Science Beyond the Boundaries

**The commercial exploration of space: land base on Mars**

**Teacher notes**

**Intended learning outcome**

Students understand the risks, costs and potential benefits for different parties involved in a commercial exploration of space; and why decisions about scientific and engineering solutions need to take account of expert opinions from a range of other disciplines.

***Commentary:***

Humans have been sending objects and people into space since the 1950s, mainly through government-funded space programmes. Over the last few decades, a strong and rapidly growing commercial space industry has been developing, particularly in the United States. This is being achieved, in part, through deliberate US government policy. NASA’s dominance in the sector is being used to develop forms of collaboration with new commercial actors that lowers the barriers of entry into the industry, encourages innovation, and creates investment opportunities for venture capitalists and others.

NASA now focuses less on developing its own technology and products and more on contracting this work out. It often posts innovation challenges online, in open competitions, to encourage innovation. It increasingly enters into fixed price contracts with the successful entrants. These contracts give new companies security to attract investment and encourages them to improve efficiency and to find lower cost solutions in order to maximise profit.

The *Mars Exploration Program* is a long-term effort to explore the planet Mars that is funded and led by NASA. One aim of the programme is to prepare for the human exploration of Mars. Already a range of companies are developing technology and products that could make such a venture possible. Amongst these are some working on ideas for an orbiting space base around Mars and others on ideas for a small settlement on the Martian surface.

Much thought needs to be put into how humans can live and work for long periods in isolated environments in space. The journey each way to Mars is likely to take between six and eight months and the occupants of a space craft making that journey would be together for all of that time and have no form of escape from each other. An orbiting space station or base on Mars would be little different.

Scientists and engineers are developing technology and equipment to overcome the technical challenges involved, but the solutions they find will need to satisfy not only the physical needs of humans, but also their social, behavioural and psychological needs. Some ways of engineering space environments could potentially exacerbate difficulties in these areas and other strategies could mitigate or alleviate them. The best designs for space environments, in which humans can live and thrive, are most likely to be developed by a wide range of scientists and engineers together with experts in other fields.

**Outline of teaching unit**

For this unit, students start off working individually to design a land base on Mars that would support an exploratory community on the surface of the planet. One design is chosen, which is perhaps modified using ideas from others, and aspects of the design are ‘put out to tender’ to groups within the class with an ‘expert’ group developing a proposal for each aspect.

The proposals are worked up by each group and are presented to the class who question and evaluate each one against the original specifications.

This process models the practice of the USA government, working through NASA, to support the development of a thriving space sector in the United States.

**Bold sections are classroom-based activities,** those not in bold can be completed either in or out of the classroom.

**Phase 1.**

**Introduce tasks for phase 2: A competition is launched for the design of a land base on Mars to support an exploratory community on the planet. Students will be asked to individually design a Mars base, using whichever format they wish to, that will be ready to be judged during phase 3 of this unit.**

**To prepare students for the competition, they complete several activities that explore some different considerations that they will need to think about for the design of their base.**

Phase 2.

Students each create their own design for a Mars base ready to present to others. This can be in whatever form they wish. It could be: a written description; a labelled picture or diagram; a computer model; a physical model; or an animation. In their design, students should show how each of the different needs identified in phase 1 can be met.

**Phase 3.**

**In groups of about five, students each present their design and the best one in each group is selected. The winning design from each group is presented to the class and the class select the best of these, which is the one they will all work on for the rest of this unit.**

**The students are now reformed into ‘expert’ groups and each group is asked to develop a commercial proposal to develop one aspect of the space settlement:**

* **Food production (biology)**
* **Power generation (physics)**
* **Oxygen generation (chemistry)**
* **Lay out of the base and social organisation (sociology, psychology)**
* **Governance and jurisdiction (politics, history, sociology, psychology)**

**The subjects in brackets indicate how the subjects that students are studying might be used to identify which ‘expert’ group they could be placed in.**

**During this phase each group will complete an activity that provides support for the development of their proposal, which includes a series of tasks that should be completed by members of each group during phase 4.**

Phase 4.

Individuals complete the tasks allocated to them at the end of phase 3, in order to enable the development of good commercial proposals during phase 5.

**Phase 5.**

**At the start of this phase students are formed into new groups that each have a range of experts from as many expert groups as possible. They then have 30 minutes to use their combined expertise to develop a proposal ready for presentation to the rest of the group.**

**One or two members of each team present their proposal to a small group of students from other teams – with the opportunity for Q and A. Questions should focus on the specification set out in each tender, which is provided for students. This is repeated once, so that each proposal is presented to two different groups of students.**

**Students then go back to their groups and rank the other teams’ proposals, and write two positives and an improvement to each one (to feedback to the teams). Evaluation focus on effectiveness; ease of use; safety; fail safe mechanisms / back-up systems; and commercial viability.**

**The best proposal can be worked out from the lowest cumulative ranking score from the class.**

***Activities for each of the five phases of learning***

Phases 1, 3 and 5 are classroom based; and phases 2 and 4 can be completed either in the classroom or independently out of the classroom.

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| **Activity** | **Phase** | **Reason for it** | **Activity summary** | **Estimated time** |
| 1 Introduction. | 1 | To introduce the unit and to launch a design competition. | Short review of some benefits and risks of commercial exploration of space; and an introduction to a design competition that will be completed in phase 2. | 15 minutes |
| 2 Land base on Mars. | 1 | Stimulus material, used to identify needs for a land base on Mars and some challenges to be overcome. | Video footage (YouTube links) of a potential land base on Mars from different perspectives. | 20 minutes |
| 3. Priorities for a land base on Mars. | 1 | To identify a range of needs that must be met in a land base on Mars and to consider what compromises might be acceptable. | A card sort with follow up questions to prompt discussion. | 20 minutes |
| *Design competition (activity 1 continued).* | *2* | *To consider how the physical infrastructure and organisational systems of a land base on Mars could be organised.* | *Complete the design competition introduced in activity 1.* | *1-3 hours* |
| 4 Land base on Mars: judging. | 3 | To review individual designs against the specification and to identify a winner. | Presentation and peer review of individual designs. | 40 minutes |
| 5 Expert development groups. | 3  *4* | To introduce the task for phase 4.  *To research essential parts of the land base, in order to improve the winning design.* | Expert groups are formed and each group is given their task.  *Research and collaborative design, working in expert groups.* | 15 minutes  *1-3 hours* |
| 6 Developing final proposals. | 5 | To integrate a range of potentially competing improvements into one coherent design; and to experience the need for compromise and cooperation with experts from different specialisms. | Groups are formed that contain a member of each expert group from activity 5.  Each mixed group works up the winning design (from activity 4) to make improvements based on the research and collaboration carried out in expert groups (in activity 5). | 25 minutes |
| 7 Judging final proposals. | 5 | To judge the improved final designs against the initial design specification. | Pairs of students from each group present their completed designs to other groups.  A structured debate is used to determine the best overall design. | 30 minutes |

**Guidance notes: pedagogical approaches**

(Add a summary of how research supports the pedagogical approaches used in the unit)

**AS/A level specification links**

AQA Physics A-Level

**Force, energy and momentum**

3.4.1.4 Projectile motion

Independent effect of motion in horizontal and vertical directions of a uniform gravitational field. Problems will be solvable using the equations of uniform acceleration.

Qualitative treatment of friction.

Qualitative treatment of lift and drag forces.

Terminal speed.

Knowledge that air resistance increases with speed.

Qualitative understanding of the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle.

3.4.1.5 Newton’s laws of motion

Knowledge and application of the three laws of motion in appropriate situations.

*F* = *ma* for situations where the mass is constant.

**Gravitational fields**

3.7.2.2 Gravitational field strength

Gravity as a universal attractive force acting between all matter.

Magnitude of force between point masses: F = Gm1m2/r2 where G is the gravitational constant.

Representation of a gravitational field by gravitational field lines.

g, as force per unit mass as defined by *g* = *F/m*

Magnitude of g in a radial field given by *g* = *GM/r*2

3.7.2.3 Gravitational potential

Understanding of definition of gravitational potential, including zero value at infinity.

Understanding of gravitational potential difference.

Work done in moving mass m given by Δ*W* = *m*Δ*V*

Equipotential surfaces.

Idea that no work is done when moving along an equipotential surface.

V in a radial field given by *V* = − *GM/r* and the significance of the negative sign.

Graphical representations of variations of g and V with r.

V related to g by: *g* = − Δ *V/* Δ *r*

Δ *V* from area under graph of g against r.

3.7.2.4 Orbits of planets and satellites

Orbital period and speed related to radius of circular orbit; derivation of T2 ∝ r3

Energy considerations for an orbiting satellite.

Total energy of an orbiting satellite.

Escape velocity.

Synchronous orbits.

Use of satellites in low orbits and geostationary orbits, to include plane and radius of geostationary orbit.

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| **Radioactivity**  3.8.1.2 α, β and γ radiation  Their properties and experimental identification using simple absorption experiments; applications e.g. to relative hazards of exposure to humans.  Applications also include thickness measurements of aluminium foil paper and steel.  Inverse-square law for γ radiation: *I* = *k x*2  Experimental verification of inverse-square law.  Applications e.g. to safe handling of radioactive sources.  Background radiation; examples of its origins and experimental elimination from calculations. |

AQA Economics A-Level

**Economic methodology and the economic problem**

4.1.1.2 The nature and purpose of economic activity

* The central purpose of economic activity is the production of goods and services to satisfy needs and wants.
* The key economic decisions are: what to produce, how to produce and who is to benefit from the goods and services produced.

4.1.1.3 Economic resources

* The economists’ classification of economic resources into land, labour, capital and enterprise, which are the factors of production.
* The environment is a scarce resource.

4.1.1.4 Scarcity, choice and the allocation of resources

* The fundamental economic problem is scarcity and that it results from limited resources and unlimited wants.
* Scarcity means that choices have to be made about how scarce resources are allocated between different uses.
* Choices have an opportunity cost.

4.1.4.8 Technological change

* The difference between invention and innovation.
* Technological change can affect methods of production, productivity, efficiency and firms’ costs of production.
* Technological change can lead to the development of new products, the development of new markets and may destroy existing markets.
* Technological change can influence the structure of markets.

AQA English Language and Literature A-Level

**Exploring Conflict**

This part of the subject content focuses on how language choices help to construct ideas of conflict between people, and between people and their societies. Students learn about the ways in which writers and speakers use language, beginning with a general focus on broad questions such as:

* How do people interact?
* How do people claim power and position others in talk?
* How do people express identity?
* What communicative strategies do people use when in conflict with others?
* How do different groups or individuals make themselves heard?

Drawing both on their everyday experiences of interaction in different modes and on published texts, students learn about how the language choices writers make are used to express relationships, drive narrative, and construct views about the nature of different societies. They apply their knowledge to the study of texts about individuals in situations of conflict.

AQA Geography A-Level

**Global systems and global governance**

3.2.1.1 Globalisation

Dimensions of globalisation: flows of capital, labour, products, services and information; global marketing; patterns of production, distribution and consumption.

Factors in globalisation: the development of technologies, systems and relationships, including financial, transport, security, communications, management and information systems and trade agreements.

3.2.1.4 Global governance

The emergence and developing role of norms, laws and institutions in regulating and reproducing global systems.

Issues associated with attempts at global governance, including how:

* agencies, including the UN in the post-1945 era, can work to promote growth and stability but may also exacerbate inequalities and injustices
* interactions between the local, regional, national, international and global scales are fundamental to understanding global governance.

3.2.1.5 The 'global commons'

The concept of the ‘global commons’. The rights of all to the benefits of the global commons. Acknowledgement that the rights of all people to sustainable development must also acknowledge the need to protect the global commons.

3.2.1.6 Globalisation critique

The impacts of globalisation to consider the benefits of growth, development, integration, stability against the costs in terms of inequalities, injustice, conflict and environmental impact

**Resource security**

3.2.5.1 Resource development

Concept of a resource. Resource classifications to include stock and flow resources. Stock resource evaluation: measured reserves, indicated reserves, inferred resources, possible resources. Natural resource development over time: exploration, exploitation, development. Concept of the resource frontier. Concept of resource peak.

Sustainable resource development. Environmental Impact Assessment (EIA) in relation to resource development projects.

3.2.5.2 Natural resource issues

Global patterns of production, consumption and trade/movements of energy and ore minerals.

The geopolitics of energy, ore mineral and water resource distributions, trade and management.

3.2.5.6 Resource futures

Alternative energy, water and mineral ore futures and their relationship with a range of technological, economic, environmental and political developments.

**Key information**

**Space Law Treaties and Principles**

The website of the United Nations Office for Outer Space Affairs ([www.unoosa.org](http://www.unoosa.org)) clearly summarises the principles of current international space law in the introduction to their booklet on current International Space Law (UNOOSA, 2017):

“The [United Nations] Committee on the Peaceful Uses of Outer Space is the forum for the development of international space law. The Committee has concluded five international treaties and five sets of principles on space-related activities.

These five treaties deal with issues such as the non-appropriation of outer space by any one country, arms control, the freedom of exploration, liability for damage caused by space objects, the safety and rescue of spacecraft and astronauts, the prevention of harmful interference with space activities and the environment, the notification and registration of space activities, scientific investigation and the exploitation of natural resources in outer space and the settlement of disputes.

Each of the treaties stresses the notion that outer space, the activities carried out in outer space and whatever benefits might be accrued from outer space should be devoted to enhancing the well-being of all countries and humankind, with an emphasis on promoting international cooperation.” (UNOOSA, 2021)

These treaties came into force between 1967 and 1984 when space exploration was predominantly led by governments.

**The role of NASA in commercialising space**

Space exploration began in the 1950’s and 60’s during the Cold War era. It was used in the East and in the West to formulate stories of nation-hood and achievement for the competing political systems of the time. Each success, for example: the launch of a satellite; the first person in orbit; and the first person on the Moon – was typically viewed as a political victory (Burwell, 2019).

In those early days, NASA embodied the state dominance of US space exploration, but more recently in the US the whole sector has been deliberately transformed into a rapidly growing commercial space industry. To do this, the US government used NASA’s dominance to develop different forms of collaboration with new commercial actors, to lower barriers to entry, and to encourage innovation and investment. (Brennan, Heracleous and Vecchi, 2018). Initially NASA worked with private industry to develop technology and products ‘for NASA’, but increasingly it enters into fixed price contracts for technology and products that it uses, but which are owned by the commercial business and can be sold to other buyers – with some restrictions that are based largely on potential military use (Heracleous, Terrier and Gonzalez, 2019).

Typically, NASA now engages in open innovation and posts innovation challenges online in open competitions. The shift has created a greater cost consciousness and an openness to solutions created anywhere within the sector (and beyond). Since 2000, investment in the US space industry has tripled every six years, with 220 new space ventures between 2000 and 2018 (Heracleous et al. 2019). It is now estimated that SpaceX (founded in 2002) accounts for half of all satellite launches (Burwell, 2019) and that in 2017, 80% of all space activity world-wide (US$ 383.5 billion) was accounted for by commercial products, services, infrastructure and support industries (Heracleous et al. 2019).

Current space industry ventures include: Earth and space imaging; mining of asteroids and planets; space settlement ventures; research brokerage to facilitate research in space; education; and space tourism (Burwell, 2019).

**Freedom engineering**

‘The extreme conditions of all extra-terrestrial environments restrict freedom of movement and encourage social, political and economic arrangements friendly to tyranny’ (Cockell, 2019).

In space everyone must depend on essential technologies for survival and in the isolation of space, coercive people may be able to exert undue influence if they have control of these. There is a need to engineer the space environment to minimise this opportunity. In his paper *Freedom Engineering: Using Engineering to Mitigate Tyranny in Space*, Cockell (2019) explains the need for engineers, political scientists, sociologists and others to work together to plan how this might work.

It could be as simple as engineering space settlements to maximise the number of oxygen, food, water and power systems, so the opportunity to control single machines on a settlement is stopped. Or it might be the engineering of essential systems that most people find very easy to repair and maintain.

An understanding of *freedom* varies between and within different cultures, so the form and function of space environments will need negotiation, international agreement and enforceable regulation.

**Conditions on Mars**

Mars is the closest potentially habitable planet to the Earth.

Mars spins on an axis in a similar way to the Earth and the length of its day is 24 hours 37 minutes. It takes Mars 687 Earth days to go once round the Sun.

Mars is about half the size of Earth and gravity on Mars is 2.7 times less strong than it is on Earth. It has a very thin atmosphere, which is mainly carbon dioxide and includes a tiny proportion of water vapour. The average temperature on Mars is - 63oC, which varies between -140oC (at its poles in winter) and +30oC (closer to its equator in the summer).

The surface of Mars is mostly volcanic basalt rock covered in a fine powder. The soil of Mars holds nutrients such as sodium, potassium, chloride and magnesium.

The distance between Earth and Mars varies between about 34 million miles and 250 million miles. The average distance is about 140 million miles. At these distances, it would take an average or 14 minutes for a message to be transmitted *in each direction* (which is between about 3 and 22 minutes, depending on the position of the planets in their orbits).

Mars does not have a magnetic field to protect its surface from forms of solar radiation harmful to humans.

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