PUPIL RESEARCHER INITIATIVE

Plants in Space

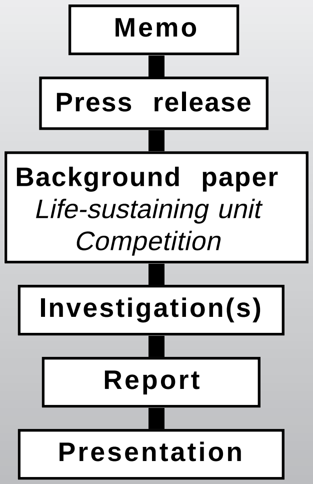
Pupil Research Brief

Teachers' Notes

Syllabus Coverage *Subject Knowledge and Understanding*

- ❒ green plants photosynthesise when it is light
- ❒ during photosynthesis light energy is absorbed by chlorophyll, found in chloroplasts in some plant cells
- ❒ this light energy is used to convert carbon dioxide and water into sugar (glucose)
- ❒ oxygen is released as a by-product
- ❒ the rate of photosynthesis is limited by low temperatures, shortage of carbon dioxide and shortage of light
- ❒ for healthy growth plants need a range of mineral ions
- ❒ the body needs a balanced diet to remain healthy
- ❒ the more active people are, the more carbohydrate and fat they need for energy

Route through the Brief



Introduction

In this Brief pupils take on the role of research scientists in a university department of bioastronomy. They are asked to carry out some preliminary work to use in a competition to design a life-sustainng unit for use in a crewed flight to Mars. They are asked to carry out investigations into various aspects of photosynthesis, to work out what plants could best be used in the life-support system, and into human physiology to work out what needs a crew would have for oxygen and food on the journey. The Brief is based on an article which appeared in *New Scientist* in the Spring of 1996. All the research activities mentioned in the background paper are real, as are the research institutions cited.

Experimental and investigative skills

- planning experimental procedures
- obtaining evidence
- analysing evidence and drawing conclusions
- evaluating evidence

Prior knowledge

Before attempting this Brief pupils should have covered some basic work on photosynthesis and methods for measuring the rate of photosynthesis, but this can be taught during the unit.

Pupil Research Brief

Teachers' Notes continued

Running the Brief

Pupil grouping

Pupils can work in a number of groupings during the Brief. Suggestions are:

Initial briefing, memo and press release	-	whole class; teacher introduces the topic and sets a context for the activities
Background paper Life-sustaining Unit Competition	-	whole class or small groups
Carrying out investigations and other research	-	pairs, threes or fours (depends on availability of equipment)
Report	-	small groups, or individuals if the work is to be assessed
Presentation	-	each group presents their results to the whole class.

Timing

This Brief involves pupils carrying out a number of investigation. This work could take 3 to 5 hours of classroom time, depending on how many investigation and research tasks are done.

Activities

The teacher should issue pupils with the **Study Guide** which provides pupils with a summary of what they should produce as they work through the Brief. It can also be used as checklist so that they can monitor their own progress. The director of the research team (the teacher) issues the researchers (pupils) with the **memo** and **Press release**. These set the scene for the work the pupils will be doing. The background paper **Life-sustaining Unit Competition** should then be issued. Teacher and pupils go through this paper, which gives details of the real work that is being done to develop the life-sustaining unit for a crewed Mars mission. The handwritten notes in the margins of this paper provide a series of investigations and other activities which pupils could do. The teacher allocates tasks to pupil groups. Alternatively, the teacher could select a series of investigations which all pupils should carry out in sequence. The Brief covers a number of key investigations on the topic of photosynthesis, which, taken together, form a stimulating way to tackle parts of this topic. Following their investigation(s), pupils are required to write a report of their work. A nominated member of each group should provide feedback to the whole class during the plenary session.

Investigation details

A key investigation in this Brief is into the factors which affect photosynthesis. The background paper mentions that a research team is trying to develop the use of flashing LEDs to illuminate plants. Pupils should investigate the effect of colour (wavelength of light) on the rate of photosynthesis. Since LEDs come in red, green, blue and yellow, these colours should be chosen for the investigation. Pupils do not need to use LEDs for the work. They could illuminate pondweed (*Elodea canadensis*) with light from a lamp fitted with a filter. Different pupil groups could investigate different colours. Before carrying out these experiments the pupils should design a standard method, so that the work of different groups can be compared. An important factor to control is the light intensity for each of the colours of light being tested.

The other tasks and investigations mentioned are:

A dietary analysis for eight people on a space mission
This would be based on researching into secondary sources.

Methods for recycling water
Pupils could investigate ways to evaporate and condense water. Although not strictly a biological investigation, it provides a context-based approach to the water cycle.

How physical activity affects oxygen consumption and carbon dioxide production
This could involve using a spirometer, or calibrated breathing bag, to measure breathing rate and tidal volumes when a pupil is at rest and during different levels of activity.

The combination of nutrients needed to be supplied for healthy plant growth
This provides a context for carrying out hydroponics experiments.

The effect of light intensity on the rate of photosynthesis
Pondweed under different light regimes.

The effect of light and dark periods on plant development
Research into secondary sources on the need for light

Pupil Research Brief

Teachers' Notes Continued

and dark periods of certain lengths to cause the onset of flowering. The need for dark periods will affect the potential for oxygen production.

The effect of CO_2 concentration and temperature on plant growth
Pondweed in water containing various amounts of sodium hydrogen carbonate, which provides plant with CO_2. Temperature can be varied using ice baths, room temperature and a range of temperatures created by using water baths.

The range of plants needed for a balance between protein production and efficient photosynthesis
This is a link back to the activity to design a diet for the long space trip. If the spacecraft is taking food plants along to supply the crew, what are the best plants to produce a balanced diet? This is likely to be a secondary source search, most likely involving diet tables.

A note at the end of the paper asks for any further suggestions for investigative work. Pupils may suggest testing a range of food plants to see which ones are the most efficient at photosynthesising. This may not produce conclusive results, but it could be a worthwhile experiment to try - if only to show that sometimes scientists do not get definite answers.
One possible approach would be to illuminate various food plant leaves (as fresh as possible) in a closed environment with a CO_2 indicator (such as bicarbonate/indicator solution).

Safety issues

PLEASE NOTE: It is also important that you prepare your own risk assessments for the practical work in this Brief in the usual way.

Many suggestions for independent pupil investigations are contained in this Brief.

All pupil plans should be subjected to check and risk assessment by the teacher before being allowed to proceed.

Assessment issues for *Experimental Investigative Science* (National curriculum for England and Wales, Northern Ireland Curriculum)

Depending on the activties carried out by pupils, the full mark range for **Skill Areas P, O, A and E** should be available.

Scottish syllabus coverage

Standard Grade Biology - *World of Plants, Body in Action.*

PUPIL
RESEARCHER
INITIATIVE

Plants in Space

Setting the Scene

You will be working as a researcher in a university department of bioastronomy. You are part of a team that is putting in a proposal to win a contract to design a life-sustaining unit for a spaceflight to Mars. You and your colleagues will carry out some research into photosynthesis, and seek out other information about dietary needs and energy requirements for astronauts during their mission. You will then write a report of your findings to present at a seminar.

Pupil Research Brief

Study Guide

Syllabus Targets *Science you will learn about in this Brief*

❒ green plants photosynthesise when it is light

❒ during photosynthesis light energy is absorbed by chlorophyll, found in chloroplasts in some plant cells

❒ this light energy is used to convert carbon dioxide and water into sugar (glucose)

❒ oxygen is released as a by-product

❒ the rate of photosynthesis is limited by low temperatures, shortage of carbon dioxide and shortage of light

❒ for healthy growth plants need a range of mineral ions

❒ the body needs a balanced diet to remain healthy

❒ the more active people are, the more carbohydrate and fat they need for energy

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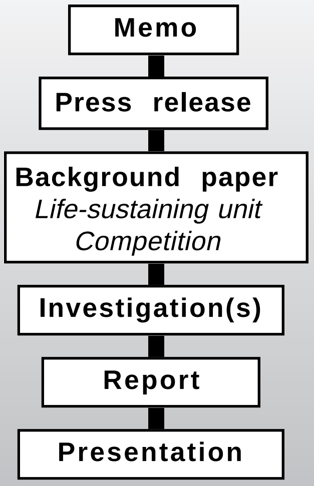

Outcome Checklist

You will carry out one or more investigations or written tasks, and produce a written a written report of your findings. This will be presented to the rest of the class. You should make sure you produce the following items as you work through the Brief

Press release and background paper

❑ investigation plan

❑ investigation report

❑ presentation

Department of Bioastronomy

Memo

From: Jan Sorensen
To: Research teams
Subject: Space Agency 'Life-sustaining Unit' competition
Date:

I have just got the details of a new Space Agency project to develop plans for a Life-sustaining Unit for use on possible future space flights. It seems that the Agency has decided to hold a world-wide competition to produce the best design for a life support system for use on long space flights. Astronauts on such flights will need food, water and oxygen supplies for journeys of 2 years or more. The winning team would get the job of designing the system, and developing the technology to go with it. I think that we should have a go - we have some good staff who are imaginative and hard working. I am sure we would have a good chance of getting the final contract. Your job will be to provide advice and ideas about some of the biological issues, e.g. getting maximum oxygen and food production from the plants taken on the spacecraft, and relating this to the needs of the crew. The Space Agency project was announced by a press release, which I obtained from their WWW site, along with further details of the competition. The main item I downloaded was a background paper which I have printed off for circulation in the department (copy attached).

I have looked through the paper and made some notes in the margins about possible investigations and background research we could carry out. Doing this work will help us get to grips with some of the problems we will need to consider when we begin drawing up the design proposal. Perhaps these could be shared out amongst the team. You will need to:

- read through the press release and background paper
- select one or more of the issues I have highlighted and carry out any necessary background research or investigations
- produce a report of your findings
- attend a meeting where the results of the various investigations can be discussed.

At this meeting we will start thinking about putting our ideas together to design the Life-sustaining Unit.

Press Release - from the Space Agency

Space Agency calls for design proposals to develop a Life-sustaining Unit for use on crewed space flights to Mars and beyond.

The Space Agency is pleased to announce a competition, open to all institutions eligible for Research Council and Agency funding, or their overseas equivalents, to design a Life-sustaining Unit for use on crewed space flights of over two years duration. The competition will result in a short-list of 10 designs, which will form the main feature of a major public exhibition to be held in one year's time to celebrate the imagination, creativity and capability of the world's scientists and engineers. The winning design will be chosen by a team of international scientists and engineers, and announced at a press conference during the final day of the exhibition. The winning team will be awarded a contract to carry out further research, and to produce a working prototype of the Life-sustaining Unit.

The design of a Life-sustaining Unit will be the first step on the road to the achievement of a space flight to Mars carrying astronauts. Following the first crewed space flight in 1958, and then the first crewed Moon landing in 1969, going to Mars represents the next major milestone in the history of human exploration of space.

Further details can be obtained from the Space Agency Home Page.

Space Agency

I have written some ideas on this paper which you might like to follow up

Life-sustaining Unit Competition

Producing the most effective design for a Life-sustaining Unit for use on crewed space flights to Mars and beyond.

At the moment no such mission is planned, but it is inevitable that it will happen during the next century. The recent discovery of structures with a possible biological origin on a meteorite which came from Mars has increased this possibility.

To provide visitors to our Web site with some background, we have produced the following information which sets out some of the key issues in the design of a Life-sustaining Unit.

Creating a Life-sustaining Unit for astronauts on a mission to Mars.

1 Introduction

In every space mission so far carried out all materials needed to sustain the astronauts (food, water, oxygen) have been sent up with the crew. Getting large masses out of the Earth's gravity is very expensive. The longer the mission, the bulkier the payload. There comes a point when the cost of sending up all the food and oxygen needed (water is recycled) is greater than the cost of installing a self-sustaining biological supply system on board the spacecraft. It is calculated that the break-even point is two years. For flights of less than this time, it is cheaper to send the food and oxygen up with the astronauts.

We need a full dietary-needs analysis for 8 individuals on an 800 day journey in space - total the amounts of nutrients, energy needed etc - list the factors which could affect the totals, and **how** they would affect them.

You could come up with and try out various methods for recycling water

For flights longer than this it is cheaper to build a supply system on the space craft. Space missions to Mars will take over two years to complete, and so the Space Agency is seriously considering the possibility of putting a balanced ecosystem, or Life-sustaining Unit, into a Mars-bound space craft, to provide the crew with all the food and oxygen they will need for the flight. It is vitally important to control such an ecosystem precisely, supplying energy in finely judged amounts so that as little as possible is wasted, and using plants that will provide the highest possible yield of food and oxygen from the minimum amount of light and nutrients.

2 Growing Plants in Space.

a Growing medium

An adult human requires, on average, 602 litres of oxygen a day. So, plants used on the space craft must be as efficient as possible at photosynthesis in order to supply the oxygen needed by the crew of the space craft. The plants will not be grown in soil, but instead, a newly developed soil substitute will be used. The material contains all the nutrients plants require and it releases them in controlled amounts, thus making it much more efficient at supplying minerals than ordinary soil.

Can we produce data on how physical activity affects oxygen consumption and CO_2 production - what, apart from physical activity, will affect these levels?

What combination of nutrients needs to be supplied to plants for healthy growth? You could also look at the types of growth mediums which could be used,

b Light

The greatest technical problem is supplying plants with enough light. The Life-sustaining Unit will be powered by panels of photovoltaic cells (solar cells) which will produce electricity. Some of this electricity will power banks of electric lights which illuminate the plants. Plants will use the light energy to photosynthesise, making both food and oxygen for the astronauts.

Each stage in this chain of energy transfers is inefficient. Light is first converted to electricity by the solar cell. This is then converted back into light by the electric lights. Finally, light is converted into chemical energy in plants during photosynthesis. Even under greenhouse conditions, only about 7% of the light arriving at a plant leaf will be used in photosynthesis. This is partly because chlorophyll molecules in the leaf's cells can only process one photon of light at a time. Any other photons arriving at a chlorophyll molecule when it is busy dealing with the last one will be wasted.

How does light intensity affect the rate of photosynthesis?

Do plants need a period of dark during each 24 hour period in order to develop? If they do, what are the implications for oxygen supply to the crew?

Scientists at the European Space Agency in Belgium have suggested using lights that flash on and off very quickly, between 2000 and 12000 times a second. This leaves a gap between the photons arriving at a chlorophyll molecule, allowing enough time for the molecule to be ready to receive its next packet of energy. The only light source which can switch on and off as rapidly as this are LEDs (light emitting diodes). These have the advantage of being very long lasting and using very small amounts of electrical energy. LEDs emit red, blue, green or yellow light, depending on the material used when they are made.

What colour of the spectrum will produce most photosynthesis? - and could plants survive on Mars where the light was mainly at the red end of the spectrum?

c Type of plant

The plants in the Life-sustaining Unit need to be both nutritious, providing the right nutrients to keep the crew healthy, and efficient at photosynthesis so that the maximum food production occurs. One square metre of vegetation supplies between 30 - 31 litres of oxygen per day. Scientists need to know the best growing conditions in which plants can thrive on the long journey to Mars, to ensure that this rate of oxygen production is maintained or improved.

Which plants will produce most food and oxygen given the same amount of light and heat?

The optimum temperature and carbon dioxide levels also need to be studied for the maximum growth of the plants to be obtained.

It is likely that only a limited range of plants can be grown on board, and this could cause problems for the crew. The prospect of having only three or four different vegetables to eat as your entire diet for more than two years would be very unappealing. This is why food scientists at Rutgers University, New Jersey, USA, are developing a machine that can produce food products with a range of textures, colours and flavours. This should help to prevent the diet from being too monotonous.

What are the optimum CO_2 and temperature levels for plant growth?

Since only a small range of plants can be grown, it is important to strike a balance between efficient photosynthesisers, and ones which produce useful amounts of protein. What range of plants do you think would be needed?

Conclusion

The problem of providing a self sustaining environment for a crew of up to eight astronauts on a mission to Mars and back are formidable. The alternative is to send up two year's (and more) supplies of concentrated food and bottled oxygen with the space craft. The cost of doing this would be enormous. It is extremely important that a study is carried out into the most effective way of cultivating the plants that will be needed on the flight. A self sustaining ecosystem will make it possible for human beings to visit the only other planet in our Solar System we could land on safely - Mars.