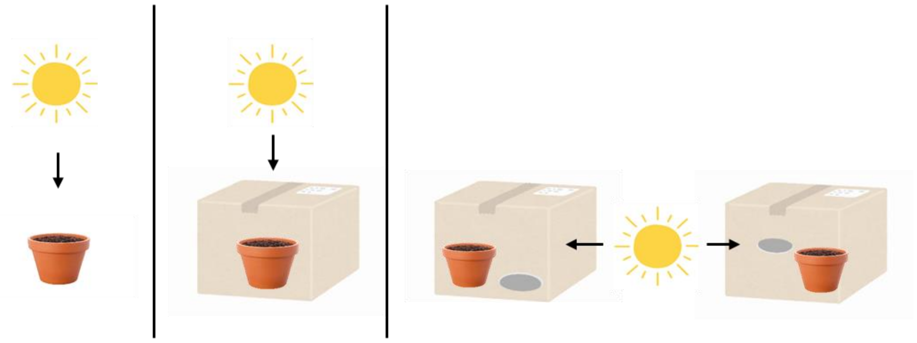
2.Place the pots inside the cardboard boxes with holes.

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

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

Optional additions pots ca
covered with boxes with h
at different positions or h
sizes or multiple holes.

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)? Plants grow straight upwards towards a light source
    - How did the plants that were grow 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 difference in growth of 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 plants grow under light and directed light look different? How might this happen? Light must do something to the cells that make up the stem to direct which way the plant grows. (Light, counterintuitively, 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. (FYI 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 thinks 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...! **3. How do plants roots grow to microgravity?** **Introduction**: International Space Station 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	

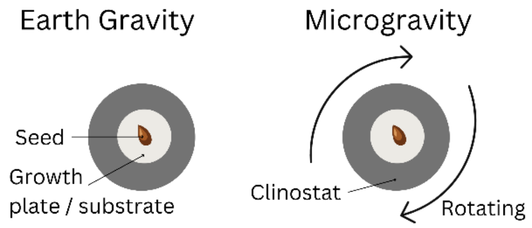
the moon in reduced gravity and compared them to Earth gravity. In preparation for this Plant for Space researchers are growing plants testing them in microgravity by rotating them in a clinostat and comparing them to plants not rotated.

Build a Clinostat build guide
Clinostat Experiment include plate turning alternative

Clinostat build and experiment include turning plates

Question: What is the effect of gravity/microgravity on root growth?

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



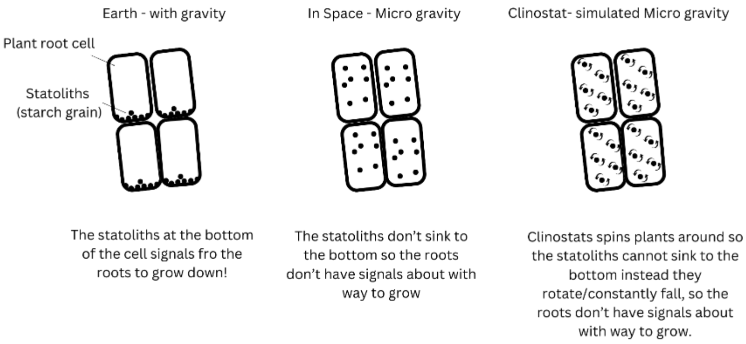
Record:
-Root growth (length of roots and direction of root growth in Earth gravity and microgravity)
-Shoot growth (length of shoots and direction of shoot growth in Earth gravity and microgravity)
-What do you notice?

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.

Space and Plant Roots



Using your data, does it agree with the current theory?
Yes
Explain why you think it does or does not.
No gravity stimuli, statoliths falling to base of cell– no gravity perception showing a loss of roots growing towards gravity and growing in random directions.

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?
We will combine both the light and clinostat experiment to replicate the conditions on the ISS. They will be in vertical farm conditions with artificial directed light, and in microgravity. How might plants on the ISS grow?

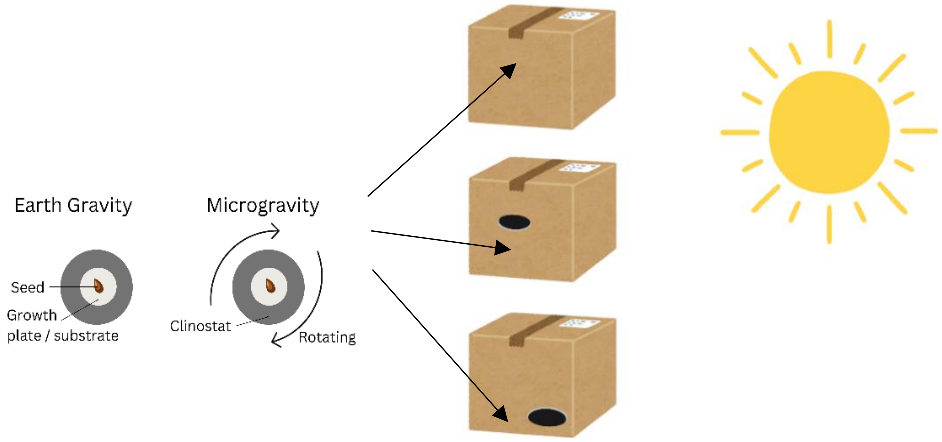
Question: How do plants grow under space conditions such as microgravity and directional artificial light source?

Hypothesis: What I think will happen is….

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

Materials

- Seeds (e.g., bean, pea, or mustard seeds)
- Small pots or containers
- Potting soil
- Water
- Clinostat Experiment set up.
- Cardboard boxes (shoeboxes or similar)
- Light source (Optional e.g., a lamp with a fluorescent bulb, alternatively place experiments near a well-lit window
- Ruler and protractor
- Camera (optional)



Method

Step 1. Set up 6 minimum plants in plates/ziplock bags (as before): Three clinostats and three 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 (minimum three as shown above

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)
3. Full light - no box (control group)
and turn on the clinostats!

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 direction of growth, stem length, and any other relevant changes. Combining the shoot and root length and direction **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. BE QUICK! Less than 30 seconds! As you will introduce light into the experiment!) **Results** a 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 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 groups? **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 on 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 future experiments to investigate 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…	
	Assessment/Performance of understanding **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 do not waste any water, nutrients, or 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. **Check list of things to think about:** -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? -How do plants respond to gravity? What parts detect gravity? -How could you change plant cells to make them even better and more efficient at growing in microgravity in in a vertical space farm?	**Teacher notes and student guide**: Yr 8 cell structure function Assessment /Performance of understanding

	-How do plants reproduce? What parts make fruits? How could you change plant cells to make them even better and more efficient at growing in microgravity in in a vertical space farm? -What would be the same and different in space vertical farm and on Earth farm? -What other ways could we change the cells of the plants to make them more sustainable? **Resources:** Explainers: Readers, Videos, graphics, story cards Independent Internet search	