

# **When will Humanity be able to Colonise Extra-terrestrial Bodies within the Solar System?**

## **Abstract**

Ever since the Moon landing, humans have been setting their next goal, which is the exploration of Mars. In addition to the realisation that humans may not be able to remain on Earth forever, people are looking up to the sky to see whether colonisation can become a reality. The question remains: When will we be able to do it?

## **Introduction**

The main reason for researching this topic as my Individual Project is because I do not know which exact career I would like to work in in the future. However, I do know that I want my future career to be science-related - specifically within the fields of computer science or physics. The research into planets and stars are directly linked with the field of physics. On the other hand, the technology that is needed in order for humanity to colonise other planets rely on computers, many of which require programs and codes written by computer scientists. In addition, outer space has always been fascinating to me, especially the mysteries, dangers and beauty of it. Therefore, through this project, I hope to discover more about space.

## **Aims and Objectives**

1. Discern how humanity might be able to colonise other planets/objects.
  - Explore the plans that currently exist for the colonisation of other bodies within the Solar System.
  - Discern technologies that may become useful in colonising other planets.
2. Identify issues that may arise if humanity does colonise other planets/objects.
  - Compare the pros and cons of the ethical issues in colonising other bodies within the Solar System.
  - Spot issues that may emerge when colonising other objects.
  - Create a questionnaire to see what issues may have been overlooked and analyse the responses.
3. Identify resources that may be needed in order to colonise other planets/objects.
  - Collect information regarding the people that would be needed to do so from official bodies such as NASA.
  - Research online the methods of producing energy in space.

## **Research Methods (Rationale)**

I will be using both primary and secondary sources in this project. Mainly, I will be using the internet as my secondary sources to answer the three aims because the internet is such a vast network that there is an abundance of information regarding outer space and celestial bodies

within the Solar System. I will also be using books to help me answer the first aim by enhancing my knowledge on the Solar System in general so that not only will I be able to justify the reasons behind why something may become useful, but this will also mean that I am not restricted to one secondary source.

The validity of some of the websites on the internet will be questionable, as there will be websites that are biased, especially on the topic of the ethical issues for colonisation. In order to combat this situation, the websites that I will mainly use are from more trustworthy organisations such as NASA and BBC (for example <http://www.bbc.co.uk/news/science-environment-37486372>). As well, there are websites that are old and dated, which means that the date of the websites will also need to be checked. In some instances, there will be some videos linked in the websites that I am going use. In order to ensure the validity of these videos, I will be cross-checking the facts between websites.

Books will tend to be more valid than websites, but the date of when the books were published will need to be checked more thoroughly because some of the information in books may have become redundant as new research appears.

I will be using questionnaires as my primary sources to answer the second aim. These questionnaires will be used to provide me with alternative perspectives on the matter as there may be issues or technology that I have overlooked over the course of this project.

The questionnaires will definitely be current and there will be no point in checking the validity, as the point of these questionnaires is for me to observe other people's opinions and see whether there are any issues or solutions that I may have missed out.

## **Analysis of Information**

### **1. How might humanity be able to colonise other planets/objects**

The recent plan that unfolded was from Elon Musk and SpaceX, where they are planning on sending humans to Mars by 2022. The base of their plan is to use a fully reusable booster and a spaceship that can refuel in orbit in order to reduce the cost of traversing between Mars and Earth.<sup>1</sup> In addition, the plan also accounted for propellant production on Mars so that the spaceship would be able to refuel on the planet.<sup>2</sup> Furthermore, it has been confirmed that Mars has water, and the atmosphere contains life-sustaining elements and compounds such as carbon dioxide and nitrogen, which means that the atmosphere may allow plants to grow.<sup>3</sup> Warming the planet would bring the temperature to a more human-friendly temperature, but it might also form liquid oceans and a thicker atmosphere. Despite this, there was no mention of how the people would be able to survive after they arrive on Mars.

A different plan that also consists of colonising Mars is the Mars One mission plan. Started in



<http://www.mars-one.com/mission/roadmap>

---

<sup>1</sup> <https://www.theguardian.com/technology/2016/sep/27/elon-musk-spacex-mars-colony>

<sup>2</sup> <https://www.youtube.com/watch?v=A1YxNYiyALg>

<sup>3</sup> <https://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars>

2011, the plan began with looking out for potential astronauts via the Astronaut Selection Program, and the selected people would go through training. Between 2020 and 2024, two communications satellites, rovers, living units, life support units as well as a supply unit and a trailer would be sent to Mars. The two communications satellites would allow communication between Earth and Mars, and the first rover would find a location that is suitable for colonisation. The rovers would also attach the units together. Using the Martian soil, the connected units can extract life-sustaining resources such as oxygen and water. Once a certain amount of these resources are stored, the astronauts are then sent to Mars by around 2026.<sup>4</sup>

NASA has also confirmed a plan to colonise the Red Planet within the next several decades by splitting their plan into three phases: Earth Reliant, Proving Ground and Earth Independent. The Earth Reliant and Proving Ground phases are research-based stages to advance technology so that as many of the problems can be solved before the Earth Independent phase, such as researching the human health and material tests. Also, the Mars 2020 rover would be sent to the planet to find a suitable colonisation for humans.<sup>5</sup>

An alternative to Mars that humans can choose is the colonisation of Venus. The temperature on the surface of Venus is approximately 735K (462°C) and the pressure is too high. This makes people think that colonising Venus is a ridiculous idea. However, approximately 50km above the surface, the pressure of Venus is 1 bar, which is very similar to Earth's atmospheric pressure. Also, the temperature at that point ranges from 0°C to 50°C, which is suitable for life. There are other advantages to colonising 50km above the surface of Venus such as the similarity between Venus' and Earth's gravity and there being an abundance of solar energy.<sup>6</sup> Cities can be constructed and left to float by using breathable air such as oxygen and nitrogen, and since the surface of Venus has industrial materials such as aluminium and iron, it may be possible to mine those resources when they have found the solution to the extreme pressure.



<https://www.theguardian.com/science/2016/sep/23/is-a-moon-village-the-next-step-for-space-exploration-esas-chief-thinks-so>

There are no official plans for colonising the Moon, but an idea that was proposed by the Director General of the European Space Agency is to build a 'Moon village' in order to increase the cooperation between nations.<sup>7</sup> It was also proposed so that technology that would be used on Mars can be tested on the Moon first, which would allow astronauts to return safely back to Earth should anything go wrong.<sup>8</sup>

Also relating to the Moon, a private company by the

<sup>4</sup> <http://www.mars-one.com/mission/roadmap>

<sup>5</sup> [https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008\\_508.pdf](https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf)

<sup>6</sup> <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030022668.pdf>

<sup>7</sup> <http://www.bbc.com/future/story/20150712-should-we-build-a-village-on-the-moon>

<sup>8</sup> <https://www.theguardian.com/science/2016/sep/23/is-a-moon-village-the-next-step-for-space-exploration-esas-chief-thinks-so>

name of Moon Express has been granted permission for a 2017 lunar mission.<sup>9</sup> Unlike a normal colonisation plan, this plan focuses on developing the resources on the Moon for use by the people on Earth.<sup>10</sup> However, it is possible that people may colonise the Moon as a result of this, meaning that it may become the 'second home' of humanity.

Another technology that may become useful is nanotechnology since nanotechnology may have the ability to reduce the mass of the rockets and spaceships. This then leads to the point that less thrust would be needed to launch the spacecraft and its content, and the cost of missions would also decrease.<sup>11</sup>

In-Situ Resource Utilisation (ISRU) would definitely be an important piece of technology when colonising an extra-terrestrial object in space due to the fact that ISRU can produce life-sustaining resources and fuel such as oxygen and methane.<sup>12</sup>

Virtual reality may become an important piece of technology for space colonisation because it allows future astronauts to be trained by simulating the look and feel of being in space.<sup>13</sup> Since virtual reality can be used to simulate the feel and look of a colonisation target, it can be used to give future colonists experience before the actual mission.

In terms of missions where rovers are needed, artificial intelligence can be rather useful so that the rover has a certain level of self-awareness and be able to act in emergency because the data received from the rover would be delayed due to the distance between the object and Earth. Furthermore, it may take a long time before a decision is made, and there may not be enough time in an emergency.<sup>14</sup>

## **2. Issues that may arise if humanity does colonise other planets/objects**

An issue that humans would face immediately as they travel into space is the lack of sustenance, therefore two priorities for colonisation is an abundance of water and the possibility of being able to farm food. An ethical issue that emerges is whether we should bring domestic farm animals with us since this can cause the food chain of that planet to be disrupted if life does exist on one of humanity's colonisation targets.

Another issue that people need to focus on is the loss of calcium in the human body and the weakening of bones due to it wasting away in low gravity.<sup>15</sup> The way to combat the situation is to have a special diet, but some of the effects may remain permanent.<sup>16</sup>

Another problem relating to the human body is radiation because radiation from the Sun

---

<sup>9</sup> <https://www.theguardian.com/science/2016/aug/03/us-startup-moon-express-2017-lunar-mission>

<sup>10</sup> <https://www.moonexpress.com/files/moon-express-press-kit.pdf>

<sup>11</sup> <https://www.theguardian.com/nanotechnology-world/nanotechnology-can-launch-a-new-age-of-space-exploration>

<sup>12</sup> <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120001775.pdf>

<sup>13</sup> <https://www.nasa.gov/audience/foreducators/spacesuits/careercorner/david-homan.html>

<sup>14</sup> <http://www.esa.int/gsp/ACT/doc/AI/pub/ACT-RPR-AI-2007-ArtificialIntelligenceForSpaceApplications.pdf>

<sup>15</sup> [https://www.nasa.gov/audience/foreducators/postsecondary/features/F\\_Bones\\_in\\_Space.html](https://www.nasa.gov/audience/foreducators/postsecondary/features/F_Bones_in_Space.html)

<sup>16</sup> <http://www.bbc.co.uk/newsround/22527246>

can cause mutations, leading to different kinds of cancer. Therefore, people would need to consider whether the atmosphere of the planet protects the people on the surface from radiation and whether the gravity is strong enough for colonisation.

The atmosphere is an important factor for colonisation. The gas within the atmosphere needs to contain life-sustaining elements such as hydrogen, carbon and oxygen and no or very little gas that can cause harm to life. The pressure of the atmosphere is considered as well due to the reason that sending humans to a body that has a very high pressure would likely cause the person to be crushed under the atmosphere.

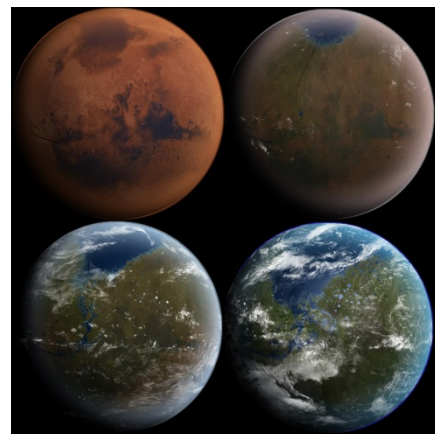
Without minerals on the extra-terrestrial bodies that are targets to colonisation, construction and maintenance of the colony would be impossible unless resources are sent from Earth. With Earth's resources currently dwindling at quite a high rate, one of the goals of colonisation is being able to gather minerals and build a self-sustainable colony on another body in space. Therefore, it would be impractical to create such a colony unless humans have become a multi-planetary species.

Sanitation would be another issue that arises if humanity is to colonise other bodies due to the fact that humans need to be kept healthy, otherwise the sewage would cause people to become sick, leading to an increase in the number of deaths. This would then effectively reduce the population before the colony is stable.

If humanity is to colonise extra-terrestrial objects, then would the people on that object obey the laws that are set on Earth, or would they create their own rules?<sup>17</sup> Since everything other than satellites and rovers do not belong to a particular nation in space, if the laws are set by the people of Earth, then the laws would probably have to be agreed on by every country on Earth.

Furthermore, the time-keeping between the extra-terrestrial object and Earth would be very different, meaning that communication between Earth and the object may be limited as a result of the time differences.

From Elon Musk's plan of warming the planet, an ethical issue rises, which is the possibility of life on Mars. Even though NASA cannot currently find life on Mars, there is strong evidence linked to the possibility of life on Mars such as the existence of water on the planet. Warming the planet, or terraforming, would cause the climate to change considerably, leading to the death of those lives.<sup>18</sup> Assuming that there is life on Mars, and they are microbes, the argument against this is that since they have been unable to evolve past the microbial stage after all this time, the likeliness of evolution actually occurring is low.<sup>19</sup> Another argument is that eventually, Earth will be destroyed, and instead of facing utter extinction, humans, animals and plants



[https://en.wikipedia.org/wiki/Terraforming\\_of\\_Mars](https://en.wikipedia.org/wiki/Terraforming_of_Mars)

<sup>17</sup> <https://www.youtube.com/watch?v=KUddy8RGwns>

<sup>18</sup> [https://en.wikipedia.org/wiki/Terraforming\\_of\\_Mars](https://en.wikipedia.org/wiki/Terraforming_of_Mars)

<sup>19</sup> [https://en.wikipedia.org/wiki/Ethics\\_of\\_terraforming](https://en.wikipedia.org/wiki/Ethics_of_terraforming)

may live on. On the other hand, people have been arguing that living on another planet would only lead to humans polluting that planet, which would then become an endless cycle.

Ultimately, the first issue that humans are going to face before any others is the initial cost of creating the rockets, boosters and modules as well as fuel. Without the necessary funds, colonisation would only remain an idea. Additionally, the second issue that they are going to face is the recruitment of people that are willing to die. Exploration of space is dangerous, and one minor mishap can cause the spaceship and all of its passengers to die. The issue is further complicated by the fact that the people that would be sent to space needs to be experts in fields such as engineering, piloting and biology in order to reduce the risk of failure.

### 3. Resources that may be needed in order to colonise other planets/objects

As mentioned previously, the people that would be needed in order for colonisation to be possible are people that are willing to die. However, they would also need to be skilled at using the equipment that is given to them in order to survive. In order to do so, those people would have to go through training to familiarise themselves with the equipment.

The requirements for being the people that would colonise the extra-terrestrial objects would likely be similar to the requirements for being an astronaut. Therefore, biological and physical scientists, engineers, pilots and mathematicians would likely be the first people to colonise an extra-terrestrial object in outer space. Furthermore, they would have to be physically healthy.<sup>20</sup>

On top of that, computer scientists would be needed as well because they would be responsible for writing the codes to automate certain processes as well as creating simulations for flights and experimenting with robotics to create rovers.<sup>21</sup>

Engineers in general are very important to nearly everything in modern society. Mechanical engineers would be required to create the components of the rockets, boosters, rovers and units. On the other hand, electrical and electronic engineers would be needed to create the circuitries and ensure that all of components receive sufficient power.

Scientists such as physicists and biologists would also be necessary because physicists are familiar with the gravitational field of objects and radiation, and biologists are familiar with organisms in general, meaning that they can carry out research such as growing plants in space or in foreign soil.

Energy production using solar energy seems to be the most obvious. With the Sun being the source of power, solar energy is reliable and plentiful.<sup>22</sup> However, using solar panels on bodies that take a long time to do one full rotation may be problematic because the time that the solar panels are exposed to sunlight would be insufficient to power a colony unless several solar farms are placed on opposite sides of the body. Additionally, if the

---

<sup>20</sup> [https://www.nasa.gov/audience/forstudents/postsecondary/features/F\\_Astronaut\\_Requirements.html](https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Astronaut_Requirements.html)

<sup>21</sup> <http://www.spacex.com/careers>

<sup>22</sup> <http://www.mars-one.com/mission/technical-feasibility>

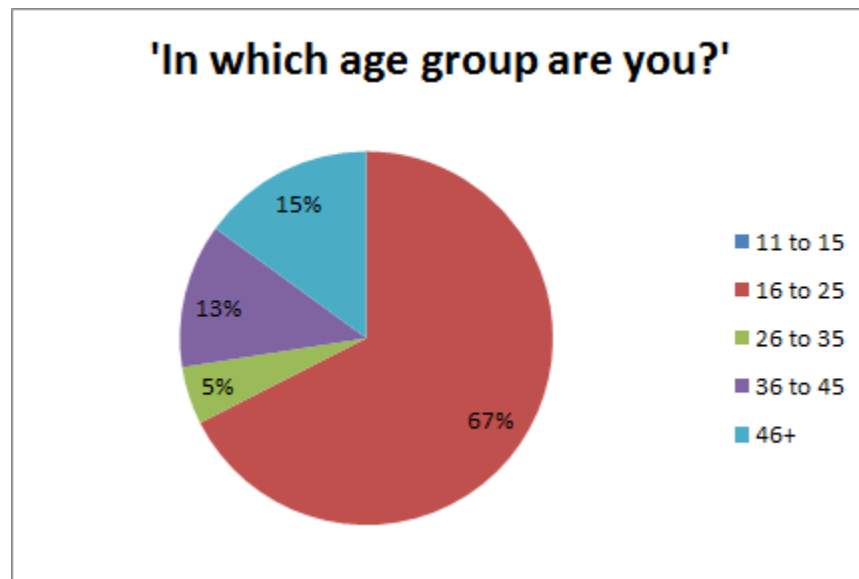
object is too far away from the Sun, there would be insufficient light to produce the energy the colony needs.<sup>23</sup>

Another way to produce energy would be to use nuclear power plants. Since nuclear power relies on material such as plutonium and uranium, rotation of the object has no impact on energy production. Furthermore, the distance from the Sun does not impact the energy that is produced. Despite this, nuclear power would pollute the body in space as nuclear waste is produced.

### **Analysis of Primary Data**

For my primary source, I created a questionnaire with 10 questions, and the total number of responses that I received was 40. However, some participants had no opinion on some of the questions, so the responses did not always add up to 40.

As I wanted to see whether age has an impact on their opinions, I separated the participants of my questionnaire in terms of their age.

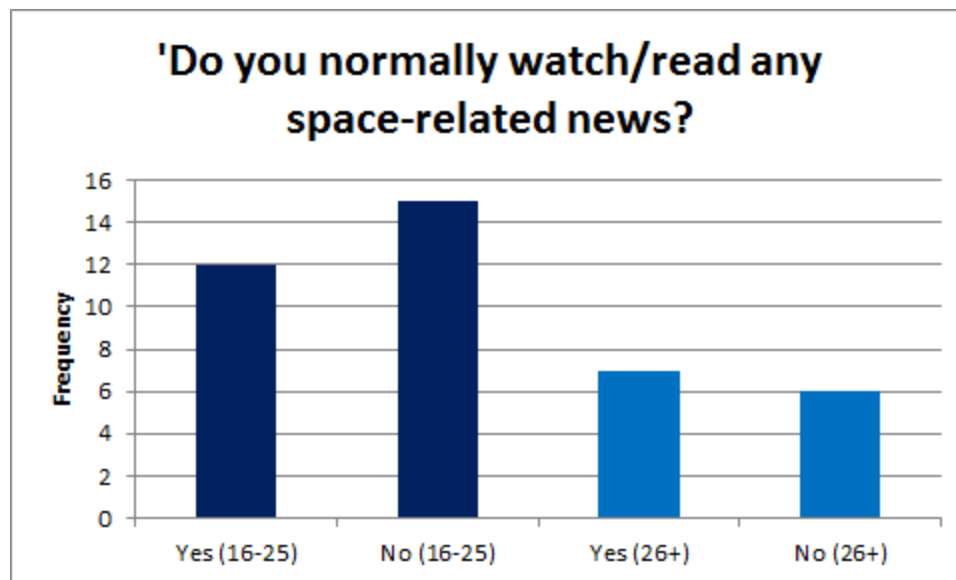


From the graph, it is clear that around two-thirds of the responses that I received were from people that are relatively young. Because the other age groups consisted of only a third of all of the responses, there was insufficient information to analyse the other age groups separately. In order to combat this, I merged those age groups together to form a 26+ age group.

I further separated the groups to four different groups:

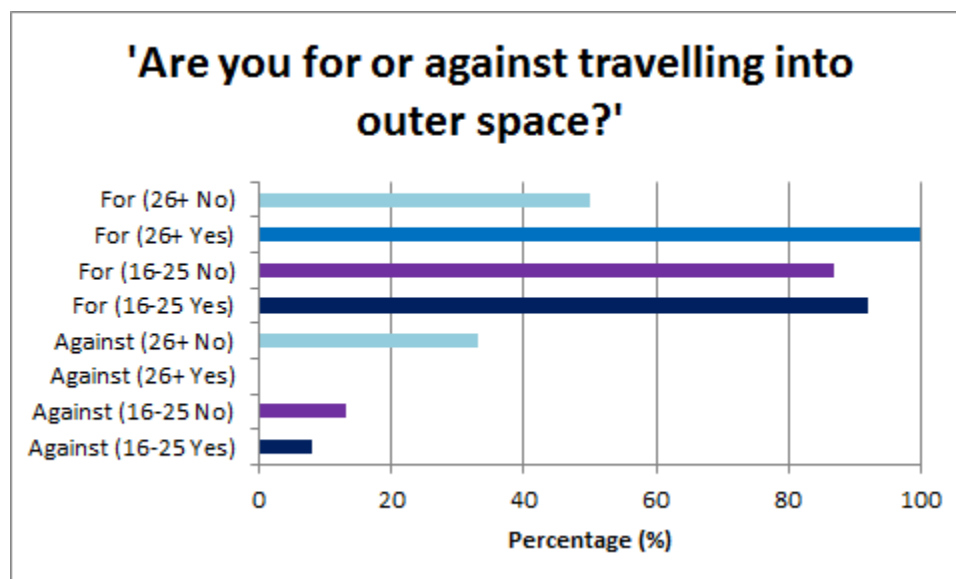
---

<sup>23</sup> <https://www.hq.nasa.gov/office/hqlibrary/pathfinders/nuclear.htm>



The majority of the people in the 16-25 group said that they do not normally watch or read space-related news. On the other hand, the 26+ group's responses revealed that the number of people that do watch or read space-related news is very similar to the number of people that said they do not.

To create a better comparison between the categories, the results for the other questions were converted to percentages, where the bars for the same colour add up to 100% unless one of the participants have no response for that question. Furthermore, the 'Yes' and 'No' in the brackets represent whether they do or do not normally watch space-related news.



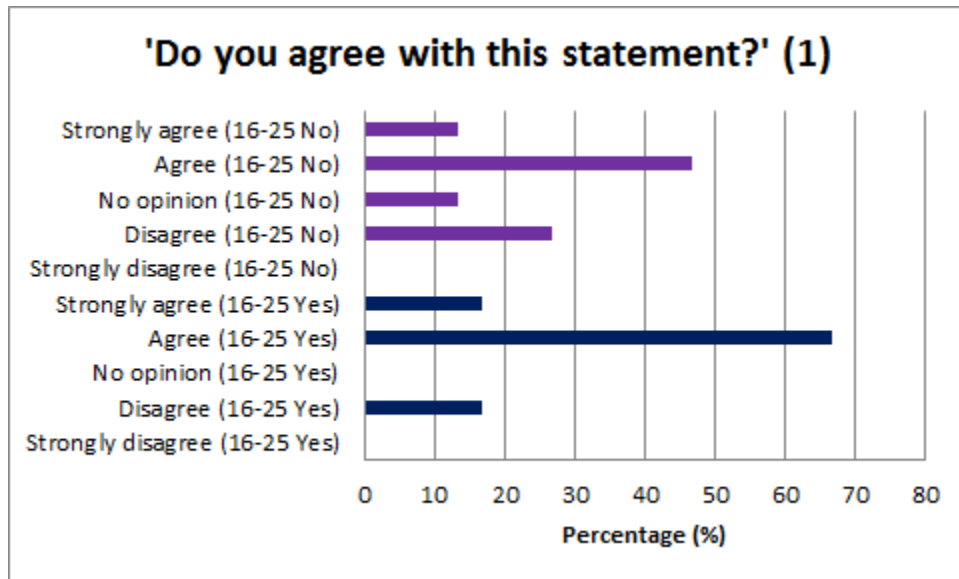
In general, the majority of the participants believe that travelling into outer space is a good idea because they think that travelling into outer space would allow humanity to gain new knowledge about both humanity and the universe. A small percentage had also mentioned the points of running out of resources if humanity remains on Earth as well as finding a new object to call home before Earth becomes uninhabitable. On the other



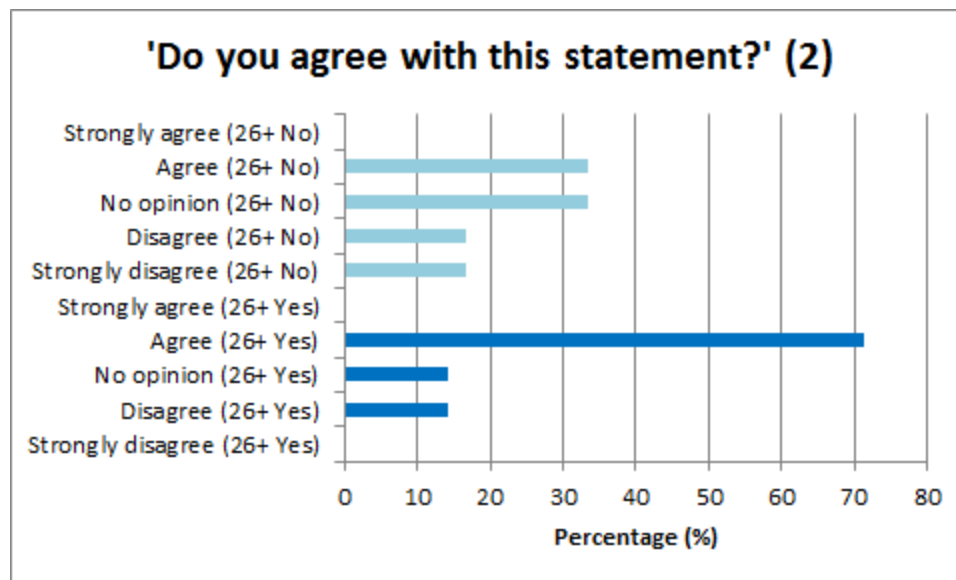
hand, the people that were against space travel generally had a similar opinion, which is that money spent on space travel can instead be used on solving problems that currently exist on Earth such as poverty and climate change.

The graph shows the people who do not normally watch the news tend to be more against space travel, which can suggest that as people are presented with more information regarding space, they are more likely to be for space travel.

The question regarding space colonisation divided people's opinions. As a divided opinion in the general public may discourage the research that would be needed to make this a reality, it can ultimately delay the time before humans can colonise other objects in space.



The statement for the graphs is 'Humans should colonise extra-terrestrial objects in outer space.' The results for the (16-25 Yes) group agree more with the colonisation of space objects than other people. This further supports the idea that people tend to agree more about space travel and colonisation when they are presented with more information regarding space.

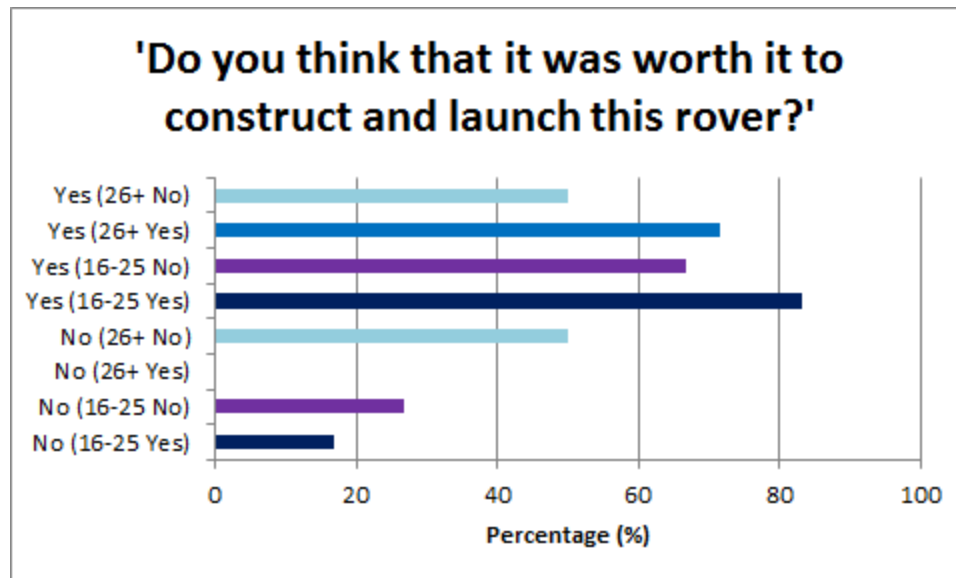


Similar to the 16-25 age group, most of the participants in the 26+ age group also agrees with the statement about space colonisation. However, the (26+ No) group disagree more strongly than the other three groups. Furthermore, the two groups that are less informed are more indecisive than the other groups. In terms of just the age groups, the 16-25 age group agrees more with space colonisation than the 26+ age group.

I also asked people's opinions toward the plans for sending humans to Mars. Some of the responses mentioned the need to reduce the risks before sending humans to space, whilst some others mentioned the point that it should be done only if necessary. But, four of the responses that I received were quite interesting because those people are sceptical about whether the plans can be carried out by the deadline; if the plans do not happen before their deadlines, there would definitely be a delay in completing the final goal, which is the colonisation of Mars.

Some of the other responses mentioned the point that being able to send humans to Mars would then mean that we would be able to do more research, inducing a greater advancement in technology.

The purpose of the Curiosity rover is to pave the way for future human exploration of Mars, and equipment as expensive as such would probably be needed for exploring other bodies that are considered possible colonisation targets. If the general public believes that recovering data regarding the extra-terrestrial bodies is not worth the money, private funding for colonisation plans would be less, resulting in a smaller budget. The people responsible for those plans would have to try and cut down the cost, leading to a delay.



The graph shows that the majority of three of the groups believed it was worth launching the Curiosity rover. It also shows that the people who watch space-related news tend to agree more with the launch of the Curiosity rover.

From the questionnaire, I was able to find that psychological and mental anguish would be an issue because communication between the body and Earth would be limited, and if a person on the extra-terrestrial body misses a person or thing on Earth, it can cause them to have depression or mental breakdowns.

The potential of developing an illness or disease is also a problem. Before colonising an object, one of the challenges that researchers would have is minimising the probability of a person becoming ill. Additionally, due to the reason that there may be unknown viruses or bacteria on the colonisation target, if a person develops a disease from the virus or bacteria, should that person be abandoned to ensure that the other people do not contract the same disease? Furthermore, another question that would arise is whether we should continue the colonisation of that object, or should we abandon the colonisation plan and the people on the object in order to prevent more people from contracting the disease?

An issue that humans are going to have to face is the potential encounter of an alien species within space, and the attitude that we should have when interacting with them.

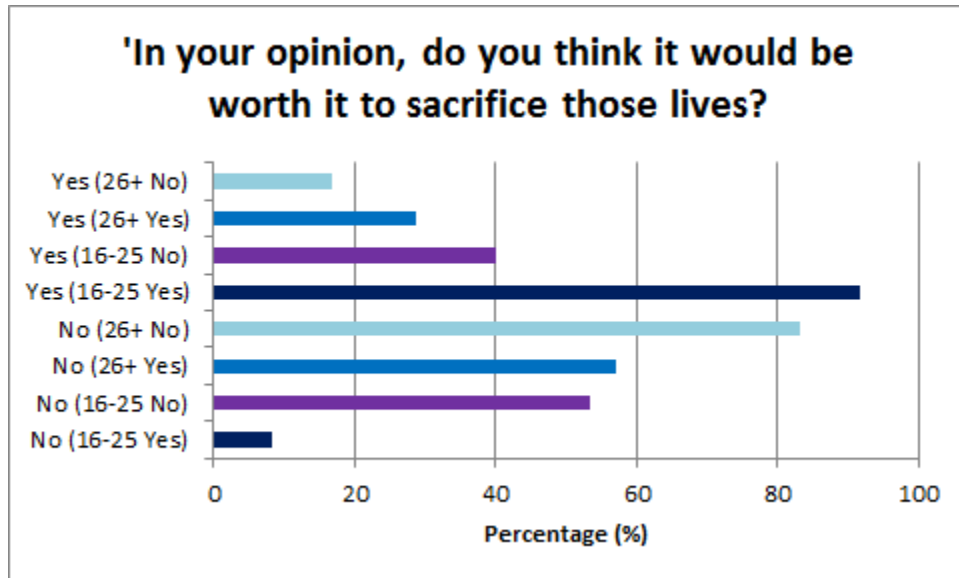
When an object in space is colonised, the debate that would likely rise is the ownership of the object. Another issue that people might encounter is the domination of a particular race, and what countermeasures should we have if we want the colony to be international.

The time that it would take to reach that object from Earth would be an issue as well because an extended period of time in microgravity would have a negative impact on the human body.

Some of the issues that were brought up from secondary sources were also mentioned by some of the participants. Examples of these were the effect of gravity on the human body and the atmosphere of the colonisation target.

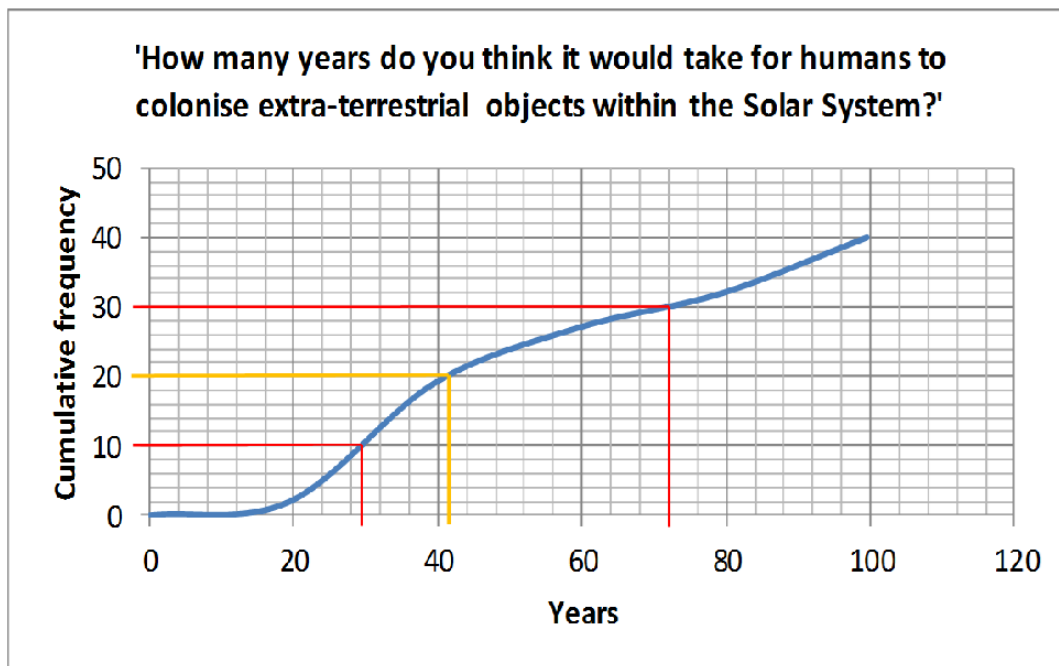
Other examples of answers that were given to me include: the adaptation to a new climate and environment and the limitations in space vehicles such as rockets for people to use.

One of the ethical issues that arise from attempting to explore and colonise other bodies in space is the consideration of whether we should sacrifice the astronauts when a major problem arises.



The responses received from this question are more divided than from the responses from question 3. This suggests that quite a large number of people do not normally consider the process that people such as astronauts go through in order to make space travel and colonisation a reality. The only group that strongly agrees with sacrificing lives for colonisation is the (16-25 Yes) group.

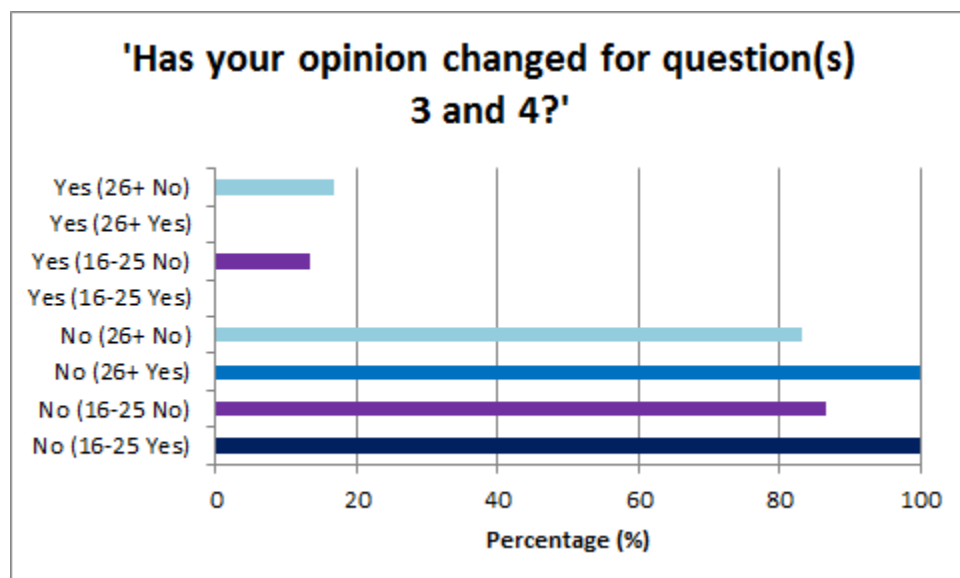
For the next question, I wanted other people's estimates on when humanity would be able to colonise bodies in space, and this is the data that I received:



The median of the diagram is 41.5 years, and the interquartile range is 42.5 (72-29.5) years. This suggests that half of the people believe humanity would be able to colonise extra-terrestrial bodies within the next 41.5 years, and the majority believe that it is possible within 42 years. On top of this, the mode of the results are 20-39 years, which means that the majority of the people believe humans would successfully colonise other bodies between 20 and 39 years.

This disagrees with SpaceX and Mars One's plans for sending humans to Mars by the years 2022 and 2026 respectively, but it also agrees with NASA's plan of being able to colonise the Red planet within the next couple of decades.

Finally, the reason I asked the final question was because I wanted to see if their opinions have changed if they are exposed to new facts.



When exposed to new information, a small percentage of people did change their opinion. As shown, the people that did change their opinion are those who answered 'No' in question 2. Of the small percentages of people that changed their opinion, some said that they agree with space travel because they can learn new things, whilst some other people said that they do not think space travel is worth risking lives. A person also changed their opinion so that they agree with space colonisation. The majority of the people that changed their opinion now agree with space travel and colonisation, which confirms the suggestion I had made in question 3.

## **Conclusion**

1. From the research, I have learnt that there are quite a few existing plans for the colonisation of Mars, and all of them are set to be underway within the next two decades. Although SpaceX's plan for sending humans to Mars does not mention anything about the human's survival on the planet, their idea of using reusable boosters and spaceships seems realistic in terms of cost, resources as well as sending people into outer space. Also, instead of getting humans to space, technology such as nanotechnology and virtual reality can also be used to reduce the time it takes before humanity can begin space colonisation.
2. Although there are many issues, both shown in the questionnaire answers as well as from the internet, many of those issues are already being researched in the hopes that it can be solved as quickly as possible. An example of this is the breaking down of calcium due to the lack of gravity.

The three purposes for the questionnaire was to find whether normally watching the news about space and age has an impact on people's opinion as well as trying to ensure no issues had been overlooked. I have concluded from the results that being exposed to space-related news causes the person to agree more with space colonisation than the people that do not. Hence, a possible solution to reduce the divide in opinions on space colonisation would be to present to the public more facts regarding space, which can then possibly increase the support and public funding of these projects. On the other hand, once categorised into groups, age does not seem to have a significant impact on the answers.

3. Other than astronauts and engineers, there are many more experts that agencies need in order to have successful missions into outer space. Due to this reason, recruitment of people that are experienced in this field would take a lot of time. Ultimately, it is unlikely that a new organisation would be the first to colonise a body in outer space, meaning that one of the plans mentioned within this project would likely be the first successful plan of colonisation for humanity.

Looking at the three aims, humanity will likely be able to create a fully functional colony on a body within the Solar system within the next four decades, with 20-39 years being the most likely.

## **Bibliography**

### **Self-Evaluation**

In terms of literacy, I tried to ensure that the vocabulary used was not too complicated for me or anyone that is unfamiliar with this topic and was accurate. As a result, I searched words that I did not understand, and in the process developed my understanding of the technology

that is currently available in the event of colonisation. In some of the aims, I tried to include statistics as proof to the readers that humanity has reached a stage where colonisation is a possibility. However, I feel that I could have integrated even more statistics, particularly for aim three.

Throughout this project, one of the problems I had was time-management. Because space is a current topic, I had to do constant research to ensure my information was accurate, which reduced my efficiency. As a result, many more hours than was needed was spent on the project, particularly the research. However, for each day I worked on the project, I implemented a goal for the next day, which restricted the amount of time I wasted. Furthermore, I planned by creating a checklist for what I wanted to write in a separate document. Rather than writing the project aim by aim, I completed bits of each of the aims over time, and I assembled the paragraphs into this order because the information I found were sometimes relevant to a different aim from what I was working on.

Rather than using books as another way to look for information, I only managed to use a book to check the validity of the statistics on one of the websites. Instead, I integrated several research papers into my project.

Another thing that became a problem was the word count limit; I had to keep the plans for colonisation brief in order to accommodate everything within the limit. In addition, I also had to leave out minute details in some areas.

The problem that I had with the questionnaire was that there were insufficient responses, which caused me to merge the age groups together. Furthermore, the feedback I received from the participants revealed that they found the questionnaire difficult to answer; the questionnaire was purposely made complicated to make the participants really think about their answers. Because of its difficulty, I realised that some participants may give up answering some questions. Additionally, I should have added a question which asks them about the people that would be needed to make colonisation a reality to expand my third aim because there is certainly information that I have overlooked for aim three. Also, the graphs that were created to analyse the responses may appear confusing to the reader, but it did allow me to compare the groups more efficiently. If I was to do another project, I would make my questionnaire online to increase the range of people that would answer the questionnaire and also save time in categorising the data into separate groups. I would also improve by making sure the questionnaire is not too difficult to answer, and I would compare more between my primary and secondary sources to see if they agree with each other.

### **Evaluation of Sources**

Wikipedia - The use of Wikipedia pages within my work is allow me to have an even larger array of opinions for research. From the Wikipedia pages, the research that I did was on the ethics of terraforming and colonisation. Since morals are different for every single person, the ethical issues revolving around colonisation and terraforming originate from opinions.

[https://en.wikipedia.org/wiki/Terraforming\\_of\\_Mars](https://en.wikipedia.org/wiki/Terraforming_of_Mars)

[https://en.wikipedia.org/wiki/Ethics\\_of\\_terraforming](https://en.wikipedia.org/wiki/Ethics_of_terraforming)

BBC - BBC is an international news network. This supports the idea that the BBC is a trustworthy organisation and is a reliable source. Furthermore, the articles have been cross-checked to ensure bias is kept to a minimum.

Kin Kwan Leung

<http://www.bbc.co.uk/news/science-environment-37486372>

<http://www.bbc.com/future/story/20141002-time-to-plan-a-space-colony>

<http://www.bbc.com/future/story/20150712-should-we-build-a-village-on-the-moon>

<http://www.bbc.co.uk/newsround/22527246>

NASA - The reason behind the use of NASA's webpages is because as mentioned in the Research Rationale, NASA is a trustworthy organisation. Because NASA is part of the American government, the government will check to ensure that the information is accurate. Additionally, the NASA websites are reviewed and updated continuously from the day that it was written unless stated otherwise.

[http://mars.nasa.gov/mer/technology/bb\\_power.html](http://mars.nasa.gov/mer/technology/bb_power.html)

<http://mars.nasa.gov/msl/mission/overview/>

<http://mars.nasa.gov/msl/mission/science/>

<https://www.hq.nasa.gov/office/hqlibrary/pathfinders/nuclear.htm>

[https://www.nasa.gov/audience/forstudents/postsecondary/features/F\\_Astronaut\\_Requirements.html](https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Astronaut_Requirements.html)

[https://www.nasa.gov/audience/foreducators/postsecondary/features/F\\_Bones\\_in\\_Space.html](https://www.nasa.gov/audience/foreducators/postsecondary/features/F_Bones_in_Space.html)

<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120001775.pdf>

<https://www.nasa.gov/audience/foreducators/spacesuits/careercorner/david-homan.html>

[https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008\\_508.pdf](https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf)

<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030022668.pdf>

<https://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars>

The Guardian - The Guardian is known internationally, and is generally regarded as a reliable source of information. Depending on the person that wrote the article, the Guardian can be slightly biased. Despite this, the articles have been cross-checked with other articles to ensure that the information is accurate.

<https://www.theguardian.com/technology/2016/sep/27/elon-musk-spacex-mars-colony>

<https://www.theguardian.com/science/2016/sep/23/is-a-moon-village-the-next-step-for-space-exploration-esas-chief-thinks-so>

<https://www.theguardian.com/science/2016/aug/03/us-startup-moon-express-2017-lunar-mission>

<https://www.theguardian.com/nanotechnology-world/nanotechnology-can-launch-a-new-age-of-space-exploration>

Youtube - Youtube is a public source, which means that the information is biased based on the individuals that uploaded the videos. Despite this, the two videos are referenced within this



Kin Kwan Leung

project are definitely suitable. On one hand, the SpaceX video details the plan that the company has for future colonisation and the video is uploaded by the company itself. On the other hand, the VSauce video was used to provide ideas on what humanity might face when they colonise Mars. Furthermore, the sources that were used to create the video are listed in the description of the video.

<https://www.youtube.com/watch?v=A1YxNYiyALg>

<https://www.youtube.com/watch?v=KUddy8RGwns>

There are other websites that I have used such as the Mars One, SpaceX and MoonExpress websites. These sources are definitely accurate because these were all used to explore their plans for space colonisation or mining. In addition, there is also a European Space Agency research paper source in my project.

<http://www.mars-one.com/mission/roadmap>

<https://www.moonexpress.com/files/moon-express-press-kit.pdf>

<http://www.esa.int/gsp/ACT/doc/AI/pub/ACT-RPR-AI-2007-ArtificialIntelligenceForSpaceApplications.pdf>

<http://www.spacex.com/careers>

<http://www.mars-one.com/mission/technical-feasibility>

<http://www.space.com/10762-nasa-mars-rover-overbudget.html>

Book: Collins Physics Third Edition (Used to cross-check the statistics on Venus)

## Appendix

### Holiadur a'r Gartrefu yn the Gofod Questionnaire on Space Colonisation

1. Ym mha ddosbarth oedran ydych chi?

In which age group are you?

11-15 o      16-25 o      26-35 o      36-45 o      46+ o

2. Ydych chi'n aml yn gwyllo/darllen newyddion sydd ei wneud â'r gofod?

Do you normally watch/read any space-related news?

Ydwyf/Yes o      Nag ydwyf/No o

3. Ydych chi o blaid neu yn erbyn trafaelio yn gofod ehangach?

Are you for or against travelling into outer space?

O plaid/For o      Yn erbyn/Against o

A pham?

And why?

---

---

4. 'Dylai bodau dynol ymgartrefu gwrthrychau arallfydol (e.e. planedau, asteroidau) yn y gofod ehangach'. Ydych chi'n cytuno gyda'r datganiad hwn? (Cylchwch eich ateb os gwelwch yn dda)  
'Humans should colonise extra-terrestrial objects (e.g. planets, asteroids) in outer space'. Do you agree with this statement? (Please circle your answer)

Cytuno'n gryf	Cytuno	No opinion	Anghytuno	Anghytuno'n gryf
Strongly agree	Agree	Dim barn	Disagree	Strongly disagree

5. Yn ddiweddar, mae Elon Musk wedi datgelu ei gynllun i anfon bodau dynol i Blaned Mawrth mor fuan a'r degawd 2020. Yn ychwanegol, mae NASA hefyd wedi datgelu cynllun i anfon bodau dynol erbyn y degawd 2030.

Beth yw eich barn chi am y mater hwn?

Elon Musk has recently revealed a plan to send humans to Mars by as soon as the 2020s. In addition, NASA has also revealed a plan to send humans by the 2030s.

What is your opinion on this matter?

---

---

---

6. Mae 'The Curiosity' rover yn robot sydd ar hyn o bryd ar Blaned Mawrth, ac yn paratoi am ymchwiliad dynol y blaned drwy geisio casglu data ar yr hinsawdd a daeareg y blaned. Cyfanswm, côst y rover (yn cynnwys côst lansiad) oedd oddeutu \$2.5 biliwn o ddolerau. Yn eich barn chi, ydych chi'n credu ei bod hi'n werth y gôst o adeiladu a lansio y rover hwn?

The Curiosity rover is a robotic vehicle that is currently on Mars, and it is preparing for future human exploration of the planet by attempting to recover data on the climate and geology of the planet. The cost of the rover (including the cost of launch) was approximately \$2.5 billion. In your opinion, do you think that it was worth it to construct and launch this rover?

Ydwyf/Yes ☐      Nag ydwyf/No ☐

7. Heblaw am y gôst a'r diffyg cyfleusterau posibl megis dŵr a bwyd, pa broblemau eraill ydych chi'n meddwl y buasai rhaid i fodau dynol eu wynebu yn cartrefu gwrthrychau arallfydol?  
Other than the cost and the possible lack of resources such as food and water, what other issues do you think that humans would face when colonising extra-terrestrial objects?

---

---

---

8. Law yn llaw â darganfyddiad ac ymgartrefu, mae'r perygl o aberthu bywydau. Yn eich barn chi, ydych chi'n meddwl ei bod hi'n werth aberthu y bywydau hynny?  
With space exploration and colonisation comes the risk of sacrificing lives. In your opinion, do you think that it would be worth it to sacrifice those lives?

Ydwyf/Yes ☐      Nag ydwyf/No ☐

**Ar ôl darllen y wybodaeth o'r holiadur hwn:**

**After reading the information from this questionnaire:**

9. Faint o flynyddoedd ydych chi'n credu y bydd hi'n ei gymryd i fodau dynol gartrefu gwrthrychau arallfydol yng nghysawd yr haul?

How many years do you think that it would take for humans to colonise extra-terrestrial objects within the Solar System?

0-19 ☐      20-39 ☐      40-59 ☐      60-79 ☐      80-99 ☐      Arall/Other ☐

Os y dewiswch 'arall' os gwelwch yn dda a wnewch chi ddatgan eich ateb isod.

If you chose 'Other', please state your answer below.

---

10. Yw eich barn wrth ateb cwesiwn 3 a 4 wedi newid?

Has your opinion changed for questions 3 and/or 4?

Ydi/Yes ☐      Nag ydwyf/No ☐

Os 'Ydi', os gwelwch yn dda datganiwch rhif y cwestiwn ac ateb y cwestiwn(au) yr ydych wedi eu datgan, isod.

If you chose 'Yes', please state the question number and answer the question(s) that you have stated, below.

---

---

---

Diolch am lenwi yr holiadur hwn.

Thank you for answering this questionnaire.