Plants for Space: Space Bones

Get ready for a plant adventure like you've never experienced before.

Years 3 & 4 Teacher Guide

Australian Government
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ARC CENTRE OF EXCELLENCE

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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.

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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), Defense 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 Melb Uni Botany Foundation.

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Space Bones

Teacher Guide

Australian Curriculum Links

Curriculum Area	Code	Description	Lesson Alignment
Science – Human Endeavour	AC9S3/4H01	Examine how people use data to develop scientific explanations.	Students use experiment data (egg and Cheerios models) to explain bone density changes.
Science – Human Endeavour	AC9S3/4H02	Consider how scientific explanations are used to meet needs or solve problems.	Understanding bone loss in space and solutions such as exercise, nutrition, and plants.
Science – Inquiry Skills	AC9S3/4I01	Pose questions and make predictions.	Predicting effects of vinegar on eggshells and reduced Cheerios density.
Science – Inquiry Skills	AC9S3/4I02	Plan and conduct investigations safely.	Conducting hands-on experiments using eggs, vinegar, and Cheerios.
Science – Inquiry Skills	AC9S3/4I04	Process, model and analyse data.	Modelling bone density using Cheerios and comparing results.
Science – Inquiry Skills	AC9S3/4I05	Evaluate investigations and findings.	Reflecting on experiment outcomes and model limitations.
Science – Inquiry Skills	AC9S3/4I06	Communicate ideas and findings.	Labelling diagrams, worksheets, and class discussions.
Health & Physical Education	AC9HP4P10	Investigate behaviours that contribute to health and wellbeing.	Exploring calcium intake, exercise, and lifestyle choices for bone health.

Suggested Brief Lesson Plan

Driving Problem

Astronauts on a long mission to the Moon or Mars are losing bone strength in space. Your job as a Plants for Space science team is to investigate why bones weaken and design a plant-based solution to help astronauts stay healthy

Students act as 'Plants for Space' scientists investigating why bones weaken in space and how plants might help protect astronaut bone health.

Success Criteria

Students will be successful when they can:
• Explain why bones weaken in space using evidence
• Describe how calcium and exercise affect bone strength
• Design and justify a plant-based solution for astronaut bone health

The 5Es Learning Sequence

Students do not receive explanations at first. They must first generate ideas, test models and revise thinking using evidence from experiments and case studies.

ENGAGE – The Mission Brief

The teacher introduces the challenge: astronauts on a long space mission are losing bone mass. Students view images/videos of astronauts in microgravity and discuss:

• What do bones need to stay strong?
• What might be different in space?

Student actions

Think–pair–share:
What do bones need to stay strong on Earth?
What might change in space?
Students record initial ideas and questions (e.g. gravity, exercise, food).

Suggested Brief Lesson Plan (cont.)

EXPLORE – Investigating the Problem
Students investigate before being told, using the guide's experiments as models of bone processes.

1. Egg in Vinegar Experiment – models calcium loss in bones. Focus Question - What happens when bones lose calcium? Students predict, observe and record changes to eggshells. Teacher prompts students with, 'What does the eggshell represent? What does the vinegar represent?'

2. Cheerios Bone Density Experiment – models bone density and strength. Focus Question - What happens when bone density decreases? Students compare crushed Cheerios at different 'density levels'. Students collect simple quantitative data (counts, percentages). Students are using models, not perfect replicas and must reason about limitations.

EXPLAIN – Making Sense of the Evidence
Students share explanations based on their experiments. The students explain first and then the teacher formalises second.
The teacher introduces scientific language (e.g. microgravity) and links it to student observations.

Student-led Explanation
Groups create a simple explanation (poster or oral) that addresses:
- Why do bones weaken in space
- How calcium and exercise matter

They use evidence from both experiments.

Teacher clarification
The teacher introduces formal terms from the reading such as :
- Bone remodelling
- Microgravity

They then link explanations directly back to student observations.

Explicit Connection
The egg experiment models calcium loss, while the Cheerios experiment models the effects of reduced bone density and bone strength.
Students can then read the reading: Bones and Space

Suggested Brief Lesson Plan (cont.)

ELABORATE – Designing a Solution

Design Challenge:
How can Plants for Space help astronauts maintain strong bones on long missions?
Students use the researcher case studies to develop a solution;

Student Task (group-based)
Each group designs one solution using plants that must:

- work in space
- help bones (increase calcium and bone building)
- be realistic
- be based on research evidence

Design Output (students choose one or decide their own):

- Mission proposal poster
- Annotated diagram
- Short oral pitch to 'NASA"

EVALUATE – Reflecting and Sharing

Evidence of learning can include:

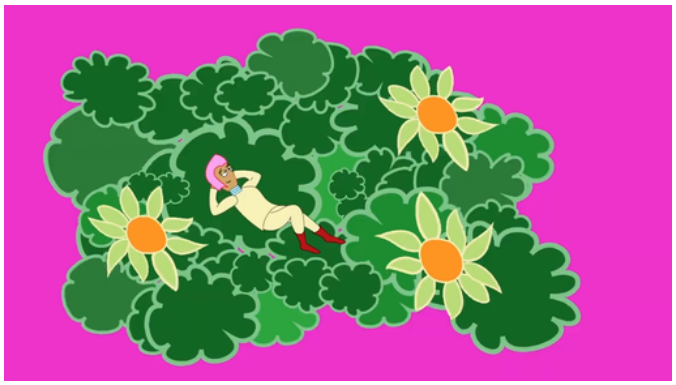
- Science journals
- Experiment diagrams
- Group design solution
- Reflection on learning - Students revisit their original ideas from the beginning of the lesson and identity what evidence changed their thinking.

Extension Activity
Over the course of one week, students can track the foods they eat using a weekly meal tracker, recording items consumed at breakfast, lunch, dinner and snacks, and estimating quantities where exact amounts are unknown. The activity begins by revisiting the key idea that bones lose strength when they do not get enough calcium, linking this to how astronauts must carefully plan their diets in space and how this is also important on Earth. Students then use an age-appropriate online calcium calculator to estimate the calcium content of their meals and compare their daily intake to recommended levels for children their age. The activity concludes with reflection and discussion, where students consider whether they are getting enough calcium, which foods contributed most, and what changes they could make to better support their bone health.

Mission: Plants For Space

Humans are returning to the Moon and even to Mars. To get theer astronauts will travel these very far distances through space for days and months. Space is a very harsh environment for living things and the scientists and engineers will need to make sure the crew members are healthy and happy to complete their mission. Some of the challenges for crew members in space flight include:

- Microgravity
- Living in cramped spaces
- Radiation
- Nutrition



www.youtube.com/watch?v=xTo063Y0roY

Plants for Space
A team of Australian scientists think plants can help astronauts in many ways to explore the corners of the universe. Watch the P4S Video about how growing plants in space might help space travel and farming here on Earth.

Learning Objectives

By the end of this lesson, you will:

- Describe how living in space affects bone health.
- Describe the effects of being in space has on bones.
- Explore why astronauts experience bone loss in space and how they counteract it.
- Conduct an experiment to visualize bone strength and the impact of calcium.
- Explain the role of plants in space can help astronauts and their bones.

Additional Teacher Notes

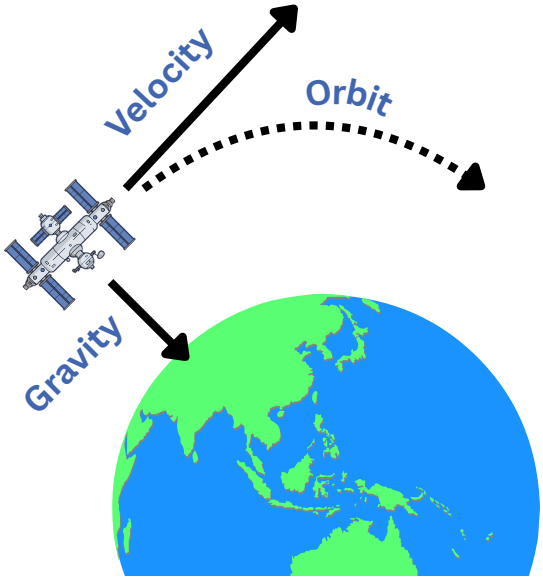
Astronaut Health - Microgravity

Floating In Space

Gravity is everywhere in our solar system, our galaxy, and the whole universe. Bigger objects, like planets, have stronger gravity than smaller objects. Gravity also becomes weaker the farther you are from an object. Astronauts on the International Space Station still experience about 90 per cent of Earth's gravity.

So why do astronauts look like they are floating with no gravity? This is because they are orbiting the Earth. Orbiting means they are moving forward very fast while gravity pulls them towards Earth. They are always falling, but they keep missing the ground because they are moving sideways at the same time. This results in the Astronauts going around and around the earth effectively constantly being in a state of free fall or in microgravity.

Living in microgravity for a long time can affect astronauts' bodies, which is why scientists study how space travel affects human health.



Health Challenges In Microgravity

When astronauts live in microgravity, their bodies undergo significant changes that scientists monitor closely. Without Earth's gravity pulling down on their muscles and bones, astronauts lose muscle mass and bone strength much faster than on Earth, so they must exercise daily to slow these effects. Their bodily fluids also shift toward the head, which can lead to vision changes and pressure on the eyes, and the cardiovascular system adapts in ways that can make returning to Earth's gravity difficult. Other challenges include changes to balance and coordination, effects on the immune system, sleep disruption, and the risk of kidney stones due to altered calcium levels from bone loss. NASA studies these effects so that future missions to the Moon and Mars can better protect astronaut health.

Keegan Barber spent an unexpected 9 month aboard the ISS.

Additional Teacher Notes

Astronaut Health - Bones in Zero Gravity

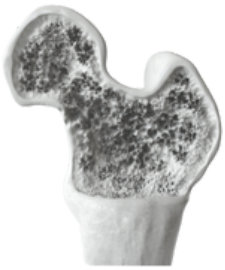
Astronauts experience rapid bone loss due to microgravity, where bones no longer carry the same body weight as they do on Earth. This can lead to a loss of up to 1–2% of bone mass per month.

Bones are constantly breaking down and rebuilding (remodeling). If the diet lacks calcium, the specialised bone cells (osteoclasts) that disintegrate bone will release calcium from bones to keep blood levels stable for critical functions like nerve signalling and muscle contraction. Over time, this reduces bone density, leading to weaker, more fragile bones and osteoporosis.

Mineral loss occurs in space due to physiological changes in the body – The osteoclast cells that disintegrate bone continue to work, but the cells that build new bone (osteoblasts) are less active because they don't receive the mechanical stress signal that occurs in gravity.

Microgravity can inhibit periostin expression in osteoblasts (a protein involved in cell building, repair, and remodelling).

Earth Bones
On earth health bones have many small holes



Space Bones
In space bones large holes form making them weaker.

These lower levels of periostin, in turn, can increase levels of sclerostin (a protein that inhibits bone formation). This process leads to reduced bone volume and thickness.

In addition, hormonal changes influence bone loss. Levels of parathyroid hormone, which regulate blood calcium, for instance, may increase in microgravity.

This increase, if sustained, results in more calcium being released from bones by osteoclasts to maintain blood calcium levels. This also leads to bone density loss. Intermittent administration of Parathyroid can increase bone formation.

Additional Teacher Notes

Astronaut Health - Nutrition and Exercise

The Importance of Astronaut Nutrition

While in the microgravity environment of space, an astronaut's nutrition plays a key role in ensuring crew members' health and performance are at their highest. Microgravity, radiation, and being confined in a small space put a lot of pressure on the human body during space travel. The astronauts' diet and nutrition pay a key role in managing health risks.
Space diets are planned to meet specific physiological (body) needs. Macronutrients—carbohydrates, proteins, and fats—are balanced to give enough energy and maintain body functions. For instance, carbohydrates provide quick energy, while proteins support muscle repair and maintenance, and fats offer a high-energy source. Micronutrients such as calcium and vitamin D are really important to offset bone density loss.

Calcium and Strength

Calcium is to bones what calcium carbonate is to eggshells—an important component for strength. Without enough calcium, the structural integrity of bones deteriorates, just as an eggshell becomes fragile without its calcium carbonate content.

Exercise and Bones

Astronauts not only have to eat well in space but also exercise using special equipment that simulates mechanical stress on their bones.

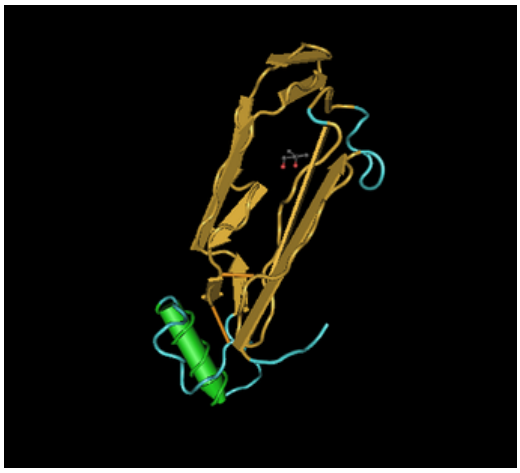
Watch the following video to see how exercise helps astronauts in Space (https://www.youtube.com/watch?v=SPzFwjTTG3g).

Additional Teacher Notes

Astronaut Health - Plants and Bones

Plants not only provide calcium rich foods, they can also be genetically changed to produce hormones (such as parathyroid to stimulate bone growth) that help with bone density.

Plants for Space scientists at the University of Melbourne are also working on changing the genes in strawberries so that they can make a special Bone Morphogenetic Protein 2 or BMP2. This protein is naturally important for bone and cartilage formation. The protein BMP-2 stimulates bone formation and repair by helping change bone cells into bone-building osteoblasts. This technology will be used for bone surgery in space.



Model of Bone morphogenetic protein 2 created using Cn3D from file located at: https://www.ncbi.nlm.nih.gov/Structure/mmdb/mmdbsrv.cgi?form=6&db=t&Dopt=s&uid=13038

There is also scope to use plants in space to treat bone fractures, traditionally used by people around the world. For example, Griffonia simplicifolia has been used in Chinese medicine. It contains a compound (5-Hydroxytryptophan) that increases in the brain the production of serotonin (a neurotransmitter for mood, sleep and melatonin and appetite). This brain serotonin dampens (reduces) other nervous system signals that slow bone formation. With the breaks off, osteoblast activity increases, as does bone formation.

This lesson helps students to explore the effects of microgravity on the structure of human bones in space using eggshells and breakfast cereal. It links to the health and nutrition needs of humans on Earth.

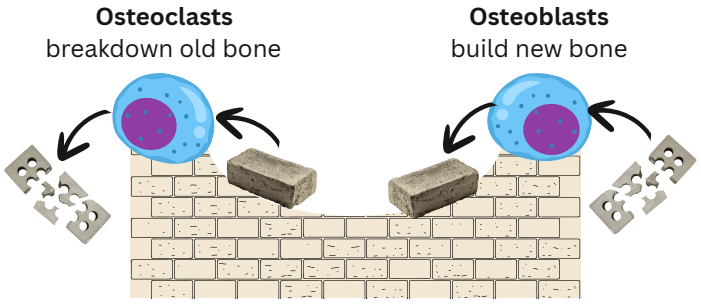
Reading: Bones and Space

Bones are alive. Bones hold a lot of calcium to make them strong. They are continuously being broken down and rebuilt. There are two special bone cells that do this:
Osteoblasts- build new bone
Osteoclasts- break down old bone.

Vitamin D from food and sunlight is needed to help the body build new bone.

Bone Remodeling
If more bone is being broken down than being made, bones get weaker. This can happen with age or illness.

Bone Cells



What Happens to Bones in Space?
In the microgravity of space osteoblasts don't work so well and build bones slower!
So bones get weaker over time. Astronauts can lose bone up to 2% per month! This mostly in the legs, hips, and spine where the body carries most of its weight.

Osteoporosis - Earth and Space
Osteoporosis is a bone disease that results in bones being broken down more than being build up, losing calcium and breaking easily. This is like what happens in space.

How Do Astronauts Protect Their Bones?

Studying bones in space helps doctors learn how to treat bone loss on Earth.

1. **Exercise**: Astronauts do exercises like cycling, lifting, and running on special machines. This helps osteoblasts work and keeps bones strong.

2. **Food**: They eat food with calcium, vitamin D, and protein.

3. **Medicine**: Some astronauts try medicines called bisphosphonates to stop osteoclast cells working and this slows bone loss.

4. **Special Lettuce**: United States researchers have genetically engineered (GE) lettuce leaves to make a human protein (parathyroid) that helps the human body built bones. Astronauts can eat the leaves instead of taking extra medicine.

Why is GM Lettuce Helpful?
1. It grows in space.
2. It is easy to use.
3. It saves space and weight in rockets.
But scientists need to test it more to make sure it's safe.

Reading: Questions

A. True or False circle your answers:
1. Osteoclasts build new bone. True / False

2. Bones need calcium to stay strong. True / False

3. Bones in space break down faster. True / False

4. Vitamin D helps the body use calcium. True / False

5. Astronauts can lose 2% of their bones each month in space. True / False

6. GE lettuce might help stop bone loss in space. True / False

7. Bones are dead and do not change. True / False

B. Short Answer
1. What do osteoblasts do?
Build new bone

2. What happens to bones in space?
They lose mass and calcium, they get more porous and weaker

3. How does exercise help bones in space?
Increase stress/load on the bones, stimulating the osteoblasts to lay down more bone

4. Why could GE lettuce useful in space?
They could be engineered/ genetically modified to produce a protein hormone that stimulates osteoblasts and grows more bone.

5. What is osteoporosis?
A disease of weakening bones and bone calcium loss due to more bone being broken down than being built up.

6. What is one more way astronauts could protect their bones in space?
Medicine, exercise and diet including high calcium and vitamin D

Bones in Space Experiments

Question 1: What happens when bones lose calcium and become thin?
(Egg shell observation)

Background
Bones in space break down more than they build up and this results in bones losing calcium. Egg shells contain lots of calcium like healthy bones. We are using the eggshells to represent bones. The acid (vinegar) will remove calcium from the shell, just like bones without enough calcium nutrition or when in microgravity.

We can observe what happens to the egg shell when we remove calcium. We can make predictions and conclusions about the effects that space might have on human bones. Scientists do this all the time; it is called a model. For example, researchers at Plants for Space are making protein medicines in strawberries that will mend bones during surgery (encourage bone making). They are using models from other scientists to try and work out how to put the gene (code to make the protein) into the strawberry.

Materials for each pair/group
· Two raw eggs in their shell
· A transparent glass or container
· A bottle of vinegar

Method
1. Place one egg in a glass and submerge in vinegar (to stimulate 'weak bones')
2. Leave the other egg out to represent a healthy bone
3. Leave both eggs for 36- hours (you could change the vinegar after 24 hours)
4. Remove the egg from the vinegar

Results
1. Examine the egg that has been left in vinegar. Describe what you see:
Calcium rich shell is removed to reveal a soft translucent membrane

2. Compare the vinegar-soaked egg to a regular egg: What happens when you gently press the soft egg?
The regular egg has a hard shell and keeps its shape. The soft egg is squishy and elastic.

3. Discuss: How does this experiment relate to what happens to bones in space?
The eggshells represent bones. The acid (vinegar) will remove calcium from the shell. This is just like what happens to bones when you don't eat enough calcium and vitamin D. It is also what happens in microgravity when more bone cells destroy old bone, rather than make new bone, and overall bones lose calcium.

Question 2: How much weaker are astronauts' bones when they get thin and lose calcium?
(Cheerios Bone Density Experiment)

Materials:
· 200 Cheerios
· 3 plastic sandwich bags
· Scale (if available)
· Heavy book

Procedure:
1. Place 200 Cheerios (or 40g) into a plastic bag.
2. Subtract 40% (remove 80 Cheerios or 16g) and place in another bag.
3. Subtract 60% (remove 120 Cheerios or 24g) and place in a third bag.
4. Press each bag with a heavy book once.
5. Count and record the number of unbroken Cheerios.

Watch the video to follow instructions
(https://youtu.be/zK-1WRDJA2c)

Results Table:

Bag	Number of Unbroken Cheerios	Percentage Cheerios after Experiment	Change in Percentage
100% (200) Cheerios	e.g. 180	e.g.90%	e.g. -10%
60% (120) Cheerios	90	75%	-25%
40% (80) Cheerios	45	56%	-44%

Discussion Questions:

1. What did you notice about the number of unbroken Cheerios in each bag?
   How did the percentage of cheerios change?

Was there any difference between the percentage of cheerios in each bag and the final percentage of cheerios?

The greater number of Cheerios in the bag, the higher number and percentage of unbroken Cheerios.

2. What is happening in bones in space to make bone density less?

The lack of gravity means that there is less mechanical stress on bones, which slows down the bone-making activity of bone cells, but the bone reabsorption remains the same. This results in bone density loss.

3. How does this experiment model bone density loss in space and on Earth?
   What conclusions can you make about any changes in bone density?

Fewer cheerios represent a loss in bone density and calcium in bones. The structure of cheerios and bones are weaker when they are less thick.

Conclusions:

1. Draw below the difference in bone structure before space travel and after space travel

There should be two pictures both outlining two bones- one before and after.
The diagram of bone after space travel should look more porous or with less bone material (less dense).

2. What did you learn about how bones are affected in space?

Bones are constantly broken down and remodelled and contain calcium. They weaken over time spent in space due to the lack of gravity which results in more bone being broken down than remodelled. This changes bone density.

Question 3: How might researchers at Plants for Space help space bones?
Space bones are a problem for long space journeys. Below are examples of studies being done by Plants for Space researchers. Use these studies to explain how Plants for Space can help astronauts maintain strong bones.

How would you use plants in space to help astronauts maintain strong bones?

Making super nutritious Duckweed

Chigozie from the University of Adelaide is working on making Duckweed a nutritional powerhouse.

They could eat healthy and nutritious food to increase the calcium intake. This could help reduce bone loss and weakness.

Making Chloroplasts become biological factories

Leni from the University of Western Australia is using the green part of plants - chloroplasts - to make different proteins that could help with astronaut nutrition and health.

They could get chloroplasts in leaves to make proteins that encourage bone growth and eat the leaves.

Using the environment to make food more nutritious

Jiayue from the La Trobe University is working out the best amount and type of light, temperature, plant growth material and fertilizer to grow the most nutritious tomatoes.

They could use the best growing variables to grow tomatoes rich in nutrition and calcium.

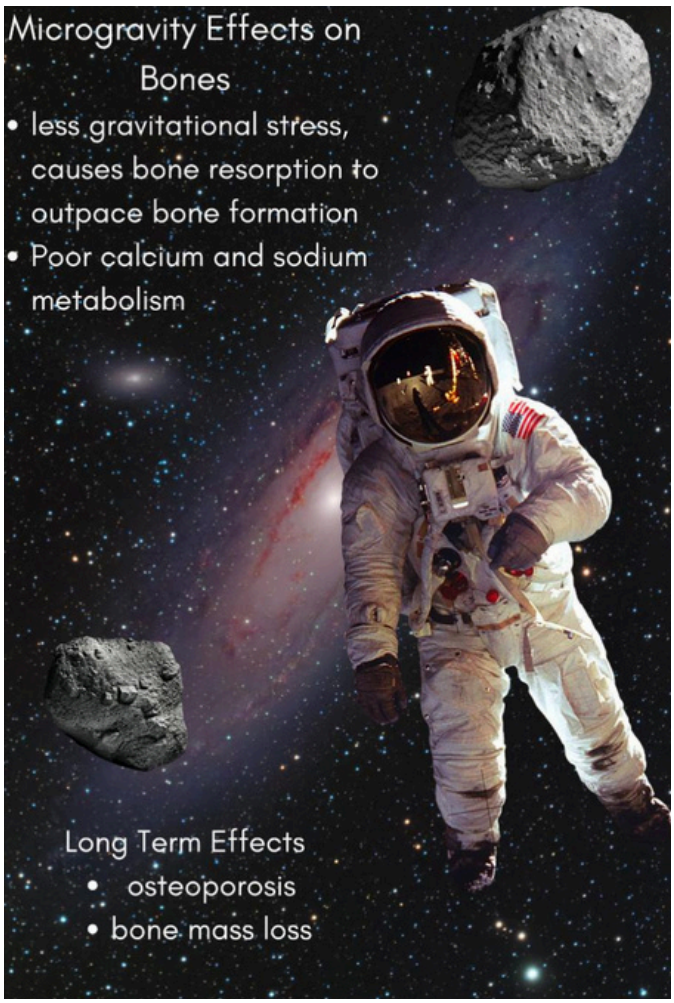
Bone stimulating hormone in plants

Ryan from the University of Melbourne is changing the DNA of strawberry leaves, engineering them to make a bone-building protein.

They could use the medicine (that encourages more bone growth) from the leaves to reduce bone loss.

Extension Activity
Are you eating enough calcium for bone health?

You have learned in the Bone Health in Space lesson that calcium is needed for bone building. You also learned that not enough calcium can lead to long-term health problems, such as bone density loss, causing weaker bones and osteoporosis (changes in bone to make them more 'porous' and brittle).



Track your calcium content in food for the next week to see if you are eating enough calcium.

- Fill out the weekly meal table on the next page, writing down the food and quantities of it under breakfast, lunch, dinner and snacks (estimate amounts if you have to).

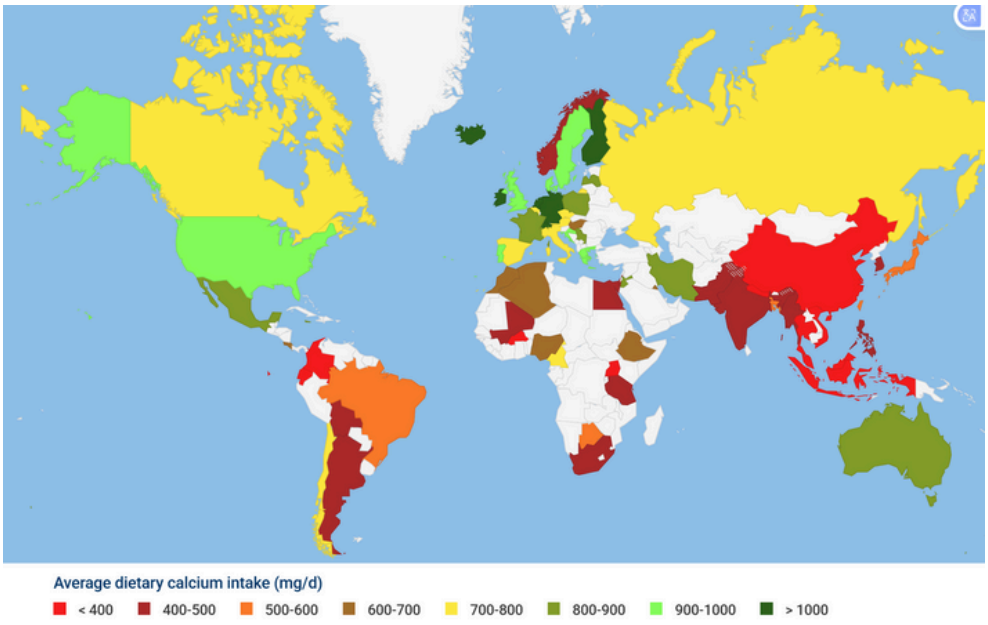
- Use the International Osteoporosis Foundation calculator to work out how much calcium was in each meal.

https://www.osteoporosis.foundation/educational-hub/topic/calcium-calculator)

Weekly Meal Tracker

Day	Breakfast	Ca?	Lunch	Ca?	Dinner	Ca?	Snacks	Ca?
Monday								
Tuesday								
Wednesday								
Thursday								
Friday								
Saturday								
Sunday								

Compare your daily (mg/d) intake of calcium with world standards on the International Osteoporosis Foundation's Calcium Map (https://www.osteoporosis.foundation/educational-hub/topic/calcium/calcium-map)



Does your calcium intake meet recommendations?

Go to the *International Osteoporosis Foundation Recommended daily calcium intakes page* (https://www.osteoporosis.foundation/educational-hub/topic/calcium/calcium-recommendations) to find out if you meet the recommendations for calcium intake.

Recommended daily calcium intakes (IOM, NAM)		
	Age	**Calcium Recommended daily Intake (mg/day)**
Infancy to Adolescence	0-6 months	200
	6-12 months	260
	1-3 years	700
	4-8 years	1000
	9-13 years	1300
	14-18 years	1300
Adulthood	19-50 years	1000
	51-70 years	Females 1200 Males 1000
	Over 70 years	1200

- Find out whether you are getting enough of this important mineral in your daily diet, using the IOF Calcium Calculator.
- Read more about calcium in our Calcium Fact Sheet.

Assessment Rubric

Years 3-4 Rubric

Aligned with Science: AC9S3/4H01, AC9S3/4H02, AC9S3/4I01, AC9S3/4I02, AC9S3/4I04, AC9S3/4I05, AC9S3/4I06
Health and Physical Education: AC9HP4P10

Criteria	Exceeding (A)	Meeting Expectations (B-C)	Developing (D)	Emerging (E)
Understanding Science Concepts (Links to AC9S3/4H01, AC9S3/4H02)	Explains clearly why bones weaken in space and compares them to bones on Earth, linking to data or examples.	Describes that bones get weaker in space and need calcium and exercise.	States that bones can change in space but doesn't explain how.	Gives limited or incorrect information about bones.
Inquiry and Observation (Links to AC9S3/4I01, AC9S3/4I02)	Independently asks relevant questions, follows procedures safely, records accurate observations, and links results to bone strength.	Completes experiments with support, makes simple observations, and relates findings to bone health.	Participates in experiments but needs help to make or record observations.	Participates with support but does not record or discuss results.
Data and Analysis (Links to AC9S3/4I04, AC9S3/4I05)	Organises and interprets results effectively, drawing logical conclusions about how gravity affects bones and suggesting improvements to the experiment.	Records and discusses basic results, identifying simple patterns in bone health or strength.	Records results but does not explain what they show.	Limited or inaccurate data recorded or discussed
Application to Health and Wellbeing (Links to AC9HP4P10, AC9S3/4H02)	Explains how astronauts and people on Earth can keep bones strong through balanced diet, exercise, and safety behaviours.	Identifies food and exercise that help bones stay strong.	Lists foods or activities but not linked to bone health or wellbeing.	Gives limited or unrelated ideas about health.
Communication and Representation (Links to AC9S3/4I06)	Clearly labels diagrams, uses accurate scientific and health terminology (e.g. calcium, bone density, gravity), and communicates ideas confidently.	Uses simple terms and drawings to show understanding.	Uses few scientific words and unclear drawings or descriptions.	Limited or no attempt to communicate ideas visually or verbally.
Engagement and Reflection (Links to AC9S3/4I05, AC9S3/4I06)	Shares thoughtful reflections on learning, explains what was most interesting or challenging, and connects findings to real-life situations.	Shares ideas about what was learned in class discussions.	Responds to questions with short or partial answers.	Needs support to engage in reflection or discussion.