Implications of Robotic Space Mining

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Date: February 8, 2010

Approved:

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Abstract

This project centered on the use of robots to conduct mining in space, specifically on the lunar surface. It examined proposed work, including the construction of a lunar base. The project investigated legal, financial and ethical concerns raised by considering such endeavors. It aims to forecast the future of space mining by gathering and analyzing information from interviews and a survey. The project concludes that the public would support robotic space mining if it were a viable source of revenue.

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1. Introduction

With the introduction of robots within the past century, there has been a burst in technological advances in robotics that have had profound impact upon many different fields of science. We now possess the necessary technology to build robots which used to be merely works of science fiction. The limitations of technology are pushed back as time goes on and new avenues of creativity are opened for people to explore.

One of the most fascinating of those avenues is robotics. Robotics plays an integral part in the advancement of information technology, biotechnology, nanotechnology, and space technology to name a few (Bekey 2008). Each of these fields can be further divided into more specific areas in which robots have greatly helped contribute to creating new scientific improvements or advances.

With special regard to advancements made in space technology, robots have played a pivotal part in helping us understand “the great beyond”. Space has remained unexplored until the past half-century. Certainly, greater understanding of the universe would be extremely beneficial to the advancement of humanity, and the use of robots for space applications is a step in that direction. Currently, robots are used to survey other planetary surfaces; in the near future they may be used to begin excavating for resources.

This report will examine the intricacies of **robotic space excavation** and the developments taking place at the time of publication. There are several aspects to be investigated:

- The impact of robots and robotic technological advances on society.
- The feasibility of robotic application to space excavation.
- The financial benefits of such an endeavor.

- Laboratory work being done with regard to space excavation.
- The extensibility of the technology.
- Possibility for future advancements.

1.1 What is a robot?

For this report, we will use the following definition of a robot:

An electromechanical system with some level of autonomy and processing ability which exists in the physical world—that is, it abides by our laws of physics—and can sense and act on its environment to achieve some goal and which follows the O-C-A cycle: Observe, Compute, and Act (Matarić 2007).

This definition changes over time as a result of technological advances. The general consensus in the Robotics Program here at WPI is that a machine must follow the O-C-A cycle in order to be deemed a “robot”. Not everyone agrees with all of the details of this definition, however, as we will see later.

The O-C-A cycle is a simple way to determine the necessary requirements needed to call a machine a “robot”. First, the robot must be able to observe its environment. This can be done with various types of electromechanical sensors, including cameras, microphones, accelerometers, or other devices. These sensors then provide some sort of data for the robot to compute. The data can then be used to control other actions, such as movement of a mechanical limb or response to a voice command. The robot must be able to do this process itself, without the help of a human. Once operational, an autonomous robot will continue to perform its specified tasks until deactivated without additional human input (Matarić 2007).

One defining characteristic of a robot is that it must extend or enhance human capabilities in some way. The goals of a robot are the goals of its creator; if it were necessary to make precision cuts and movements like those required in surgical operations, but it turned out that it would not be humanly possible, we would devise some means by which to accomplish it. Innovation is part of human nature. We create robots to do things that are difficult or impossible for us to do. Some robots are used to make precise, controlled welds which are not achievable by even the most steady-handed humans. Still more have cameras with extremely high resolutions or microphones with many levels of volume amplification, enabling them to see and hear things that would be impossible for an unaided human to sense. In other words, robots extend human senses as part of their observation step in the O-C-A cycle.

Secondly, a robot must be able to compute or calculate. Of course, without any input there is nothing to compute. The observation step of the O-C-A cycle provides information for the robot to abstract and then use it in turn to calculate something. The end result is the output of actions for which the robot was designed. These calculations could be something simple like Cartesian distance, or something much more complex, such as relative gravity on a curved incline. For example, a robot may combine the use of cameras with distance algorithms to determine its distance from another object. There are many applications where a robot receives its input through some means, either human or mechanical, before it will begin performing its calculations (Matarić 2007).

Lastly, a robot must be able to act on its environment. This is one of the most important details of the definition; it differentiates a robot from, say, a computer or a toaster. These machines cannot influence their surroundings in ways that can be physically noticed by humans—at least not on their own—where a robot can. This is a defining characteristic that separates a robot from other electromechanical devices. Acting on the environment by a robot can be done in various ways, be it manipulating objects or moving itself. These actions are usually driven by actuators – mechanical parts for motion, grasping etc. For example, wheels and mechanical limbs can be considered actuators. To function properly, however, is a difficult problem. A robot must use both the “observe” and “compute” parts of the O-C-A cycle in order to act on its environment properly; this all depends on the task for which the robot was designed (Matarić 2007).

A clause of the definition of a robot which merits some investigation is that of autonomy. There is a clear distinction between a machine that is teleoperated, meaning that it is controlled remotely by humans, and one that can operate on its own. For a robot to be autonomous, it must be able to act based on its own decisions. A robot can be given information and data from humans and still be considered autonomous if it must decide how to act upon the information obtained (Matarić 2007).

An important distinction to make is that autonomy and artificial intelligence are not equivalent. A robot can be completely autonomous without having any advanced form of AI. A factory robot used to align boxes for proper packaging, for example, is fully autonomous within the confines of its environment. It can *observe* how the boxes are arranged with the use of a camera. It can *compute* where the misaligned box will be when it reaches the robotic hand. It can then *act* by moving the box so that it is correctly aligned and placed properly with respect to all the surrounding boxes. The factory robot can do this continuously without any human interaction, apart from general maintenance needed to keep the robot running. Many people blur the distinction between autonomy and artificial intelligence; AI can provide the major aspects of autonomy with the addition of a critical improvement — the ability to learn. Granting the ability to learn to a machine is no mean feat, though steady progress has continued for several decades, as we will discuss in a later section (Matarić 2007).

There are many different ways that one may consider an electromechanical machine to be a robot or not. For some, if the machine has the capabilities to make choices on its own, it is considered a robot. This includes self-driven cars and the like. Others may consider an electromechanical machine with operable limbs to be a robot. The former view is more popular with engineers whereas the latter is more common among laymen. As there is no single correct definition of a robot, it is acceptable to have different variations of the characteristics of a robot (Matarić 2007).

This brings us to an important question: What is it that constitutes a robot? The characteristics of a robot have been previously explained. Now we will put this definition to the test with some basic examples: Is a computer a robot? No; although it can observe and compute, it has no means to act on its environment, even if it can be considered autonomous because of its programs and background processes. It would be possible to enable a computer to act physically on its environment; in this case, however, it would no longer be just a computer. Is a toaster a robot? No; it lacks the ability to observe its environment to gain information (timers and thermometers notwithstanding). One may argue that in a way the toaster is in fact acting on its environment by toasting the bread, but an important point to note that it is not doing so on its own; the toasting of the bread requires a person to monitor the bread and stop the toasting or set a predefined time limit. The toaster does not have any *choices* to make and because of this it cannot be considered a robot.

1.2 Advantages and Disadvantages of Robots vs. Humans

A robot may be able to perform actions that humans are incapable of accomplishing. These might include lifting heavy objects or having greater mobility than that of a human. Pertaining specifically to space excavation, these would include the ability to survive in a harsh space environment for extended periods of time.

In the robotics industry there are generally three rules, or more commonly known as the three D's, to consider when deciding whether or not a robot is more suited for a specific task than a human. These include:

- Is the task *dirty*?
- Is the task *dangerous?*
- Is the task *dull*?

If the job fits some or all of these qualifications, then we may be inclined to have a robot do it instead of a human. Of course, each of the three D's weighs differently in importance based on the value of human life. Certainly *dangerous* would be the most crucial factor to consider when choosing between a human and a robot, while *dirty* and *dull* have less weight because they do not have tremendous impact on our safety.

We would not want to send a human out into space to dig for resources on the moon or Mars. This is because it would be a *dirty* task, one that would be unfit for an astronaut who has endured many strenuous hours of training and studying. Sending a trained astronaut to dig for hours on end would be counterproductive. Secondly, the task in itself is a *dangerous* one, as there is a high risk of accident, such as the malfunction of a space suit or spacecraft failures that could jeopardize a person's life. A robot is replaceable, however a human is not. Finally, space mining as a job would be *dull*; even if someone were excited at first, spending hours doing the same thing over and over again would eventually make it boring and *dull*.

In addition to their affinity for the three D's, the benefits of sending robots rather than humans into outer space are the following:

- Robots do not require food.
- Robots do not get lonely.
- Robots can be productive for longer periods than people can.
- Robots do not need training, just programming.
- Robots are reproducible.
- Robots can send data to Earth electronically, eliminating the need for a round trip.
- Robots have a higher attrition rate in inclement environments.
- Robots require less provisions, and may be cheaper to maintain.

A robot is able to operate with no need for food or interaction with others. A human requires food and water to be able to survive, thus this will be extra luggage to take on a journey. There is also a need for a constant supply of air for humans to survive. Robots also need power, usually in the form of battery cells, to function; but these are much more abundant and can easily be recharged through solar power. Humans also require sleep, which will deplete the resources on a spacecraft even when nothing productive is happening. Robots will need to be recharged periodically but this is far less frequent compared to the amount of sleep humans need. Food, water, and oxygen increase the cost of manned missions, however a robot requires none of these human necessities. There is also the possibility of a psychological breakdown. These are incidents that astronauts can be trained for, but may still be difficult to avoid under certain circumstances. These breakdowns are nearly impossible for people to predict, as they can happen at any instant, especially if the astronaut is isolated in a foreign environment without any human interaction. Such isolation can lead to depression and other mental illnesses. Similarly, a robot could malfunction due to poor programming, but with most modern day robots there are contingency plans for these unexpected problems, such as sending patches electronically or automatically rebooting with factory defaults (Van Pelt 2007).

Robots usually do not require training to complete the task that is assigned to them because they were originally built to complete that specific task. Generally, when a robot is programmed, it will follow the code and not deviate from the program. This is more cost effective because the same code can be copied and given to other robots. However, every new astronaut candidate needs to be trained starting from the basics. This process takes time, and is not the same for every person. Furthermore a human could, in a state of panic, forget their training and become unable to complete a task. A robot can also be uploaded with new software that issues new commands for the robot to complete. More sophisticated robots are able to some extent to learn through experience (Van Pelt 2007).

Unlike humans, robots can be replaced easily in the case of a malfunction. If a mission were to go horribly wrong, the astronaut would be lost forever and the valuable time spent into training would be lost, not to mention the loss of a human life. However with a robot the source code is most likely backed up in the event of such a scenario, in which case the development process of the robot can now be skipped and the manufacturing of a replacement robot can take place. There is less of a sense of loss when we lose a robot in outer space when compared to that of a human (Van Pelt 2007).

When we send a human into space there is a need for that person to come back. A human will need to come back to Earth after some amount of time, however a robot was made so that it did not matter whether it returned or not. We would not think twice about leaving a robot on a distant planet, whereas leaving a human stranded in space would immoral. Not having a return trip for robots save on several costs, the greatest probably being fuel. It would require half the amount of fuel for a robot to complete its job compared to a human.

When a human is in space many other factors come into play that could jeopardize the life of the astronaut. Some missions in which we have sent humans into outer space have had unfortunate accidents that have resulted in human casualties. Unlike humans, robots were made with these risks in mind. If a spacecraft carrying a robot were to explode, it would not have nearly as much of an impact on society because it was not a human that was lost in the accident, but just a machine.

An important point to note is that when designing shuttles and rockets with humans in mind there needs to be minimal error in the construction of the vessel. Failing to minimize error could result in a potentially fatal malfunction, however with a robot there can be a larger margin of error. Not only would life support malfunctions be negligible for robots, but such systems could be entirely removed to save money in construction. (Van Pelt 2007).

Another factor to consider, that will be further elaborated on in a later section, is the cost effectiveness of sending a robot as opposed to a human. Generally it will cost $500 million for a low orbit space operation that lasts for approximately two weeks. For the same price, an extraterrestrial land vehicle can be researched and developed that will be able to comb the surface of other planets for a much longer duration of time.

Consider the Mars Rover as an example. The first one sent was only expected to last a few weeks but instead it lasted for three months. This has become a common theme among Mars Rovers—they have greatly outlasted their designed functionality time. If we were to send an astronaut to Mars, the amount of supplies and equipment needed for them to get there would outweigh the benefits of even sending them there in the first place. A one-way trip to Mars would take approximately eight and a half months, which would correspond to a year and five month round trip! (Launius 2008)

It would not financially feasible to send a human to a distant planet for a few days or weeks just to gather some data and return home. However for a robot, it is a one-way trip. There is no need for excess fuel, food, supplies or all the other necessities required for people. This way it is much more efficient and cost effective for a robot to be sent instead of a human. A robot could be designed for a wide array of scouting capabilities, such as an orbital probe or a land vehicle. The orbital probe would be sent first in order to ascertain the geographical terrain of the planet, moon, or asteroid. Then, only after it is determined that there is a high probability of valuable materials, a land vehicle is sent to obtain further data on the terrestrial surface. Finally the robots would be able to dig on the surface for resources, or just wander around gathering data on the ecosystem of the planet (Van Pelt 2007).

The new Mars Exploration Rover (MER) Project, consisting of rovers Spirit and Opportunity, has greatly exceeded initial expectations. At the start of the MER Project, NASA was very cautious with the rovers, fearing that they would break down quickly within the Mars ecosystem because of all the dust storms and climate hazards. However, the rovers lasted for much longer than anticipated; because of this unexpected longevity, NASA is taking greater liberties in the tasks assigned to the rovers, such as sending them into a ditch to fetch a sample of the earth (Van Pelt 2007).

With the great difference in the number of possible tasks per unit price between humans and robots, it is clear which one is more cost effective. Using a metaphor to demonstrate: Why pay for an expensive car that looks good to the public but lacks features and mileage than you would pay for a decent looking car with excellent mileage and features? The same can be said for the cost effectiveness of sending robots as opposed to humans. The performance to price ratio is just that different (Van Pelt 2007).

We have discussed the financial advantages of using robots over humans, but now we must consider that robots can usually only accomplish a certain number of tasks, where there is limitless potential in humans. The disadvantages of sending a robot in place of a human are the abilities to reason and decide which humans possess and robots are unable to match. A robot is essentially a programmable finite state machine which is primarily composed of several phases: start, input, transition, and exit. The robot will strictly follow the program it is given without questioning (Matarić 2007).

It is clear that robots are not as versatile as humans. For example, if there is an interesting object off in the distance, a human will most likely investigate it; a robot must be programmed to do so. Humans have superior intelligence because they have the ability to reason and think critically in different circumstances and situations. Robots fall short in this category because they are only designed to complete certain tasks and nothing more. It is very hard to make a robot that will be able to adapt to every possible situation, and because of this, humans are better in most cases. Of course, there have been great strides in the field of artificial intelligence which try to bridge the gap between the human and robot; this will be discussed more thoroughly in later sections.

1.3 So Which Should We Send?

The utilization of robots in space is a subject which demands careful consideration. The options scientists have when building a crew for a particular mission are: all humans, all robots, or some humans and some robots. An all-human crew requires layer upon layer of safety measures, life support, food and water, but alleviates the concern of human-robot cooperation and provides the maximum level of adaptability to changing circumstances. An all-robot crew resides on the opposite end of the spectrum; their ability to perform repetitive and/or tasks with an extremely high level of efficiency and to work in environments unfit for humans, along with the absence of life support and emergency safety measures would save a great deal of money. The drawback of such a team, however, is the mindless nature of its members. Unable to reason for themselves, they would have great difficulty in adapting to a new situation. The final option, a combination of humans and robots, appears to be the most reliable. Although the presence of humans requires safety measures and life support and thus more funding, it also adds human intuition to the list of assets for the team. Furthermore, the robots will be able to perform their tasks with human supervision, increasing efficiency and allowing for dynamic reprogramming of the robots.

Schmitt (2006) claims that:

> "Deep space exploration should always be conducted by employing the best combination of human and robot techniques. In this context, many will argue the value of robotics. Indeed any data collection that can be successfully automated at reasonable cost should be."

While he supports the use of robots to the greatest extent, Schmitt argues that human presence in space offers invaluable benefits and will continue to do so in the foreseeable future. Our ability to adapt, both physically and mentally, is the key to our value as explorers. For example while camera lenses can see farther and clearer than our eyes, and microphones are more sensitive than our ears, they cannot match our ability to interpret sensory input in a meaningful way (Schmitt 2006).

The above advantages and disadvantages must also be weighed against the duration of the proposed mission. It is safe to assume that a robot will not experience any problems in space resulting from environments that cannot be simulated on Earth. Humans, on the other hand, are well suited for only some of Earth's environments and not at all for space. We experience myriad physiological issues in zero gravity, including altered circadian rhythm, blood volume decrease and muscle atrophy (Schmitt 2006). Some of these effects may be less prevalent in an environment with some gravity, such as the moon, but nevertheless should not be overlooked. Clearly, any initiative to take advantage of the resources available in space must take into account the associated health risks, and the advantages and disadvantages of the composition of a crew selected from human and robot candidates.

2. Regolith and Space Excavation

Regolith is a term used to describe the surface material of the moon. This material is often composed of various types of rocks, dust, and soil. As Harrison Schmitt explains:

> "The Lunar surface material or soil consists of debris derived from all the underlying rocks by eons of meteor impact and fits nicely into a category of geological material called 'regolith'."

The deeper regolith on the moon has a much finer average grain size as opposed to that nearer to the surface. This is important because the finer the grain size means that it has a greater surface area to volume ratio, and as such it will contain a greater density of captured solar wind particles, including Helium-3 and Oxygen. Another important factor is the temperature of the moon at different times of day. This has great impact upon the amount of Helium-3 that is retained in the regolith; the higher the temperature, the more Heluium-3 will be captured. After processing, it is possible to extract some amount of Helium-3 from the regolith (Schmitt 2007).

Now that we have a basic understanding of what regolith is and how it is formed, we must look at Helium-3, the most important ingredient in regolith.

2.1 About Helium-3

Helium-3 is non-radioactive isotope that is pursued for use in nuclear fusion research. It is a byproduct of tritium decay. Scientists want to study the isotope in order to possibly create more efficient forms of nuclear fusion. First-generation nuclear fusion used deuterium and tritium which had low efficiency in terms of power yields. However, scientists have theorized that the combination of deuterium and Helium-3 could have a power yield efficiency of up to 70%. Having a large abundance of Helium-3 could make it possible to power nations for several hundreds of years and would be much cleaner than fission plants. Other uses for Helium-3 include, but are not limited to neutron detection and cryogenics (Schmitt 2007).

The concentration of Helium-3 in regolith is typically very sparse. It is estimated that 100 million tons of lunar regolith, once processed, will yield one ton of Helium-3. Unfortunately, this means that it would take a great deal of regolith excavation before Helium-3 could be put to practical use (Schmitt 2007).

2.2 The Need for Regolith

We have explained the various uses and properties of regolith, but is there really a need for it? NASA has high hopes that they can use the lunar regolith to accelerate the construction of a lunar base:

> "At the core of NASA's future space exploration is a return to the moon, where we will built a sustainable long term human presence. As the space shuttle approaches retirement and the international space station nears completion, NASA is building the next fleet of vehicles to bring astronauts back to the moon, and possibly to Mars and beyond" (NASA 2009).

In the hopes that a manned mission to Mars will become a possibility, NASA plans to send astronauts back to the lunar surface after a thirty-seven year absence, and has designed a base which will be built at one of the lunar poles. The base will be solar powered, and supplied with oxygen through the on-site processing of regolith. Ideally, it will be possible to use this lunar base as a stepping stone for longer space missions; in particular, NASA intends to launch a new type of spacecraft that will be able to take advantage of the reduced gravity of the moon (NASA 2009).

NASA's desire to build such a structure on the surface of the moon may also lead to commercial interest in the resources there. The known byproducts of regolith processing are oxygen and Helium-3, but it is also thought to be possible to isolate silicon and titanium. Oxygen will be necessary to sustain any human presence on the moon, titanium will be used in the construction of new spacecraft, and silicon will be useful for building solar panels to power the base. As it stands now, there is no industrial need for Helium-3, as we are yet unable to control and sustain a fusion reaction; however, it has been suggested by many that university and government research groups could use the Helium in attempts to master the technique. Doing so would solve many of the resource-related issues facing our global economy, and open the door for deep-space exploration (Schmitt 2006).

The moon is currently non-territorial, like the continent of Antarctica. What would happen if one nation were to construct buildings on the moon? It is possible that territorial disputes may arise, which would require international treaties and agreements. We will elaborate further on this topic in a later section.

2.3 Possibilities of Near-Earth Locations for Mining

Current terrestrial locations of interest for exploration in space are Mars and the Earth's moon. There are several compelling reasons for humans to explore each of these possibilities.

The moon has always been in Earth's orbit, but discoveries suggesting the presence of water on the moon were not made until recently. The moon's surface is composed of a loose layer of rocks, dust and soil called regolith. The presence of atoms of Hydrogen and Helium within the regolith on the surface of the moon has been confirmed. The discovery of Helium on the surface is of particular importance, as it is not ordinary Helium but Helium-3. This isotope is a very rare substance on Earth because it is only found near places of volcanic activity. It has potential for use in fusion reactions, possibly making fusion a viable source of energy. Both the discovery of water and Helium-3 on the moon have proven to be significant finds, because with an abundance of these new resources, our energy consumption habits may change (Matloff 2007).

The moon may have many more secrets that could be discovered by more thorough investigations. The recent discovery of frozen water on the moon may lead to further missions that could potentially lead to the creation of a lunar base. This lunar base could be a waypoint of sorts for mining operations and refueling of passing shuttles. The discovery of water also makes the idea of actually living on the moon less a farfetched dream and more a possibility. Water is the most vital part of our human ecosystem. Without it, life as we know it would cease to exist. The presence of water on the moon makes it more feasible to live there and also makes it another resource that we do not need to transport into orbit, which would spare us some costs.

2.3.1 The Moon

There are several reasons why it would be financially beneficial to mine on the moon. There are valuable resources such as Helium-3 and Hydrogen which could be used in a variety of ways to create energy. Because Helium-3 is very hard to find on Earth, it is reasonable to look at the moon as a viable place to obtain it. The important aspect of Helium-3 is that it is shown to have a much more stable fusion reaction than the current deuterium and tritium combination and has higher energy yields (Stone 2009).

Hydrogen is another valuable resource that we could use. There has been recent interest in using hydrogen as fuel in cars and other vehicles, which would reduce the amount of pollution compared to that of carbon dioxide exhaust. Hydrogen also has the capability to be used in rocket fuel as described by William Stone, an aerospace engineer and explorer from Shackleton Energy Co.:

> "Assuming the [moon] ice exists and can be extracted, our plan calls for establishing a fuel- processing operation on the lunar surface. The first step would be to melt the ice and purify the water. Next, we'd electrolyze the water into gaseous hydrogen and oxygen, and then condense the gases into liquid hydrogen and liquid oxygen and also process them into hydrogen peroxide, all of which could be used as rocket fuels."

This is based on the hypothesis that there is indeed buried ice on the moon, which has recently been confirmed. However, it is more likely that the supply of Helium-3 and Hydrogen will come from the lunar regolith. Large amounts of this substance are found in craters spread out across the moon. Regolith has very unique properties that give it the consistency of wet sand, which could cause malfunctions in mechanical components of a robot. These properties of regolith lead scientists to believe that there may be large amounts of ice under the surface layer of regolith on the moon. The Shackleton crater was one of the many craters that exhibited large amounts of Oxygen when scanned by the lunar prospector (Stone 2009).

With the production of efficient fuels, and power generated from the processed materials on the moon, we may reach a new frontier in human history. Commercial space flight and further exploration/expansion could then become possible.

The construction of a lunar base as headquarters for lunar excavation operations is a logical first step. The base would be beneficial because the processing of the regolith could be done on the moon and then have the materials shipped back to Earth. This would be much more efficient, saving money on fuel as well as time in shipping. The lunar base could also serve as an outpost for refueling and maintenance of spacecraft (Stone 2009).

The construction of a lunar base would require a significant amount of funding—funding which no country currently wants to provide. It will take years before any tangible difference in society is observed as a result from construction and subsequent use of a lunar base (Stone 2009)

2.3.2 Mars

Another possible site for space mining is Mars. Infrared spectra of the Martian surface have revealed areas of intense hydration near the poles, which are indicative of large amounts of hydrogen, perhaps in the form of ice or water buried deep beneath the surface (Encrenaz 2006). There is also an abundance of carbon dioxide, which constitutes about 96% of Mars's atmosphere. This pure carbon dioxide could potentially be split into carbon monoxide and oxygen to be used as propellants. It could also be processed into solid carbon and ozone (Lewis 1997).

Here are some of the most common resources you can obtain from the atmosphere of Mars taken from John Finn and K. Sridhar's report on mining the martian atmosphere:

- **Compressed carbon dioxide:** There are several uses for the compressed CO_2 utility gas. In science instruments they can be used to blow dust off optics and instrument interiors, clean specimens, etc. In robotic missions they can be used, among other things, to blow dust off solar panels, inflate panels and structures, give propulsive thrusts to unjam stuck mechanisms, and provide the "feed stock" for propulsion generation plants. In manned missions, the gas can be used for the above applications as well as oxygen generation for life support, and for plant growth chambers. They can also be used as a means of providing the "green-house gas" for an enclosed Mars dome.

- **Nitrogen and argon mixtures:** The gases can be used as a carrier gas in instruments, buffer gas for life support, and as a source of nitrogen for other chemical processes (production of ammonia for example).

- **Oxygen generation:** Oxygen can be produced from the predominantly carbon dioxide atmosphere by a process called solid oxide electrolysis. In this solid state process oxygen and carbon monoxide are produced from the feed gas of carbon dioxide. Oxygen thus produced can be used for propulsion and/ or life support.

- **Carbon monoxide:** Carbon monoxide is the byproduct of the CO_2 electrolysis process. This "fuel" can be used to advantage for Mars surface propulsion, and as a fuel to operate a regenerative fuel cell in the night, if the electrolysis is performed during the day with photovoltaic cells. In this manner, the same CO_2 electrolyzer stack hardware will perform as a fuel cell during the night (an energy storage device with high efficiency).

- **Carbon:** Carbon can be produced by disproportionating the carbon monoxide to produce solid carbon and CO_2 . If this process is added to the electrolyzer, the end products of the combined process would be solid carbon and oxygen. Carbon can be used as a fuel, or as valuable carbon fiber that will be used to build reinforced fiber composites.

- **Water:** The small amounts of water present in the atmosphere can be mined using a temperature swing adsorption process. The volume of air that needs to be processed to obtain significant amounts of water is quite high in most locations. Since the planetary materials required for the above processes come from the atmosphere that is relatively homogeneous, this concept can be site independent as long as it is on the surface of Mars. Most of the processes described here require very little, if any, electrical energy. The primary source of energy for most of the processes comes from the diurnal temperature swing on the surface. Most of the components involved in these processes are solid state, i.e., they have very few moving parts and hence, inherently more reliable. The solid oxide electrolysis technology can be used to extract oxygen in the carbothermal or hydrogen reduction process used for LUNOX from regolith (commonalty of technology for Moon and Mars ISRU). (Finn 2009)

2.4 Problems with These Locations

Now we take a look at the problems surrounding each of the near-Earth locations for mining. First let us take a look at the moon. The moon is the most likely candidate for establishing an extraterrestrial base of operations. There are two ways in which the regolith on the moon could be processed: we could send it back to Earth, or process it on the moon. The latter is generally more supported, because the amount of fuel spent and the burden on spacecraft leaving the moon orbit would be very costly even though the moon is $1/6^{th}$ the Earth's gravity (Schmitt 2006). Also important to note is that we would be sending unprocessed regolith back to Earth. Recall that the ratio of Helium-3 obtained per ton of regolith is very little. It would be inefficient to send a payload of about four tons back to Earth when it would only yield about a hundred pounds of Helium-3! If we decided to process the regolith on the moon, we could send four tons of pure Helium-3 with no extra garbage included (Schmitt 2006).

The moon is subject to drastic temperature changes, making it difficult for humans to be on the surface of the moon for extended periods of time. This is where the use robots comes into play. Robots would be able to work in these harsh temperatures, both hot and cold.

2.4.1 Territorial Dispute over the Moon

Like the Antarctic, the Moon is also considered non-territorial. Only recently have nations begun gathering resources from Antarctica's continental shelf; indeed, this has caused much dispute and new laws and regulations have been enforced (Schmitt 2007). This process was very drawn out and it hindered the accessibility of resources. From this process, people have learned that the moon shares many similarities with the Antarctic, including its harsh and hazardous environment which makes it very difficult to gather resources. As a consequence of the mistakes made during the Antarctic treaties, nations have devised a much more flexible treaty for space, as explained by Harrison Schmitt:

> “The only space treaty directly related to the use of resources from space to which the United States and other spacefaring nations are party, the 1967 Outer Space Treaty, specifically provides a generally recognized legal framework for such use. The Outer Space Treaty does not contain specific rules relative to the extraction and use of lunar resources. The Treaty's provisions, however, imply certain guidelines that should be adhered to by any national or private effort to use lunar resources.”

The guidelines set forth by the 1967 treaty stipulate that the moon does not belong to any one country, but is rather “the province of all mankind.” Furthermore, any wealth which is gained through exploitation of the moon is to be divided among all countries (Office for Outer Space Affairs, 1967).

2.4.2 Difficulties with Mining Mars

The complications surrounding Mars are the distance, climate, and questionable need for the resources available there. To get to Mars it would take around eight and a half months (Launius 2008). It would take far too long to return the processed materials to Earth. The only plausible reason for a trip to Mars, then, would be to inhabit the planet, which introduces another problem: the atmosphere of Mars is very thin, and is mostly carbon dioxide. A potential Martian ecosystem would need to be altered in order for humans to live there. Finally, there is currently no major demand for mining anything from Mars, as most of the materials available on Mars are not exceptionally rare.

3. Past and Current Work

Beginning as a side-effect of the allied rocketry research in the first and second world wars, the American space program has seen dozens of continuing missions and hundreds of eager astronauts volunteering for them. In the past, NASA has sponsored attempts to observe the other planets in our solar system as well as our sun, and spent considerable amounts of time and resources pointing satellite cameras at far-off areas of the night sky (NASA 2009). Our desire to learn about and understand our environment is what compels us as a society to continue in this area.

3.1 Past Work

One mission in particular, the Genesis mission, which launched in 2001, exemplifies our thirst for knowledge. Its aim is to gather information that might lead to answers for lingering questions we have about our solar system. Particularly, how the solar system was formed and why there is no detectable life anywhere but on Earth. As is always the case when we try to learn something new; we uncover more questions that need to be addressed. When fuel production costs for shuttles become more economically viable, there will certainly be space missions to much farther destinations than what we have attempted in the past (NASA 2009).

Robotics has been a rapidly developing field since the early 1940s. A pioneer in the science fiction genre, Isaac Asimov, wrote several rules that a robot must always obey:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.

3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law. (Asimov 1991)

Although these rules were born from a book, they are widely accepted as the rules that govern robots.

In the late 1970s there was a boom in the establishment of institutions for developing robotics. Some of the more notable ones were Carnegie-Mellon, Stanford and Cal Tech. Other institutions have followed suit over time and robotics started gaining more and more momentum. These institutions have researched various applications which center on the use of robots.

To tie space mining and robotics together, lack of breathable atmosphere and extreme hot and cold temperatures make space a very dangerous environment for humans. In keeping with the nature of robotics, it is logical to send robots into space for the sake of our safety. Of course, robots cannot be expected to replace humans entirely, and many of the current applications of robots in space rely heavily on having humans present (Launius 2008).

3.2 Current Work and Research

We have discussed the past work that has led us to the current level of interest in space mining. The current work in this area would be impossible without the foundation that has been built over the past 60 years.

3.2.1 Down-Well Tactile Exploration

MIT's Steven Dubowsky, with group members Dan Kettler and Francesco Mazzini, are currently researching ways for robots to autonomously probe and navigate different types of surfaces. Their approach makes use of a robotic arm to sense the surrounding environment. This is done through tactile means: the robotic arm touches surrounding surfaces, then through information obtained from its sensors, is able to create a map of its environment (Dubowsky 2009).

Although this research is being conducted for current terrestrial applications, their project is extensible to space mining applications as well. An excerpt is taken from the project website:

> Concurrently with the design and construction of the manipulator, the control strategies required by such a system are being developed and tested. The robot, provided with only joint angle sensors, needs to autonomously move in the environment and tactily probe the surface. Information obtained this way is used to incrementally guide the robot in order to complete the exploration in the least possible time, and to create a three-dimensional map of the environment. As a generalization of the oil well problem, this approach is currently being extended to the tactile mapping of a generic man-made environment. The primary areas of investigation are:
>
> -Design of guidance strategies to complete the exploration with minimum time and maximum precision.
> -Processing of the acquired tactile data in order to create an accurate 3D map.
> -Dealing with constraints due to the environment, like how to reach “hidden” surfaces or avoid unwanted collision between robot links and surroundings. (Dubowsky 2009)

3.2.2 Fundamentals of Digital Mechatronics

MIT’s Steven Dubowsky, with group members Lauren Devita (MS student), Cristina Paul (visiting student), Jean-Sebastien Plante (PhD student), and collaborators Professor Sergio Pellegrino, Matthew Santer and Tyge Schioler from Deployable Structures Lab of Cambridge University, and Professor Ferenc Jolesz and Dan Kacher of Harvard Medical School, are currently researching the development of both the fundamental design schemes for digital systems and the potential actuation mechanisms in order to improve the capabilities of a robot. For example, the traversal of a legged robot over various sorts of terrain would only be possible with many binary actuators (Dubowsky 2009).

A binary actuator has two states, which correspond to '0' and '1'. Unlike a general mechanical system with continuous-range-of-motion actuators, a mechanical system with such binary actuators has only a finite number of kinematical states (Hanahara1999).

Taken from the MIT Field and Space Robotics Laboratory Website:

> Current actuators like DC motors and pneumatic cylinders are too heavy, expensive, or complex for binary robotics, and therefore new actuator technologies are being developed. An important focus of this research is Electrostrictive Polymer Artificial Muscles (EPAMs). Currently we are developing models for explaining the behavior of these actuators and optimizing their performance. Various analytical and experimental studies are being done to evaluate their effectiveness as conventional actuators for use in digital systems or other scientific and commercial applications. (Dubowsky 2009)

With the increasing use of new types of actuators, performance and efficiency of robots will vastly increase, granting robots the capability to handle more diverse tasks.

3.2.3 NASA's Regolith Excavation Challenge

NASA's 2009 Regolith Excavation challenge was completed with nineteen teams entering in the competition. The total prize money was $750,000 and the event was sponsored by Centennial Challenges program in NASA's Innovative Partnerships Program Office. This is the third that that NASA has held a competition for robotic regolith excavation. However, this is the first time in which prize money was actually awarded to any team (NASA 2009).

The competition took place at NASA Ames research center at Moffett field. The winners of the competition were Paul's Robotics of Worcester, Massachusetts who won $500,000 dollars for placing first, Terra Engineering of Gardena, Calif., who was a three-time returning competitor and was awarded second place prize of $150,000, and Team Braundo of Rancho

Palos Verde, Calif., took the third place prize of $100,000 as a first-time competitor (NASA 2009).

The competition required that the machines were able to excavate at least 330 pounds of regolith in a 30 minute time slot. The rules allowed the use of tele-operated robots that had a 4 second round trip time delay to simulate transmitting and receiving signals from the moon. The robot also had to weigh less than 176 pounds (NASA 2009).

Paul's Robotics excavated 1,103 pounds within 30 minutes making them the overwhelming winner in the competition. The runners-up, Terra Engineering and Team Braundo, excavated 595 pounds and 580 pounds respectively (NASA 2009).

Lynn Baroff, executive director of the California Space Education and Workforce Institute, who lead the panel of judges said:

"It's really encouraging that we saw three teams achieve the minimum requirements and shows that innovation is not only alive but growing. It's really great that through this competition NASA is actively seeking to recognize citizen inventors from across the nation whose ideas may one day contribute to space exploration"(NASA 2009).

Regolith is a very difficult substance to excavate because of its viscous nature. This makes it hard to create a robot capable of operating when dust particles could potentially damage various components. The winning teams in this competition showed great technical prowess because their robots were able to both traverse through regolith and carry it back without much problem (NASA 2009).

Greg Schmidt, deputy director of the NASA Lunar Science Institute at Ames said:

> "This was an incredibly tough competition, and teams came up with fantastic ideas, some of which might find use in future missions to the moon. It's great to have a winner this year. The biggest win is getting so many talented young people involved in NASA's mission of exploration" (NASA 2009).

3.2.4 Artificial Intelligence

Another area whose development is important to robotics is that of artificial intelligence. Today's robots make use of AI for a wide range of things, including sensory interpretation and movement (Russell, Norvig 2009). There are many aspects of AI that would fit nicely with the requirements for a space excavation robot.

A digging robot might keep track of its own location with Monte Carlo localization—a comparison of possible states the robot could be in, based on evidence it has gathered with its sensors (Russell, Norvig 2009). This would take some of the burden off of the robot's controller; rather than constantly monitoring where each robot is all the time, each robot would report its location to the controller.

It would also be useful to have some way to compensate for the damage that is likely to occur when working with lunar regolith, which can block cameras and otherwise interfere with sensors. There are many approaches used in AI to deal with uncertainty, which include probabilistic modeling and methods for determining the most likely state. Using a combination of these methods (and an arbitrary coordinate system), a report given by a robot whose sensors are not functioning properly might look like this:

- Time – 19:52:07, 11/2/2023
- Sensor failure – camera blocked or damaged
- Last known location – (114, 82)
- Believed location – (114, 84)

Machine learning could also be applied to robotic space excavators. Using sensors to keep track of the amount of regolith excavated, a robot could be programmed to mine at different rates or angles, in different locations, etc. It would then report the method or location that yielded the highest efficiency in order to improve future mining attempts made by the robot.

3.3 Impact

The immediate impact of successful space excavation will neither be a tremendous financial boost nor will it likely be a long-lasting international news story. The truly important aspect of this endeavor is that it opens the doors for other projects; projects which have much greater costs and payoffs. One of the reasons for wanting to excavate regolith on the lunar surface is to make way for construction of a lunar base. The existence of such an outpost would make longer-range space missions a possibility, as the moon's reduced gravity will reduce the amount of fuel necessary to launch. Another major reason is the potential of the byproducts of regolith processing, especially helium-3.

There has yet to be a manned space mission to any extraterrestrial surface other than our moon. While there has been talk of sending astronauts to Mars, major obstacles exist in the form of financial and technological constraints. We do not have the life supporting technology to send humans such a great distance over such a long period of time – approximately 8 and a half months. The need of a return trip essentially doubles the costs. For these reasons, the only craft we have sent to Mars to date have been cameras and robotic rovers.

Finally, and perhaps most importantly, a controlled nuclear fusion reaction is theoretically possible. Sustaining such a reaction at a manageable temperature for some significant duration of time would be an enormous breakthrough. Such a development has the potential to solve many or all of Earth's outstanding energy crises. Progress in this field is rather sluggish, however, owing in no small amount to the lack of raw materials necessary for research.

Production of helium-3 using materials available on Earth is possible, mainly as a byproduct of existing nuclear reactors, but the financial and safety concerns are essentially prohibitive. It would be far more economical to devise some method of efficiently extracting helium-3 from lunar regolith. Doing so would open the doors for increased fusion research which, if successfully completed, would repay its funding at least several thousand times over.

4. Financial Aspect

This section will briefly discuss the financial aspects of robotic space mining specifically pertaining to our moon because it is currently our only viable option for resources. We will explore the reasons for why there is such a push for robotic space mining, the concerns of undertaking such an endeavor, and the current financial status of NASA.

4.1 Rocket Costs

The first and most important factor to consider when determining the total cost of sending a rocket to and back from the moon are the rockets and fuel needed to propel them. The cost of this is highly dependent on the type and current dollar per kilogram of fuel used in the rockets. Rough estimates range from $3000/kg to $10,000/kg (Schmitt 2006). If for example we were to send a payload of 100,000kg then it would cost $300 million-$1 billion to launch it. This does not include the amount required to send the shuttle back to Earth from the moon but that amount is substantially less. In total it costs around $1.7 billion to $2 billion to build and launch a space shuttle. Development costs for the actual rocket are generally expensive to design and build (Schmitt 2006).

4.2 Price of Processing Regolith

According to NASA, using a test area of 100ft x 100ft and filled to a depth of 3ft as an example, to simulate the cost of lunar regolith we use the cost for processing rock for road fill on Earth:

Begin by tabulating some basic characteristics.

The regolith weighs approximately 1.6 g/cm^3
Conversion factors: 1 ft^3 = 0.0283 m^3 = 28,300 cm^3 ; 1 lb = 0.45 kg
Simulant weight per volume: 45.3 kg/ft^3 = 100lb/ft^3 ; 1 m^3 =1,600 kg
Local bulk rock for road fill is ~$10/ton (English).
Haul cost for local material is ~ $10/ton (English)
This assumes a vehicle able to make several trips from the quarry to construction site (processing plant) each day.
Volume: 30,000 ft^3
Weight per volume: 100 lb/ ft^3
Unit conversion: 2000 lb/ton
Cost per ton: $20/ton
Total weight: 1,500 tons
Final cost: $30,000
(Rickman 2009)

It would cost approximately $30,000 to move 1,500 tons of road fill. This approximation does not include labor costs and other extraneous costs such as additional crushing of the lunar regolith. The yield of Helium-3 is about 1 ton per 100 million tons of lunar regolith (Schmitt 2006). According to Schmitt the development of a lunar miner-processor and associated facilities would cost approximately $1 billion, requiring an annual upkeep of around $200 million.

Analysts speculate that the cost for prospecting lunar regolith will cost $20 billion over the course of a decade (Stone 2009).

4.3 Costs of Researching Helium-3 for Fusion

As with most new technologies a lot of money is spent in research and development. This is no exception with Helium-3 processing. At first a few experimental processes which will take several years will be explored in parallel costing around $150-$300 million each. Then after a candidate process is finally selected several billion dollars will be invested in creating a power plant capable of using the accepted process. This in total would be around $4-6 billion (Schmitt 2006).

4.4 Benefits of Helium-3

The only way that space mining would be feasible is if helium-3 would help in the development of fusion technologies. As stated previously, research is being done to investigate the possible combination of deuterium and helium-3 to further fusion power development (Schmitt 2006). From a financial standpoint, the realization of fusion power would reduce the cost of electrical power to consumers (Schmitt 2006). This of course will take a few decades in order to be economically feasible for the consumer.

4.5 Costs of Research and Development of Robots for Space Mining

The primary mission for the Mars Exploration Rover (MER) Project cost approximately $820 million (Musser 2004). The Mars Rovers are capable of exposing fresh rock over an area of 4.5cm in diameter, to a depth of 0.5cm (Haldemann 2001). The robotic vehicles needed for lunar excavation would need to have similar features to that of the Mars Rovers, except they should be able to carry large loads of regolith. Therefore the estimated price range of the robotic space mining vehicle should be in the same general vicinity as the costs of the Mars Rovers.

4.6 Current Financial Status of NASA

NASA's current yearly budget is $18.7 billion. NASA was expected to receive extra funding for their Constellation Systems Project which would enable manned missions to the moon once again. Just recently President Obama's budget request for 2011 has been released and effectively terminated the Constellation Program (Achenbach 2010). According to the budget request:

> The Administration proposes to cancel the Constellation Systems program intended to return astronauts to the Moon by 2020 and replaces it with a bold new approach that embraces the commercial space industry, forges international partnerships, and develops the game-changing technologies needed to set the stage for a revitalized human space flight program and embark on a 21st Century program of space exploration. (United States of America 2010)

Their justification is as follows:

> The National Aeronautics and Space Administration (NASA) initiated the Constellation Systems program in 2005 to develop rockets, capsules and other systems to return astronauts to the Moon and eventually send them to Mars and beyond. Initially, the first major elements of the program were planned to come online no later than 2012. By early 2009, however, the program was behind schedule, could not achieve its goals without multi-billion dollar budget increases, and was not clearly aimed at meeting today's national priorities. Costs for the program had grown by billions of dollars and the first elements of the system were not projected to be available until 2015. In April, 2009, the Congressional Budget Office estimated that NASA's budget would need to be increased by about $2.5 billion per year to maintain current schedules, and that even then the International Space Station -- scheduled for completion in 2010 -- would need to be abandoned in 2016 to free up funding for Constellation.
>
> In May 2009, the Administration commissioned an independent blue-ribbon panel to review NASA's human spaceflight programs and plans. The review found that the Constellation program would not be able to land astronauts on the Moon until well into the 2030s -- more than 10 years later than planned -- without large budget increases.2 The review also noted that investment in a well-designed and adequately funded space technology program is critical to enable progress in exploration, that increased international cooperation could lead to substantial benefits, and that commercial services to launch astronauts to space could potentially arrive sooner and be less expensive than Government-owned rockets.
>
> In place of Constellation, the President's Budget funds a redesigned and reinvigorated program that focuses on leveraging advanced technology, international partnerships, and commercial capabilities to set the stage for a revitalized human space flight program for the 21st Century. The President's Budget will also increase NASA's funding, accelerating work -- constrained for years due to the budget demands of Constellation -- on climate science, green aviation, science education, and other priorities. (United States of America 2010)

Although NASA would still get an increase of more than $1 billion a year it was not nearly as much as the previously expected $3 billion to fund the Constellation Systems Program (Achenbach 2010).

5. Mining

This section will explore the different mining techniques capable with our current technology. Since the moon and mars has such a different environment from that of Earth we are challenged with problems that arise due to extreme temperatures and low gravity. Methods that ordinarily work on Earth may need to be reconsidered and reworked to function properly on other planetary surfaces.

5.1 Surface Mining on the Moon

These methods do not require personnel to go underground in order to harvest the resources. These techniques are more popular and applicable than the underground mining methods. The most appropriate methods are open pit mining, strip mining, and dry dredging (Gertsch 2009).

5.1.1 Open Pit Mining

This method of mining is best used when dealing with thick deposits that are at shallow depths. Open pit mining is done by removing all the material and creating horizontal "benches". These benches progressively become smaller in area the deeper the pit becomes. The unnecessary material is then discarded into stockpiles on the nearby surface (Gertsch 2009).

5.1.2 Strip Mining

This method is similar to open pit mining but instead of dumping excess material in nearby stockpiles you discard it in previously mined areas. Strip mining is generally done when the majority of the resources are near the surface. This method removes a large strip of land and moves on to the next strip of land (Gertsch 2009).

5.1.3 Dry Dredging

This method requires the drag scraping of material and then tossing the unwanted materials out while keeping the required minerals. This method is similar to slusher mining used in many underground mining methods (Gertsch 2009).

5.2 Underground Mining on the Moon

These methods require the use of passages deep beneath the surface layers. The main types of underground mining applicable to the moon are unsupported, supported, and caving (Gertsch 2009). The first technique requires no support beams to hold up the passages, the second technique requires the use of beams to hold up the tunnels created, and the third technique removes the support beams in order to cave in the roof of the tunnel to potentially making it possible to mine more materials (Gertsch 2009). These methods would dig into the harder and more compact lunar regolith. Currently this option is not feasible until we know more about the composition of the deeper layers of regolith.

5.3 Complications

Due to low gravity, temperature, and regolith composition complications may arise. Our current techniques for mining have only been applied to Earth. There are several problems:

- Our current technology is too bulky and heavy to send to the moon.
- Current mining methods require too much energy.
- Large amount of personnel will not be available in space.
- The environment causes problems with equipment design.

5.3.1 Heavy Equipment and Energy

Large scale operations require heavy equipment to mine and then a lot of energy process the material. The problem is that we need to send this equipment to the moon. This requires a lot of resources to do and most likely will not be attempted (Chamberlain 1993).

The solution to these problems may lie with percussive digging. Our current machines rely on shear force and weight. Since the moon is 1/6th the Earth's gravity this approach is not feasible, not to mention the launch costs associated with sending such a large piece of equipment into space (Zacny 2009).

The percussive digging method uses a percussive actuator—which vibrates or rotates cutting tools rapidly so that it can dig deeper and faster with force that is much lower than a corresponding non-percussive scoop (Zacny 2009). Since this machine is much lighter than other machines it would save billions in launch costs alone. The only trade-offs are that it requires additional energy to drive the actuator, however this is offset by the fact that it can be solar powered (Zacny 2009). Figure 1 below is an example of a percussive digger set-up.

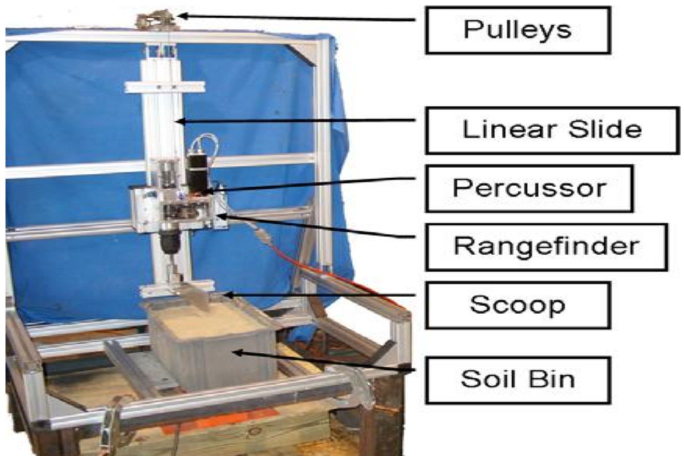

Figure 1: Percussive digger set-up.

5.3.2 Large Amount of Personnel

It is no surprise that extraterrestrial environments are not the most human-friendly. That being said we will not be able to consistently monitor mining progress on site. The solution to this would be having teleoperated robots do the digging for us. By doing this we will be able to monitor the progress of mining and be able to control to a certain extent where exactly we want to mine (Chamberlain 1993).

5.3.3 Environmental Concerns

The moon has 1/6th of Earth's gravity, making conventional methods of mining which require Earth's gravity non-applicable. Some machines would need to be 6 times their normal size in order to produce the same results. Another concern is the extreme temperatures of the moon. During the day temperatures will go as high as 125^{o}C and will reach -170^{o}C during the lunar night. This makes it extremely difficult for engineers to design equipment that can withstand such a high fluctuation in temperature. Since the moon has such a thin atmosphere the machines will be affected by space vacuum. This makes most lubricants deteriorate quickly preventing mechanisms from functioning correctly (Chamberlain 1993). The last concern is you are not protected from solar particle radiation and galactic radiation. Normally the Earth's atmosphere provides us protection from such radiation, however on the moon there is no such atmosphere this is one reason why we cannot send large amounts of people to the moon. The amount of radiation would be too much for humans to handle. Another problem is that this radiation can interfere with electronic circuits on robots or machines (Schmitt 2006).

The solution to most of these environmental concerns would be to create a new mining technology that does not depend of conventional gravity techniques, can effectively withstand large fluctuations in temperature, not rely of lubricant, and can be shielded from radiation. The answer most likely lies with that on a teleoperated robot that is compatible with the lunar environment and does not require much maintenance to operate (Chamberlain 1993). Of course it is not as easy as it sounds. There are still variables that we cannot account for such as how much long-term regolith mining would wear the machinery, which only time can tell (Gertsch 2009).

5.4 Mining on Mars

Most of the techniques used on the moon would be applicable on Mars. They would need to be adjusted so that the machinery would be able to effectively run on the Martian surface. Other than mining the surface of Mars, there is another interesting approach that involves mining the atmosphere of Mars.

5.4.1 Mining Mars Atmosphere

The Mars atmosphere contains carbon dioxide, nitrogen, argon, water, oxygen, carbon monoxide, and carbon. By using different techniques we can extract these resources. The adsorption/desorption cycle is a way that we can separate nitrogen and argon from the atmosphere as well as produce compressed pure CO_2. The key concepts behind this idea are separation, compression, and reaction units. The separation and compression of the Martian atmosphere is done with temperature-swing adsorption (Finn 2009).

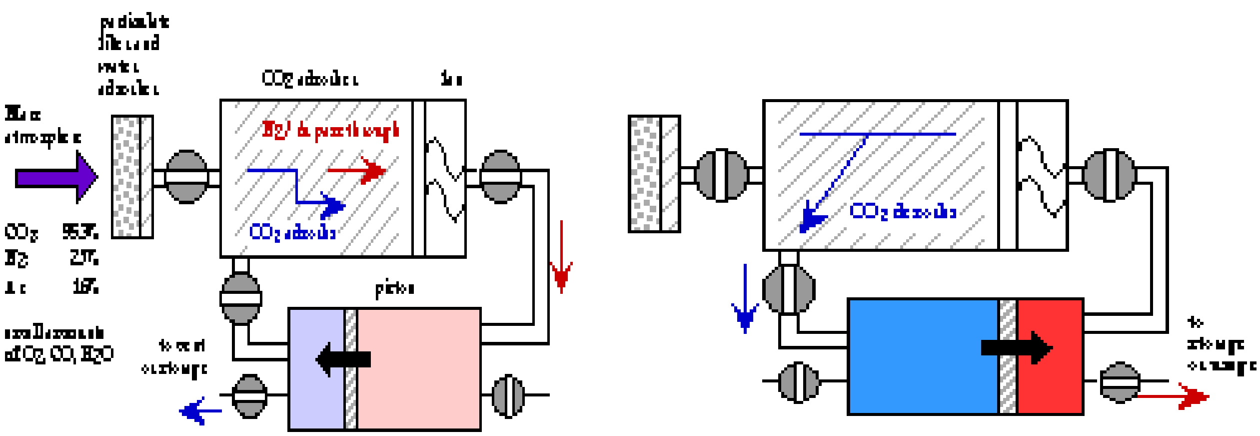

Figure 2. Simplified schematic of an adsorption-based process for production of compressed pure CO_2 and N_2/Ar gas from the Martian atmosphere. At **left**, the atmosphere is drawn under cold nighttime conditions through a column that selectively adsorbs CO2 while N_2/Ar passes through and is collected. At **right**, the column warms under daytime conditions and desorbs CO_2 at elevated pressure. In this drawing, the CO_2 is used to compress the N_2/Ar mixture (Finn 2009).

6. Robot Ethics (Roboethics)

> "Robots are going to permeate our society, from the humanoids, to robots of several different shapes and functions, according to the roles they will be performing in society. Human life will depend ever more from robot's interventions, both because they will control the elementary activities and facilities, and because, ultimately, on them the well being or even the extinction of humankind is going to lie." (Veruggio 2004)

This section will briefly describe the controversial topic of whether using robots in a given application is ethical or not. Roboethics is rapidly gaining recognition as a field that must be given attention due to all the concerns regarding various applications of robots.

6.1 Concerns

With new emerging technological advances in robotics, concerns have been raised about whether these accomplishments can be considered ethical. A meeting was held 30th - 31st January 2004 in Villa Nobel, Sanremo, Italy called The *First International Symposium on Roboethics.* Their goals were:

- To increase public awareness about Robotics, opening a debate based on correct information, permitting people to actively take part in the process of creating a collective consciousness able to understand and prevent the wrong use of technology.
- To actively promote the development of Robotics to move towards the social progress of Humankind and the protection of the Earth.
- To refuse any involvement in programs aimed at the design, the construction and the use of Robots against human beings and their Environment.
- To contribute to the creation of a “common ethic”, that could be shared by all cultures, all nations and all faiths, according to which the design, building and use of “intelligent machines” against human beings is considered a crime against Humankind

(Veruggio 2004)

Roboethics encompasses the topics of economy, psychology, law, health, military application of robotics, environment, and technical dependability. From the proceedings of the 2009 IEEE

International Conference on Robotics and Automation held in Kobe, Japan from May 12-17 of 2009 the following topics in each field were discussed:

Economy:

- Replacing humans in the workplace;
- Robotics and job market;
- Cost benefit analysis;
- Transparency and public consensus;
- Robots as things;
- Remote control and cooperation in the workplace.

Psychology:

- Position of humans in the control hierarchy;
- Robots and kids;
- Robots and elderly, disabled and ill people;
- Robotics in Education.

Law:

- Robots and liability;
- Identification of autonomously acting robots;
- Position of humans in the control hierarchy;
- Biometric data processing by intelligent systems;
- Multi-agent decision making.

Health:

- Robotics in surgery;
- Robotics in health care and prosthesis;
- Connecting the human brain to robots;
- Bionics for enhancing humans.

Military application of robotics:

- Advantages and Risks;
- Autonomous systems and responsibility in warfare;
- International Conventions and Laws.

Environment:

- Underwater robotics noise pollution;
- Cleaning nuclear and toxic waste;
- Decommissioning plants;
- Using renewable sources of energy;
- Space trash collection.

Technical Dependability:

- Availability;
- Reliability;
- Safety;
- Security.

(IEEE. Kobe, Japan 2009)

One of the largest concerns is that robotics will be used in the very same way that nuclear physics was used to develop the atomic bomb. Examples that demonstrate this are robotic soldiers or bombers. In the field of medicine, nanotechnology has been a big concern. Of course it could have great benefits but from that research biological weapons could be produced as well. Engineers need to think critically about how their research might impact the world (Kazuo 2004). However many concerns of the public, such as robots taking over the world, stem from science fiction, which is far from reality given our current technology.

6.2 Roboethics Pertaining to Robotic Space Mining

There are no set ethics regarding robotic space mining. However, this field seems to be ethically and morally sound. Since using robots in this type of application typically does not hurt or injure humans in any form (Hsu 2009). This topic is generally seen as a “good” use of robotic technology and is considered justifiable (Appendix 2-A). Using robots for tasks that are ill-suited or dangerous for humans to attempt meets with the goals and expectations of the International Committee on Roboethics.

7. Goals

The goals of this IQP are:

- To obtain a better understanding of the current research and development being done on robotic space mining.
- To obtain a better understanding of the implications that such activity could have.
- To conduct an unbiased survey to sample public opinion on the subject.
- To predict what new applications might be feasible in the near future.

We feel that a survey which reaches both experts and non-experts in robotics and space mining is appropriate, as both demographics will be affected in the future if space mining gains popularity in industry. The attitudes that people will have toward robots in space, particularly mining operations, will naturally coincide with robots becoming more advanced and more affordable (Takayama 2008).

8. Methodology

We will conduct a survey of experts and non-experts in relation to the fields of space, robotics, space robotics, and space mining. The aim of this survey is to gain insight into how the public feels on the topic of space mining. This will show whether or not the practice of mining in space is generally supported or opposed. Below are the questions we ask in the survey and the reasoning behind them

The data was collected via www.surveymonkey.com. Using this data, we measure various parameters of the participant: their interest in the topic, how informed they are on the topic, what they think about the economic benefits, the impact they think it could have on society and so on. All of these will help us to determine whether the public generally supports or opposes the idea of robotic space mining.

The data will be analyzed through means of charts and descriptive statistics to prove or disprove our hypotheses and to reinforce our goals. From these charts we will be able to interpolate a general idea of what public opinion is, and draw from that to create a conclusion.

Our tool set consists primarily of Microsoft Excel to create the charts, and surveymonkey.com to collect and compile the data.

We will conduct several interviews with local experts in the fields of robotics, artificial intelligence, space mining, ethics etc. The interviews will consist of slightly different questions from the survey, but will still aim to gather similar information. In order to obtain more detailed responses, the wording and order of the questions may change between interviews, but a list of the types of questions we will ask is detailed below.

8.1 Survey Question Selection

The goal of this survey is to assess public opinion regarding the practice of space mining, specifically when performed by robots. While the target demographic was meant to be non-experts in robotics and space, we did not strictly prohibit such experts from participating. Instead, we included some questions to identify those with more extensive backgrounds in these fields. The initial questions gather very basic information about the participant, including their gender, age range, and field of study / interest. Additionally, the first two allow a deeper analysis of results by gender or age group.

The remaining questions which gather information rather than opinion from each participant ask them to rate their level of knowledge of recent robotics and space technology, and their interest in space mining. It would not be surprising if opinions were to differ between a person who is very interested in space mining and one who is not. Furthermore, it can reasonably be expected that people with extensive knowledge of robotics or of space mining will respond differently to questions about either of those topics.

One of the consequences that would arise as a result of practicing space mining is an increased focus on space exploration. To reflect this, we added a question about the supposed importance of space exploration in order to determine if there is any relationship between it and that of space mining. We also ask the participant to rate the importance of mining as a method of resource gathering, both on and off of Earth. Our reasoning behind these questions was that people who support mining in general will probably be more likely to support mining done by robots. We also ask whether the participant believes that a lunar base would lay the necessary groundwork for expansion into or colonization of space. Any endeavor involving space travel will be quite expensive, but there is potential for the cost of regolith mining to be offset with the income that could be received from it. As such, we thought it important to include questions about the financial aspects of space mining, including whether it should receive more funding and whether that funding would be put to better use elsewhere (i.e., should receive less funding). Finally, we touch upon media exposure of space mining; this is one of the core questions of the survey, as it ties in directly with the perceived importance of space mining without explicitly mentioning it.

Whether there exists a pressing need is a question frequently asked of a project before it is set into motion. Naturally, such a question must also be asked of space mining; is there really any need to mine in space when we already mine on Earth? The answer may not be immediately obvious, as there are many factors to consider. We attempted to touch upon these factors with our survey questions in order to ascertain whether people think there is a need; specifically, whether we are in need of resources that can be mined from space. While space is suggested by some to be an additional site for mining to take place, it is also proposed as an alternative. Those who believe that exhaustive mining of Earth is inappropriate may feel differently about exhaustive mining of the moon, being as how the moon is uninhabited.

The use of robots in any environment tends to raise some ethical concern. There are arguments both for and against the increased use of robots to perform tasks traditionally done by humans; the case of space mining in particular, however, fits quite well into the description of the intended domain of robot use. Robots are intended to perform tasks which are dirty, dull and/or dangerous—operating excavation machinery in an environment with no oxygen and extreme temperatures certainly qualifies. Public opinion may not take these intentions into account, however, as the general public is not as likely to be acquainted with them. Nevertheless, we ask participants whether they believe space mining can or should be done by robots (if at all), and if it would be cost-effective to send robots to space in place of humans.

In addition to asking whether space exploration is important, we decided to ask whether it has a positive impact on society. Perhaps some people who place low priority on space exploration still feel that it is a good thing. In some cases where a person would be otherwise undecided, the added benefit of space exploration in tandem with the potential financial rewards may be the deciding factor. Furthermore, some practices which were colossal moneymakers have been outlawed because of their negative impact on society; supposing that space mining would be tremendously profitable at the cost of human lives, it would most certainly be condemned. We aimed to weigh these concerns by asking participants about the impact that space mining would have on society and economy.

In order to understand opinion on the use of robots in space, we added several questions about the best team to send on a space mission. The options consisted of only people, only robots, or some people and some robots. Our expectation is that robots will have enough support to earn at least some place, but will not be trusted to such an extent that an all-robot crew would be chosen.

The final few questions return to the topic of finance, with the focus now on some side effects of space mining: helium-3 for fusion research, and the construction of a lunar base. We ask whether it would be financially beneficial to build a lunar base because it is the most widely discussed side effect. Although we do not ask whether the participant believes a lunar base should be constructed, if many people believe that a lunar base would be financially beneficial or that it would help with expansion into space, the possibility arises that many people may also support building one. Finally, we ask whether space mining is worthwhile even if it is not immediately profitable. It is our belief that if many participants respond positively to this question, there will be more support for increased priority given to space exploration, fusion research, and the construction of a lunar base.

8.2 Interview Question Selection

Our goal in each of the interviews was to elicit as much detail as possible. Because of this, rather than ask identical questions in a sequential order, we modified the wording and timing of some questions to allow the interviewee to express their thoughts. The main questions we wanted to touch upon in each interview were:

- What is your area of expertise?
- How extensive is your knowledge of robotics?
- What are your thoughts on the current state of robotic technology?
- What are your thoughts on robotic autonomy?
- Do you think we are heading in the right direction with respect to technological advancement in the field of robotics?
- What do you think of using robots in place of humans?
- How familiar are you with the idea of space mining?
- What do you think would be the advantages and disadvantages of space mining?
- What are your thoughts on the theoretical consequences of space mining? (including fusion research, a new generation of spacecraft, etc.)

The questions we asked in each interview are the ones at the core of this project. Our goals were to ascertain what public opinion about space mining might be, so we asked questions that cover the main points of controversy. Namely, our questions address financial concerns of such a large-scale project, positive and negative impact of space mining on society, and the ethical concerns accompanying increased levels of robotic autonomy and replacing humans with robots.

9. Survey Analysis

In this section we will examine the responses to each question, the results of the survey as a whole, and our interpretation of those results. Due to time constraints, the survey was limited to members of the WPI community. Because WPI is a unique environment which consists of people with a specialized knowledge set, the opinions of the WPI community will not necessarily reflect those of the general public.

9.1 Hypotheses

Our expectations for the survey results are as follows:

- We believe that the WPI community will be supportive of space exploration.
- We believe that the WPI community will be supportive of space mining.
- We believe that the WPI community will be supportive of the use of robots for the above.

9.1.1 Survey Demographics

Since the survey is confined to the WPI community, we expect a large majority of participants to be undergraduates. Probabilistically, the majority of these undergraduates are likely to be male, based on the male-female student ratio at WPI. As of this writing, the current undergraduate student ratio is 76% male to 24% female, and our survey responses consisted of 68% male and 32% female. We hope to see a respectable amount of graduates and faculty/staff to participate as well. We expect to see the majority of the participants under the age of 25, again because of the previous assumption of undergraduate majority.

WPI hosts a variety of fields of study. Thus we expect to see a fairly even ratio between those who have studies related to robotics—primarily Robotics Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Computer Science—and those who have other fields/studies.

We hope that people will answer truthfully and responsibly when taking our survey, in hopes that we can obtain an accurate understanding of the public's opinion of robotic space mining. Below are the hypotheses we had about the survey based on age, gender, and field of study of all participants.

9.1.2 General Survey Responses

We hypothesize from the survey we will learn:

- That most participants do not to have much knowledge of robotics—even more so of robotic space mining, but still have an interest in the topic.
- That most participants believe robotic space exploration to be important and have a positive effect on society, but have mixed feelings about the prospect of robotic space mining.
- That most participants are unaware of the financial aspects of robotic space mining.
- That most participants believe mining to be necessary whether on Earth or other extraterrestrial surfaces.
- That most participants agree with the idea of sending both human and robot for space mining tasks.
- That most participants agree with the idea of a lunar base.

9.2 Individual Survey Questions

Here we will examine one survey question at a time, taking into consideration the gender, major and age of the participant. The first four questions of the survey will not be analyzed, as they are solely meant to gather demographic information.

An online survey was conducted from November 2009 through January of 2010 with a total of 486 people participating. 482 (99.2%) people consented to participating in the survey and 4 (.8%) did not. Of the 486 people who participated, 376 (77.4%) people completed every question of the survey. There were 7 (1.4%) responses which were determined not to be serious, and were discarded. These responses included one or more of the following: profanity or lewdness in comments, or absence of comments and all questions answered the same way (this is highly improbable, as strongly agreeing to both questions 24 and 25 is a direct contradiction). All data analysis consists of only people who completed the survey in its entirety, subtracting outliers. The final count was 369 (75.9%) people completed the survey, and 106 did not. This pruning was done to ensure consistency between every question. The data showed that people did not answer the later questions. This may have been due to lack of time or interest of the participants.

For our analysis of the survey questions, we compared responses based on gender, age and field of study. Because only 33 participants were older than 25, we simply compared under 25 and over 25, rather than the four age ranges specified by question 3. To compare fields of study, we grouped computer science (CS), mechanical engineering (ME), electrical and computer engineering (ECE) and robotics engineering (RBE) together as “robotics related.” There were many other fields reported, listed here as “not robotics related.”

9.2.1 Question 5

“I have extensive knowledge of current robot technology”

Overall: The results lean towards the negative side, indicating that most members of the WPI community do not have extensive knowledge of current robot technology.

By Gender: The male population was shown to be more knowledgeable about current robot technology compared to the female population.

By Age: Both age groups expressed that they did not have extensive knowledge of current robot technology.

By Major / Field of Study: As expected, the robotics related majors had a higher mean than other majors.

9.2.2 Question 6

“I have extensive knowledge of recent developments in space mining”

Overall: The results are strongly negative, indicating that most members of the WPI community did not have extensive knowledge of recent developments in space mining

By Gender: The male population was shown to be slightly more knowledge on recent developments in space mining.

By Age: Both age groups expressed that they did not have extensive knowledge of recent developments in space mining.

By Major / Field of Study: Surprisingly both means are similar. This shows that both groups do not have much knowledge of recent developments in space mining.

9.2.3 Question 7

"Current research and development of space mining technologies is of interest to me"

Overall: This question had a positive response, indicating that most people are interested about the topic of space mining.

By Gender: Both groups showed positive responses, with the male population being slightly more positive.

By Age: Those younger than 25 had a slightly more positive response compared to those over 25.

By Major / Field of Study: Both groups responded positively, which shows their interest in R&D of space mining technologies.

9.2.4 Question 8

"I believe space exploration is important to society"

Overall: A strongly positive response from the participants means that a majority of people believe space exploration to be important to society.

By Gender: Both groups responded positively to the question which shows that they believe space exploration is important to society.

By Age: Both groups believe space exploration is important to society, however those younger than 25 had a higher positive response.

By Major / Field of Study: Both groups have strongly positive responses.

9.2.5 Question 9

"I believe mining on Earth is important"

Overall: A high percentage of overall responses was positive showing that people believe mining of resources on Earth is of importance.

By Gender: Both groups were positive with the male population being slightly more positive.

By Age: Both groups responded positively with those older than 25 being slightly more positive.

By Major / Field of Study: Both groups believe that mining on Earth is important.

9.2.6 Question 10

"I believe mining on extraterrestrial (non-Earth) surfaces is important"

Overall: Relatively positive, showing that people believe that mining on other surfaces besides Earth is important.

By Gender: Both groups are slightly positive about the importance of mining on non-Earth surfaces.

By Age: Those younger than 25 had a positive response while those older than 25 had a slightly negative response. This shows that those who are older then 25 do not see as much importance compared to those under 25 on the importance of mining on non-Earth surfaces.

By Major / Field of Study: Both groups responded positively to the importance of mining on extraterrestrial surfaces.

9.2.7 Question 11

"I believe funding for space mining would be better spent elsewhere"

Overall: An overall neutral response, indicating that maybe most people do not really care one way or another about funding for space mining.

By Gender: Both groups were neutral on the subject of funding for space mining.

By Age: Both groups were fairly neutral with those over 25 being slightly more positive. This shows that those who are older may have other concerns such as health care and etc. and do not see the funding for space mining as a necessity.

By Major / Field of Study: Both groups are neutral on the subject.

9.2.8 Question 12

"I believe that robotic space mining needs to be given more media exposure"

Overall: A fairly positive response shows that most people believe robotic space mining needs to be covered in media to a greater extent.

By Gender: Both groups were fairly positive about robotic space mining needing more media exposure.

By Age: The younger generation believes that robotic space mining needs to be given more media exposure whereas the older generation is more neutral about the topic.

By Major / Field of Study: Both groups responded fairly positively.

9.2.9 Question 13

"I believe that robotic space mining needs to be given more financial backing"

Overall: As for question 10, it is an overall neutral response. This is perhaps because people are unaware of the current costs required for such operations.

By Gender: Once again both groups were neutral.

By Age: Both groups are neutral about the topic with those under 25 being slightly more positive and those over 25 being slightly more negative.

By Major / Field of Study: The robotics related majors responded more positively compared to those of other majors.

9.2.10 Question 14

"I believe we are in need of more (minable) resources"

Overall: A relatively positive response shows that most people think that we are running short on our current resources and need more.

By Gender: Both groups were fairly positive on the subject of needing more resources. The male population was slightly more positive compared to the female population.

By Age: Both groups are relatively positive on the subject of needing more minable resources.

By Major / Field of Study: Both groups responded positively, which meant that they believe we are in need of more minable resources.

9.2.11 Question 15

"I think that exhaustive mining of Earth is inappropriate"

Overall: A strongly positive response shows that the members of the WPI community thought that exhaustive mining of Earth was too excessive.

By Gender: Both groups were strongly positive.

By Age: Both groups believe that exhaustive mining of the Earth is inappropriate.

By Major / Field of Study: Both groups were strongly positive in their responses. Both groups believe that exhaustive mining of Earth is inappropriate.

9.2.12 Question 16

"I think that exhaustive mining of the moon is inappropriate"

Overall: A relatively neutral response, indicating that people are unsure about exhaustive mining of the moon being inappropriate.

By Gender: Both groups were slightly positive on the subject. The female population was noticeably more positive which meant that they considered exhaustive mining on the moon to be more inappropriate compared to the males.

By Age: Those over the age of 25 are more positive than those who are under 25, indicating that the older generation believe exhaustive mining of the moon to be more inappropriate compared to the younger generation.

By Major / Field of Study: The robotics related majors are more neutral compared to the other majors.

9.2.13 Question 17

"One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there"

Overall: A high percentage of people believed that it was more morally responsible to mine on the moon as opposed to the Earth.

By Gender: Both groups were showed fairly positive responses.

By Age: Both groups are slightly positive on the subject with the younger age group being more positive than the older.

By Major / Field of Study: Both groups responded fairly positively.

9.2.14 Question 18

"I think it would be more cost effective to send robots to space in place of humans"

Overall: Strongly positive response, indicating that most members of the WPI community believe that robots are more economical than humans for space missions.

By Gender: Both male and female participants responded positively, though the average was slightly more positive for males than for females.

By Age: Participants over the age of 25 were less positive than those under 25, but each demographic responded positively.

By Major / Field of Study: Robotics related majors and non-robotics majors responded positively. Robotics majors had a larger percentage of 'strongly agree' responses.

9.2.15 Question 19

"I think that mineral mining in space can currently be done by robots"

Overall: Nearly two thirds of responses were positive, which means the majority of participants believe robots are currently capable of mining in space.

By Gender: Both male and female participants were strongly positive about this question. More than two thirds of female responses were either 'agree' or 'strongly agree.'

By Age: Each age group responded positively, though participants under the age of 25 were noticeably more positive than those above 25.

By Major / Field of Study: Between participants from fields related to robotics and those from other fields, the average response to this question was the same. The fact that those with more knowledge of robotics are positive about this question may indicate that space mining can indeed be done with our current level of robotic technology.

9.2.16 Question 20

"I think that mineral mining in space should be done by robots"

Overall: More than two thirds of responses were positive, meaning that most responders believe that robots would be well allocated for use in space mining

By Gender: Both genders were very positive about this question, and both genders had more than two thirds of their responses either 'agree' or 'strongly agree.'

By Age: Very similar responses in each demographic, though the over 25 group is less positive than the under 25 group.

By Major / Field of Study: Unsurprisingly, those participants who work in fields related to robotics are more positive about this question than those who do not. They advocate the use of robots where and when they believe it is appropriate. Based on these results, it appears that the WPI community would favor the use of robots for space mining.

9.2.17 Question 21

"I think space exploration has a positive impact on society"

Overall: More than four fifths of responses were positive, which indicates a strong support of space exploration by the WPI community.

By Gender: Both male and female participants were overwhelmingly positive about this question. Fewer than 10% of either gender disagreed or strongly disagreed.

By Age: Participants of all ages were positive about this question. No participants over the age of 25 strongly disagreed.

By Major / Field of Study: All majors were positive about space exploration and its impact on society. Nearly 85% of robotics related majors either agreed or strongly agreed. The WPI community as a whole is very supportive of space exploration.

9.2.18 Question 22

"I think space mining will have a positive impact on society"

Overall: Moderately positive response, though more than one third were neutral. There is a generally positive opinion of the expected impact of space mining on society.

By Gender: Both male and female participants were significantly positive about this question. For each gender, fewer than 15% disagreed or strongly disagreed.

By Age: Each age group had a positive response, but again the younger group was noticeably more positive than the older group.

By Major / Field of Study: Robotics related majors were slightly more positive than non-robotics majors, but each group was significantly positive about this question. Based on the results to this question, we can assert that WPI would generally support the practice of space mining.

9.2.19 Question 23

"I think space mining would be financially beneficial"

Overall: Moderately positive response, though the most common response was 'am neutral.' There is a slight indication that the WPI community expects space mining to turn a profit.

By Gender: Male responses were slightly more positive than female ones, but both genders responded positively.

By Age: Participants under 25 responded positively and those over 25 responded slightly negatively.

By Major / Field of Study: Both groups were positive about this question, with fewer than one fifth of either set of fields disagreeing or strongly disagreeing. It seems that the general consensus across demographics among members of the WPI community is that space mining has potential to produce financial gain.

9.2.20 Question 24

"I think sending only people is the best choice for space mining operations"

Overall: Overwhelmingly negative response. This shows that most members of the WPI community believe that space mining teams should be partially or completely composed of robots.

By Gender: Both male and female participants were extremely negative about this question. Fewer than 3% of either gender agreed or strongly agreed.

By Age: Both age groups were extremely negative about this question. No participants over the age of 25 agreed or strongly agreed.

By Major / Field of Study: Each demographic was extremely negative about this question and, unsurprisingly, robotics related majors were far more likely to strongly disagree. No robotics related majors strongly agreed, and fewer than 2% agreed.

9.2.21 Question 25

“I think sending only robots is the best choice for space mining operations”

Overall: Significantly negative response. Combined with the negative response from the previous question, we expect that most participants will strongly favor teams of both robots and humans.

By Gender: Both genders were significantly negative about this question, though males were slightly more negative than females.

By Age: Both age groups were significantly negative about this question. Each demographic had more than three quarters of their responses being either ‘am neutral,’ ‘disagree,’ or ‘strongly disagree.’

By Major / Field of Study: Though there was a slightly more positive response from robotics related majors than from non-robotics majors, though neither group was overwhelmingly positive.

9.2.22 Question 26

"I think sending both people and robots is the best choice for space mining operations"

Overall: Significantly positive response. As expected, the majority of participants favor hybrid space mining teams.

By Gender: Female participants were not as positive as males, but each gender had a significantly positive response to this question.

By Age: Each age group was significantly positive about this question. No participants over the age of 25 strongly disagreed.

By Major / Field of Study: Both demographics responded positively to this question, with a slight edge of positivity belonging to non-robotics majors. Among questions pertaining to teams for space mining, this question had the most popular responses across all demographics.

9.2.23 Question 27

"I think it would be more cost effective to process the mined minerals on Earth"

Overall: Slightly positive response. The most popular response was neutrality, which means that most members of the WPI community do not have a strong opinion regarding relative costs of processing minerals on Earth or in space.

By Gender: Each gender had a slightly positive response, but females were noticeably more positive than males.

By Age: Each age group was neutral about this question. There most popular response for each age group was neutrality.

By Major / Field of Study: Non-robotics majors are slightly more positive about this question than robotics related majors are, though each group is only slightly positive. Again, the most popular response was neutrality. We see that no demographics feel strongly one way or the other about the relative costs of processing minerals on Earth or on-site in space.

9.2.24 Question 28

"I think it would be worthwhile to continue space mining if the practice was shown not to be profitable"

Overall: Slightly negative response, indicating that more people would like to see some financial promise before committing to support of space mining.

By Gender: Each gender was slightly negative in their response to this question, but females were more negative than males.

By Age: Strongly negative response from participants over 25, indicating that that demographic feels strongly that there must be financial gain to make space mining worthwhile.

By Major / Field of Study: Participants in fields related to robotics and those in other fields had slightly negative responses to this question. Based on this and other demographic comparisons for this question, the majority of the WPI community would support space mining only if there is some profit to be made.

9.2.25 Question 29

"I think it would be financially beneficial to build a lunar base"

Overall: Slightly positive response, with the most popular response being neutrality. This indicates that more participants are optimistic about the financial potential of a lunar base than not.

By Gender: The average response was slightly positive for each gender, and the most popular response was neutrality.

By Age: Participants under 25 were slightly positive about this question, while those over 25 were significantly negative.

By Major / Field of Study: Neither group was overwhelmingly positive about the financial promise of a lunar base, which was a similar reaction to those of other demographics. As we will see in the next question, however, there is still strong support for building a lunar base.

9.2.26 Question 30

"I think that building a lunar base would lay the groundwork for expansion into space"

Overall: Overwhelmingly positive response, which shows that the vast majority of participants believe that a lunar base would be the first step towards extraterrestrial settlement.

By Gender: Both genders were extremely positive about this question. Fewer than 20% of females and fewer than 15% of males disagreed or strongly disagreed.

By Age: For each age group, over 90% of responses were non-negative (that is, they were either neutral or positive).

By Major / Field of Study: The trend of positivity for this question continues with our comparison of majors, and again more than 90% of each group was either neutral or positive. The WPI community appears to be very enthusiastic about the prospect of a lunar base as a stepping stone toward expansion into space.

9.3 Survey Results Analysis

The first few questions of our survey asked for some very basic demographic information, including gender, age range and field of study. For the sake of participant anonymity, we did not cross-examine any of the responses to these questions. That is, we did not investigate demographics in conjunction with one another; for example, we did not calculate the number of female computer science majors. We expected that the ratio of male to female survey responses would be heavily in favor of males; the actual ratio was 68:32, which shows a good rate of participation of females. For the age groups, 91% of participants were under 25 years old. Because of this, we chose to align those over the age of 25 as a single group. Our last demographic question was field of study. We expected that the ratio of robotics-related to non-robotics-related fields would be close to 50:50; the true ratio came out to approximately 52:48.

9.3.1 Space Exploration

One of the most outstanding aspects of our survey was the immensely positive outlook on space exploration. The average response to the importance of space exploration question was 4.02, indicating that the average WPI community member agrees that space exploration is important, with a slight edge toward strongly agreeing. Even more impressive was the 4.12

average for the question about the impact of space exploration on society. It is clear that space exploration is strongly supported by WPI as a whole.

9.3.2 Space Mining

There were some mixed results about space mining, but generally participants were positive about it, with a slight tendency toward neutrality. We expected that responses would be very negative about space mining being done by humans alone, slightly negative about space mining being done by robots alone, and positive about space mining being done by both humans and robots. The results clearly show that is the case, at least among members of the WPI community. Unsurprisingly, human safety is a concern shared by people of different genders, ages and fields of study.

We suspected that there would be some support for reallocating funding away from space mining, as there are a great deal of other pressing concerns facing our society and global economy. Participants tended to favor less funding for space mining, but to an even greater extent than we anticipated. Interestingly, participants also indicated that they thought space mining needed more exposure in the media. Perhaps what space mining needs right now is simply an increased level of public awareness, with financial support to follow in years to come.

9.3.3 Mining on Earth

While it is agreed that mining on Earth is still a necessity for the sake of meeting our energy needs, there was a strong negative attitude toward exhaustive mining of Earth. This is to be expected; such mining could have negative effects on Earth's ecology, which in turn affects our quality of life. Participants were significantly less negative about exhaustive mining of the moon, but still felt that it was inappropriate to do so. We suspect that the apparent lack of life on the moon is what caused this difference of opinion.

10. Expert Interviews

The interviews were structured with a tentative list of questions to address. These questions were more in-depth than the survey questions, requiring each participant to think carefully and critically about their responses. Based on the reactions and responses of the person being interviewed, we would adjust our questions and try to gain more insight into why they felt a certain way about a topic. Rather than read each question verbatim, we tried to ask all of our questions while going along with the flow of the interview. Refer to Appendix 2 A-F for the expert interviews.

10.1 Interview Summaries

Below we will briefly summarize the interviews we conducted. For the full interview transcripts, see Appendix 2. For the purposes of these interviews, we have used the term 'professor' as a title of respect for these distinguished teachers, regardless of their official title at WPI.

10.1.1 Professor Sanbonmatsu

Professor John Sanbonmatsu from the Department of Philosophy at WPI is currently writing a book on the philosophy of technology. His opinion on the current state of robotics is that it is too advanced, that our technology is evolving much faster than our morality. He said that robotics is a field that is manipulated by the military like many other engineering fields for unjust causes. Professor Sanbonmatsu told us that his general feeling is that we need to take care of things here on Earth rather than spend all our time and money on space missions.

On the subject of robotic autonomy, Professor Sanbonmatsu is skeptical about the potential of true artificial intelligence in machines. However, he is also concerned with the level of autonomy we currently have. He said that depending on the application and how much autonomy is given to the robot, that it could be considered immoral. He talks about robots that are used in military applications and the ethical problems that arise concerning them. He stated that having fully autonomous robots should not be a goal that we should be striving for.

On the topic of dehumanization of human achievements, Professor Sanbonmatsu argues that a robot can never really discover anything, since robots are unable to interpret or ascribe meaning to what it is that they discover. Thus humans will always be the ones that discover things because they are the ones that create the robot in order to do such tasks. Robots extend human capabilities.

Professor Sanbonmatsu said that if there was an ethical case for the use of robots then it would be in mining—both on Earth and in space—as they would help keep humans out of danger. However, he argues that we should be taking care of our Earth rather than thinking about mining other worlds.

With regards to funding given to space robotics, Professor Sanbonmatsu told us that he believes we have invested too much in, and that the money should have been spent on other things such as feeding and clothing people around the world.

Concerning space mining itself, Professor Sanbonmatsu sees the practice as impractical. He says that most of the resources we are mining are exuberant—that most of the stuff in Wal-Mart and other retail stores are unnecessary.

Professor Sanbonmatsu said he does not believe that we will have a lasting presence on the moon because of all the expenses needed to sustain the program. He stated that if our government needed the materials mined from the moon then it would devote all of its resources to acquire it regardless of whether it was economically feasible or not. He finalized his thoughts on the matter by adding that it would only be justified if it is on the grounds of national security.

Regarding nuclear fusion technologies, Professor Sanbonmatsu was cautious of the topic and thought that rather than depend on that type of energy consumption we should go to decentralized forms of energy like solar and wind power.

Concerning robotic probes or vehicles using nuclear power, Sanbonmatsu strongly argued that in no way shape or form should you endanger life in the pursuit of knowledge. He did not agree with stacking nuclear piles on robots because if it were ever to explode in our atmosphere, that would lead to dire consequences.

Professor Sanbonmatsu says that there is no ethical problem with mining the moon, however if we were to involve the peoples of Earth then it would indeed have an impact.

On the subject of the moon being territorial, he claims that as long as we remain nationalistic and militaristic there are bound to be problems. He says that as long as there exist large corporations then conflicts will always arise.

Our next question was about the merit of mining on or off of Earth. Professor Sanbonmatsu told us that mining on Earth should be minimal, and that mining on the moon should only be done if it is for the greater good of life on Earth.

As we brought the interview to a close, Professor Sanbonmatsu stated that he does not believe we are currently heading in the right direction with robotics, and that he is concerned about the future of our society with the development of robots for use in unethical applications.

10.1.2 Professor Looft

Professor Fred Looft is a teacher of Electrical and Computer Engineering and has close ties with the Robotics Program. He told us that he is interested in seeing the development of new robot applications in the near future, such as robotic healthcare and the like, and that he believes that robotic assisted surgery and demining, which is the process of removing land mines or naval mines, applications of robots will have an impact on our lives.

Pertaining to the role of robots in space mining, he stated it will be integral, but also that he wonders about the politics behind it. Professor Looft said that robotic autonomy at its current level not a bad thing. However if we were to gain a higher level of autonomy such as true artificial intelligence he does have philosophical concerns on the issue.

Professor Looft said that it is absolutely necessary to have robots on space missions because of all the hazards that are associated with man-space travel. Robots would be able to withstand the radiation.

On the subject of funding allocated for space robotics, Professor Looft says that the amount of money given to NASA and most federal agencies is not enough. He argues that these agencies have been told what to do and where to go but do not necessarily get the funding required to do so. He argues that we need to give more money to NASA.

Professor Looft told us that depending on what is found when digging in space, it could lead to future projects. He also suggests alternative places to mine such as asteroids but gives concern about whether they are economically feasible given the amount of energy required to perform such operations. He said his belief is that we should send more probes to scour the surfaces in order to map the area rather than immediately digging.

On the topic of nuclear fusion, Professor Looft stated that it could be beneficial in many ways. It could provide near unlimited energy which would potentially make electric cars viable and in turn that would reduce pollution.

Regarding the creation of a lunar base, Professor Looft said that it is too expensive at our current state of economics to support—that perhaps at a later time when it would be economically feasible.

He said that exhaustive mining of the Earth is not a good practice but that he has mixed feelings about how we should mine the moon.

Professor Looft closed by saying that he would like to see robotic space mining move forward, that he wants there to be dedication in the field to produce results. He argues that we need to think our decisions through and make sure that we are careful when mining extraterrestrial places, considering territorial conflicts and so on.

10.1.3 Professor Wilkes

Professor John Wilkes is a sociologist at WPI. He is also one of the few members that are currently in the field of astrosociology, which studies the development of communities emerging in space. He says that a new age will take place in the future that will be a very significant part of our history—the spacefaring age.

Professor Wilkes was the one who brought back news to WPI about the regolith excavation challenge, which Paul‘s Robotics of WPI ended up winning. He strongly argues that the presence of Helium-3 on the moon will have a historic and economic impact for Earth.

His views on the state of robotic space exploration favor autonomous systems. He disagrees with NASA‘s views and their push for man-space missions. He says that the push should not be towards systems which are too autonomous but semi-autonomous systems. He stated that his reasoning for this was based on human history with technology getting out of control, for example the atomic bomb.

Professor Wilkes says that the subject of autonomy is very controversial. As he put it:

"I remain cautiously optimistic this is a development that bears watching because it could change the man-machine relationship, which as you know I am okay with in space in a hostile environment where we're probably looking for some new way of operating. But the autonomous systems we're talking about on Earth, particularly at the nano level we may see something that is destructive on the scale of the Plagues before we're through just because we don't know what we're doing."

Professor Wilkes argued that because we have a social momentum in the direction of developing humanoid robots that it will eventually happen.

On the topic of using robots rather than humans in space, he tends to like the idea. However, he envisions that the workforce would be not entirely humans or robots but a mixture of both.

With regards to the amount of funding that NASA is receiving for their space robotics department, Professor Wilkes claims that NASA will continue to underfund its own sectors that are not part of its greater goal, which is to send man into space. He says:

“They have a bias toward keeping humans present and in control. I don't think that's going to pay for itself. I don't think that is where the future lies.”

Wilkes told us that the whole aspect of robotic space mining has to make economic sense in the long run. He says that the case for mining the moon is that it would be the base on which you develop an infrastructure in space. Wilkes suggests:

“We're going to see something very interesting, we're going to see Helium-3 going from the moon to Earth and what the moon will want in return is very plentiful on Earth—Hydrogen. It will be a gas trade.”

Professor Wilkes stated that the recent discovery of water on the moon will determine where the first lunar base will be built.

Professor Wilkes is very cautious on the topic of robotic autonomy and its development. He believes that the attempt of the technical community to create truly autonomous systems does not make sense given our current, immediate needs. He says that he sees the case for creating such systems for operating in long-distance space operations, but still believes that we are just starting out in the field.

10.1.4 Professor Rich

Professor Charles Rich is a teacher of CS and IMGD here at WPI, and is currently doing research on human-robot interaction. Our interview with Professor Rich began with a short, concise prediction about the future of robotics. He said:

"I think it's on the cusp of huge breakthroughs."

Among those we had the opportunity to interview, this optimism was shared by professors of engineering, but not by professors of humanities. Another sentiment which divided the two groups of professors was the idea of fully autonomous robots. Whether they believed it would ever happen, or whether it were even possible were questions which returned different answers. Professor Rich does believe that fully autonomous robots will probably exist in the future, but not for a long time.

On the topic of robots for space applications, we first asked whether Professor Rich believed sending robots to space in place of humans were an acceptable practice. His answer was very positive, and he also pointed out that teams don't have to be all-robot or all-human. Perhaps a team consisting of 80% robots and 20% humans would be the most cost-effective. Professor Rich does believe that—in the short term at least—it would be much cheaper to send only robots, as robots do not require life support systems, food etc.

Next we asked about the implications of space mining being done by humans versus robots. Professor Rich offered the idea that there isn't "anything uniquely qualitatively more dangerous about outer space than about any other frontier." He does not believe that there is anything ethically wrong about sending humans into space for the purposes of space mining. His belief is that the question of who is to do the mining is strictly an economic one; if it is cheaper to use robots, then we should use robots. Another question pertaining to robots and humans was the emphasis that NASA places on each. We asked whether Professor Rich thought NASA should be focusing more on humans or robots, and he told us that was because it is a better way to maintain our momentum with space exploration. His concern is that firmly declaring that space exploration should only be done by humans will greatly reduce the amount of exploration that can be done.

Our discussion continued to cover the financial aspect of space mining. When asked about the merit of doing any space mining, Professor Rich was not sure whether there was any significant money to be made in doing it, and asked just what it is that we would be mining for. Following a brief discussion of lunar regolith, the potential byproducts of processing regolith, and the relative abundance of those materials relative to Earth, Professor Rich reiterated that the choice to do space mining or not is economic.

The next question we posed was whether or not space mining would lay the groundwork for future operations in space, by NASA or other organizations. Professor Rich responded that it would absolutely lay the groundwork for future operations. He said that simply being in space produces a sort of experience curve among scientists and others:

> "Let me put it this way: if you're not there, you're not going to learn anything. I think there's a huge experience effect."

The next stage of the interview asked Professor Rich for some predictions about the future. First we asked what he thought the consequences of mastering nuclear fusion would be.

He pointed out that this is indeed a very hypothetical question, but that mastering fusion would be of monumental importance. He said that a causal link between regolith excavation and fusion progress would be a tremendous justification for space mining. We also asked whether the moon should remain non-territorial. Professor Rich had mixed thoughts about this. He believes that it could be beneficial as it may lead to international cooperation. He also noted that it could be "an impediment to development and efficient exploitation."

Professor Rich made an interesting point with respect to space mining and space exploration. We asked whether he thought we needed to do a large amount of 'cleaning up' on Earth before it would be appropriate to start mining space. His response was

> "I don't think the problems that we have on Earth are an excuse to not look beyond, simply put. There will always be problems, there will always be an excuse, then we'll never do it..."

This is an outlook we did not initially expect, but which certainly makes a lot of sense. We also asked Professor Rich whether he thought we needed to exercise a certain amount of restraint when mining the moon. He told us that he had two different opinions on the subject, one in favor of using the moon to whatever extent and one more in favor of stewardship of the moon. Among the two, Professor Rich did not specify which he believed more strongly.

The last few questions were about the current and future states of robotics, and the ethics of continuing research and development. Professor Rich again noted that he believes the field is on the verge of many good breakthroughs. We asked whether he thought that advancement could ever become unethical, and he said yes, that it could potentially become unethical. As with any field, before making any great developments in robotics, we must first be sure that the good that will come of it will outweigh the bad.

10.1.5 Professor Ciaraldi

Professor Michael Ciaraldi is a teacher of CS and RBE, as well as a member of the Moonraker project which recently reached its completion. He is currently working on an autonomous vehicle for the Intelligent Ground Vehicle Contest.

The first main question we asked Professor Ciaraldi asked for his thoughts on the current state of robotics. He gave us a very detailed account which compared the field of robotics to that of computer science, with an offset of a few decades. The analogy he made was that robotics is only now beginning to emerge as a field where it is practical for individuals to do work, whereas in the past the costs were prohibitively expensive. Perhaps robots will progress and we will see a similar trend, where the private ownership of robots will increase and many people will own more than one.

As for the role of robotics in space exploration, Professor Ciaraldi believes that robots will be very useful for extending the capabilities of their controllers, and increased levels of robotic autonomy would only make the systems more reliable. Professor Ciaraldi identified robotic autonomy as a necessary thing, without which the utility of the robot would be greatly diminished. Although computers lack anything resembling a human's ability to reason, he said that the extent to which computers can make their own decisions is probably sufficient to conduct space mining.

The question of true robotic autonomy is less about necessity and more about time, according to Professor Ciaraldi. The comparison he draws is to the capacity for robots to be autonomous now. In certain contexts, it is possible for a robot to operate in a completely autonomous fashion, for example the iRobot Roomba. As the environment in which a robot is able to act autonomously grows, we will slowly approach a generation of robots which are closer to the fully autonomous ones from iRobot the movie.

Next we asked Professor Ciaraldi for his take on the use of robots for space applications, especially where they would be taking the places of humans. His response was similar to that of Professor Schachterle; both men pointed out that NASA tends to favor manned missions because humans in space are more interesting to the public than robots in space. Professor Ciaraldi also indicated that robots would be cheaper than humans in almost all cases, and would eliminate the risk of any potential tragedies in which humans lose their lives. Another question we asked Professor Ciaraldi which pertained to the use of robots in space was the difference between robots and humans for space mining; he said that robotic miners would likely be much more productive.

The next two questions were all about the implications of mining in space, particularly on the moon. First, we asked Professor Ciaraldi about the advantages and disadvantages of mining space in general. His response was that in most cases, it would not be financially worthwhile to mine anything from space and bring it back to Earth. What he was more optimistic about, though, was the prospect of excavating certain materials from the lunar surface for use elsewhere in space. The next question assumed the hypothetical situation where a sustainable fusion reaction has been developed and mastered: what do you think the effects of mastering fusion would be? Professor Ciaraldi's primary hope for the side-effects of mastering fusion is the much cleaner nature of the reaction. Current nuclear power produces a great deal of radioactive waste which is difficult to dispose of safely. Sustained fusion reactions would produce far less waste, and the power could even be used to help clean up the waste of fission reactions.

Our last question for Professor Ciaraldi was about the future of robotics. We asked whether he believed we were heading in the right direction with technological advances in robots. His reaction was optimistic, with a slight edge toward careful consideration of the applications of robots being built. His concern was that, in the future, military robots may be given authorization to use lethal force. While such robots do not currently have the intelligence necessary to distinguish ally and enemy forces without human guidance, Professor Ciaraldi also noted that such advanced robots will probably not be used by the military for years to come.

10.1.6 Professor Schachterle

Right from the outset of our interview with English Professor Lance Schachterle of the Humanities Department, he emphatically stated that he is not an expert of robotic technology. He told us that the bulk of his experience in the field of robotics came as a result of his involvement in the creation of the Robotics Engineering program here at WPI. The particular aspects of robotics which he finds most interesting are those of robotic autonomy and the ethics of using robots.

Concerning robotic autonomy, Professor Schachterle believes that the technology behind autonomous robots will inevitably improve, "because that is the way technology has always worked." He is also concerned that robotics engineers will not display sufficient care with regard to the ethical and safety concerns that arise with a higher degree of autonomy.

Concerning the ethics of using technology, Professor Schachterle pointed out that "the history of engineering has shown either that engineers have not put enough thought into the social and moral questions or, more tragically, if they have they have been overruled by the people who run the country." Specifically, the case of the atomic bombs being detonated in Hiroshima and Nagasaki is a prime example of politicians overruling engineers due to time constraints or other problems. He noted that the engineers responsible for building the technology are seldom the people who decide how it is used.

The next topic we covered was the use of robots for space applications. Our first question in this vein pertained to the adaptability of humans versus that of robots. Professor Schachterle believes that human adaptability is a valuable asset to have, but that sometimes the need for such adaptability could be eliminated by replacing humans with robots. For example, the malfunctioning life support system of Apollo 13 would be very difficult for a robot to repair.

Then again, if only robots were on board the spacecraft, the very need for life support would be eliminated. Professor Schachterle also favors saving money by using robots instead of humans for space missions. He is skeptical about the scientific value of human presence that could not be obtained by robots. To further solidify this point, here is the answer he gave when asked whether robots should handle space mining if it becomes a common practice:

"Definitely. Even more strongly than robots not humans, *always robots, never humans*."

When asked about the merit of a lunar base, Professor Schachterle stated that he does not believe sending humans to the moon is worthwhile. Were such a base to be used for refueling and repair of robots, he would support it only in the case that there is some scientific value to be had.

The financial aspect of robotic space mining is a difficult topic to address, as there are no exact figures for the costs and profits, only estimates. Professor Schachterle believes that the practice may be worthwhile if there is some scientific gain, preferably accompanying some financial gain as well. He stressed that any such mining should only be done by robots, and that he would be opposed to spending even one cent to send humans back to the moon. Economic concerns also tie into another topic we discussed with Professor Schachterle: nuclear fusion.

Helium-3, one of the primary ingredients of lunar regolith, is sought after as a potential fuel for fusion research. We asked Professor Schachterle's thoughts on the matter, in the hypothetical situation that a sustained fusion reaction becomes possible. Specifically, we wanted to know if he thought free power would be constructive or destructive. He responded positively to the prospect of fusion, particularly because it would be much cleaner. Concerning an abundant source of cheap energy, he believed it would be ultimately positive, as it would free up other resources for different uses. "Oil is too valuable to burn for energy, there are other uses for oil like making plastics where it still has a significant part."

The other questions we asked Professor Schachterle pertained to mining itself. We asked what he thought about mining other locations besides Earth, and what degree of mining he thought might be appropriate. He said that while he does not know exactly what the costs would be to mine in space, that it may be cost effective if there are extremely rare materials available. As for appropriate levels of mining, he was cautiously optimistic. "I have no problems at all with any kind of manipulation of the lunar surface for the sake of either scientific discovery or to bring back to Earth minerals or ions like Helium that we could use, so long as we don't upset whatever ecology exists on the moon." There may or may not be any organic material, but as he put it "I would hate to see any mining operation interfere with the discovery and then contamination of any organic molecules."

10.2 Analysis of Positivity

Apart from simply asking each professor their opinions, we decided to go a little deeper. We conducted a simple numerical analysis of the responses we received from them, to get a better idea how positively or negatively they thought of a given subject. Our approach was a slightly modified version of Carol Bush's content analysis (Busch 2005). It picked out individual phrases used by the professors when responding to different questions, in an attempt to determine their attitude toward a particular question based on the positivity or negativity of their word choice. Due to the fact that not all professors granted permission to print the transcripts of their interviews, we cannot give an exact listing of all of the words and phrases we analyzed. What follows is a set of example words and the weighted positivity associated with them:

Word	Score	Word	Score
acceptable	1	inevitable	-2
adaptable	1	interesting	2
bad	-2	justifiable	1
beneficial	2	kill	-5
biased	-2	liberating	3
cheap	2	mess	-1
cinch	3	mistaken	-1
clear	2	modern	1
complicated	-2	nasty	-4
conservative	1	never	-3
constructive	2	oppose	-2
dangerous	-3	optimistic	3
deadly	-5	outrage	-4
dependant	-2	problematic	-2
destructive	-4	promising	3
dull	-1	realistic	2
enough	2	salvation	5
ethical	2	scary	-3
evil	-5	simple	2
excellent	4	skeptical	-1
exploit	-2	sketchy	-1
false	-2	slaughter	-5
fantastic	4	stupid	-2
fascinating	3	suspicious	-2
flexible	2	tragic	-4
fraud	-3	unethical	-3
good	2	unexpected	-2
great	4	unlimited	3
hard	-2	upset	-2
huge	3	waste	-1

Table 1- Sample words used in Content Analysis

We read through each transcript carefully, choosing non-neutral words that were either directly or indirectly related to the professor's response to a question. After choosing all of the words we wanted to use, we ranked them in terms of intensity relative to each other. As an example, the word 'skeptical' conveys a stronger feeling than the word 'suspicious,' so we assign it a heavier weight. Our scale ranges from -5 to +5, or very negative to very positive.

In addition to giving positivity scores to nouns and verbs, we chose adverbs and the word ‘not’ to use as modifiers for other words. Our selection method was similar for modifiers as it was for positive or negative words; we read through each transcript, and chose words that increased the intensity of the positive or negative response. For example, the word ‘really’ has a connotation of strong feeling, and the word ‘extremely’ conveys a very powerful feeling. To give an example of how we used this system, the word ‘good’ has a positive score of +2 and ‘extremely’ has a weight of x3, so the phrase ‘extremely good’ would carry a score of +6. ‘Not’ is the only negative modifier we used, which is -1. So, for example, the phrase ‘not bad’ has a score of (-1 * -2) = +2. Here is a short list of the modifiers we used:

Word	**Modifier**
a lot of	1.5
absolutely	2
always	2.5
enormously	3
extremely	3
incredibly	2.5
not	-1
really	1.5
terribly	2
very	1.5
worst	2.5

Table 2- Sample modifiers used in Content Analysis

After constructing this system for analysis, we examined each professor’s responses to each question and computed their positive or negative scores. The following tables show each question, along with that professor’s positivity on that question, the average positivity of all professors, and the difference of each professor from the average. To compensate for the fact that not all responses were the same length, we also computed the average score per sentence for each response the professors gave us. We listed their positivity per sentence, the average positivity per sentence of all professors, and each professor's difference from the average.

10.2.1 Professor Sanbonmatsu

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	-14	8	-22	-3.5	1.21	**-4.71**
Robotic Autonomy	-8	1.16	-9.16	-0.88	-0.03	-0.85
Technological Advances in Robotics	-15	3	-18	-1.36	0.47	-1.83
Use of Robots in Place of Humans	10	13.67	-3.67	1	1.18	-0.18
Advantages and Disadvantages of Space Mining	-7	4.91	-11.91	-0.63	0.47	-1.1
Lunar Base	-14.5	-1.41	-13.09	-1.81	-0.28	-1.53
Possible side-effects of Space Mining	-6.5	9.58	**-16.08**	-0.54	0.84	-1.38

Table 3- Computed Positivity of Professor Sanbonmatsu.

On the whole, Professor Sanbonmatsu's responses had more negative scores than those of other professors. In particular, the opinions he expressed towards the prospect of a lunar base and the current direction of robotic advances were very skeptical. On the other hand, he was positive about the use of robots in place of humans, especially where it would be removing humans from danger.

10.2.2 Professor Looft

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	15	8	7	1.67	1.21	0.46
Robotic Autonomy	7	1.16	5.84	0.7	-0.03	0.73
Technological Advances in Robotics	9	3	6	1.29	0.47	0.82
Use of Robots in Place of Humans	21	13.67	7.33	1.17	1.18	-0.01
Advantages and Disadvantages of Space Mining	5.5	4.91	0.59	0.69	0.47	0.22
Lunar Base	-4	-1.41	-2.59	-0.57	-0.28	-0.29
Possible side-effects of Space Mining	-4	9.58	**-13.58**	-0.44	0.84	**-1.28**

Table 4- Computed positivity of Professor Looft

Professor Looft mostly had good things to say about robotics, but was slightly less positive about space mining itself. His response to our questions about the lunar base was slightly negative, but where Professor Sanbonmatsu is against it entirely, Professor Looft said that building a lunar base is probably too expensive given our current technology.

10.2.3 Professor Wilkes

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	12	8	4	3	1.21	**1.79**
Robotic Autonomy	3	1.16	1.84	0.38	-0.03	0.41
Technological Advances in Robotics	9	3	6	1	0.47	0.53
Use of Robots in Place of Humans	17	13.67	3.33	1.21	1.18	0.03
Advantages and Disadvantages of Space Mining	22.5	4.91	17.59	2.05	0.47	1.58
Lunar Base	17	-1.41	**18.41**	0.85	-0.28	1.13
Possible side-effects of Space Mining	25.5	9.58	15.92	1.96	0.84	1.12

Table 5- Computed positivity of Professor Wilkes

Professor Wilkes was very positive about the use of robots to remove humans from danger, but even more so about the potential of space mining. He said he believes that space mining will lead to great scientific breakthroughs in the future, and will lay the groundwork for the eventual salvation of the human race.

10.2.4 Professor Rich

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	6	8	-2	6	1.21	**4.79**
Robotic Autonomy	4.5	1.16	3.34	0.9	-0.03	0.93
Technological Advances in Robotics	8	3	5	1.6	0.47	1.13
Use of Robots in Place of Humans	13.5	13.67	-0.17	1.5	1.18	0.32
Advantages and Disadvantages of Space Mining	-10	4.91	**-14.91**	-0.91	0.47	-1.38
Lunar Base	4	-1.41	5.41	0.8	-0.28	1.08
Possible side-effects of Space Mining	11	9.58	1.42	1.22	0.84	0.38

Table 6- Computed positivity of Professor Rich

According to the scores we computed, Professor Rich was more neutral than most. The questions he had stronger positivity toward were about the possible side effects of space mining, especially the hypothetical case of mastering nuclear fusion, and the use of robots in place of humans in dangerous environments.

10.2.5 Professor Ciaraldi

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	31	8	23	2.07	1.21	0.86
Robotic Autonomy	15	1.16	**13.84**	1.15	-0.03	**1.18**
Technological Advances in Robotics	9	3	6	1.29	0.47	0.82
Use of Robots in Place of Humans	8.5	13.67	-5.17	0.47	1.18	-0.71
Advantages and Disadvantages of Space Mining	15	4.91	10.09	1.15	0.47	0.68
Lunar Base	6	-1.41	7.41	0.6	-0.28	0.88
Possible side-effects of Space Mining	22.5	9.58	12.92	1.32	0.84	0.48

Table 7- Computed positivity of Professor Ciaraldi

Professor Ciaraldi was one of only two professors we interviewed who had a positive response for each question we asked, the other being Professor Wilkes. Professor Ciaraldi was most positive about the robotic technology that exists today, and the possible side-effects of space mining, including fusion research and improved artificial intelligence. He was also more positive than average on every question except the one about building a lunar base.

10.2.6 Professor Schachterle

Question	Score	Average	Difference	Score/Sentence	Average S/S	Difference
Current State of Robotic Technology	-2	8	-10	-2	1.21	**-3.21**
Robotic Autonomy	-14.5	1.16	**-15.66**	-2.42	-0.03	-2.39
Technological Advances in Robotics	-2	3	-5	-1	0.47	-1.47
Use of Robots in Place of Humans	12	13.67	-1.67	1.71	1.18	0.53
Advantages and Disadvantages of Space Mining	3.5	4.91	-1.41	0.44	0.47	-0.03
Lunar Base	-17	-1.41	-15.59	-1.55	-0.28	-1.27
Possible side-effects of Space Mining	9	9.58	-0.58	1.5	0.84	0.66

Table 8- Computed positivity of Professor Schachterle

Professor Schachterle and Professor Sanbonmatsu were the only two professors we interviewed who were less positive than average on every question. They were more concerned with finding solutions to problems on Earth than with mining space. However, they each support using robots for appropriate applications, especially when those applications are dangerous.

10.2.7 Comparison of Experts

Despite the fact that there were outstanding differences between each professor we interviewed, there were also some interesting similarities. While everyone had something different to say about the prospect of mining the moon, some positive and some negative, there was one response shared by everyone. Each professor agreed that using robots for dangerous tasks in place of humans was a good thing.

The idea of a lunar base was on the opposite end of the 'agreement spectrum.' Professor Wilkes was the most positive on this topic, Professors Ciaraldi, Looft and Rich were more neutral, and Professors Sanbonmatsu and Schachterle were more negative about it. Professor Wilkes expressed optimism toward the potential for scientific discovery and technological advancement that could result from it, while Professor Schachterle argued that there is no scientific gain to be made; at least none that could not be done by robots.

The potential side-effects of mining space, especially nuclear fusion research, was another subject where the opinions of professors varied greatly. Responses ranged from highly enthusiastic to cautiously optimistic to very skeptical. Professor Wilkes was the most positive about the idea of nuclear fusion research moving forward, mentioning that fusion research could be done on the moon with materials from the moon to improve technology developed on the moon. Professor Sanbonmatsu expressed a belief that fusion would be a very clean energy source, but that it could also be potentially dangerous to rely on centralized energy. Generally speaking, the professors we had the opportunity to interview were skeptical about fusion being feasible, but optimistic about its hypothetical benefits.

11. Future Work/Prediction

In this section we speculate on what may happen in the future based on current progress and trends of developments in robotic space mining.

11.1 Near Future

We predict that in the near future there will be a push for mining extraterrestrial surfaces in order to:

- Build a structural basis for further mining operations
- Gather more resources
- Explore unknown terrain
- Create new mining technologies
- Create new robotic technologies

If we did not mine the moon for its resources then it would be to create a lunar base. Creating this lunar base would require a tremendous amount of money and resources, which currently no nation is volunteering. It will be very possible to create a lunar base in segments much like the Space Station, and to continue construction over an extended period of time. We believe that this is technologically feasible at this point in time, however the amount of resources required to do such a task would be tremendous.

The lunar base would provide a basis for future mining facilities on or off the moon. We would be accustomed to the environmental hazards and design improved instruments to better deal these constraints. We predict that once the creation of a lunar base is seen as a functional source of income, then it will become the standard for economic growth in the space sector.

For obvious reasons we would want to mine extraterrestrial surfaces for the amount of resources they had. The real questions remain as to whether or not it is profitable to mine and whether or not it is necessary. At the current rate of human population growth and resource consumption we will eventually run out of resource. Thus, we will see the incentive to acquire resources from off-planet sources. Currently it may not seem economically viable, but in the future, in order to bolster the growth of space communities we must take advantage of all resources.

We have yet to fully explore what is under the surface of most planets. Only by digging will we be able to ascertain the minerals buried deep down below the planetary surface. For example, the moon has a hard rocky deposit of regolith under the soft sandy surface layer. By exploring the depths of planets we will be able to map the geography better, and see if there is anything hidden underneath those layers. We predict that by mining deep into extraterrestrial surfaces we will be able to understand more about the composition of planets and moons.

Our current mining technology is insufficient for mining in vacuums like space or other extreme environments. Thus we need to rethink our mining techniques. This will create new methods with which we can mine, perhaps without being so destructive and dirty. We predict that new mining technologies will be created that will work in space environments. It remains to be seen whether these new methods will be cleaner than what we have now.

As shown with the Regolith Excavation Challenge sponsored by NASA, new emerging technologies will be created in the robotics field. These involve the field of mechatronics, sensory devices, and autonomy. There will be need to create fault resistant technology that can withstand lunar environments and conditions, such as the tires used to maneuver a robot or the cameras it uses to sense it's environment. We predict that robot autonomy will become a major part of robotic mining. With the previous years of the Regolith Excavation Challenge, NASA had wanted a more autonomous robot capable of mining regolith. However, because the challenge was too difficult and nobody met the requirements, NASA decided to lessen the restrictions and requite teleoperated robots instead. Their initial goal was to have a robot mine by itself with limited instructions from humans. We expect that this will also occur in the near future.

11.2 Distant Future

We predict that in the distant future:

- Robotic space mining will be a normal source of capital.
- Robotic space mining will determine space colonization.

In the distant future space mining may become one of our largest industries. We predict that will replace fossil fuels and be a new "gas" business in space.

Finally, in the very distant future, we humans will have to leave Earth. We expect robotic space mining to play an integral role in the colonization of space. Wherever we are able to get the most resources will be where we will settle.

12. Conclusions

At the start of this project, we had some clear ideas about how we thought the WPI community would react to the idea of robotic space mining. We thought that a lot of the same sentiments expressed by the experts we interviewed would be mirrored in the survey results. Most of all, we thought that WPI in general would be supportive of space mining and of space exploration.

12.1 Survey

The survey results matched our expectations more closely than those of our interviews. We expected positive results from the WPI community about space mining and the possibility for related work, and were met with positive responses on every such question.

12.2 Expert Interviews

Our expert interviews turned out more or less how we expected, with experts in technical fields being more enthusiastic about the use of robots in space than experts of a more philosophical nature. Looking back, we see that we underestimated the desire of people to take care of business on Earth before worrying about business being done in space, with a few notable exceptions including Professor Rich. His theory was that, while of course we can't ignore the problems facing us now, we should also not ignore the potential of space.

There was a definite disparity between the attitudes of engineering experts and those of philosophical experts. On the one hand, everyone we interviewed believed that removing human beings from danger was a good use for robotics. On the other hand, while the engineers tended to favor further development of robotics, the philosophers thought that there were other things we should tend to first.

12.3 Comparison of Interviews and Survey

When we compared the results of the survey with the results of the interviews, taking into consideration the fact that some different questions were asked, we noticed a fair amount of agreement. One particular area where almost everyone agreed was the team composition for space mining missions. Nearly all of the participants believed that the best choice was a team of both robots and humans. Of course, there were some exceptions to this as well; Professor Schachterle, in particular, believes that sending humans to do something that can be done by robots is ill advised.

12.4 What we Learned

Throughout the course of this project, we learned many things, each of which contributed to the project in some way. After all of our research into the subject, we have become intimately familiar with it. Apart from just the subject matter, though, we have also acquired knowledge and skills that will help with future projects. These skills and knowledge include, primarily: how to conduct a survey, how to conduct an interview and the necessary steps which must be taken before conducting an interview or survey.

12.5 Final Thoughts

With the culmination of all of our work on this project, and the generosity of WPI students and faculty who took the time to complete our survey or agreed to be interviewed, we can now make some conclusions about the impact and implications of robotic space mining. Or survey analysis showed a general support for space mining and especially space exploration. Our expert interviews showed great enthusiasm for the potential of robotic technologies, and a reminder that engineers must be responsible for their work. This responsibility includes all the necessary safety measures to protect human life, and all the ethical consideration that must be done. While the future of space mining remains uncertain, whether done by humans, robots or both, we can say that the WPI community will support robotic space mining given a few prerequisites, the most important of which is that space mining must produce some financial turnover.

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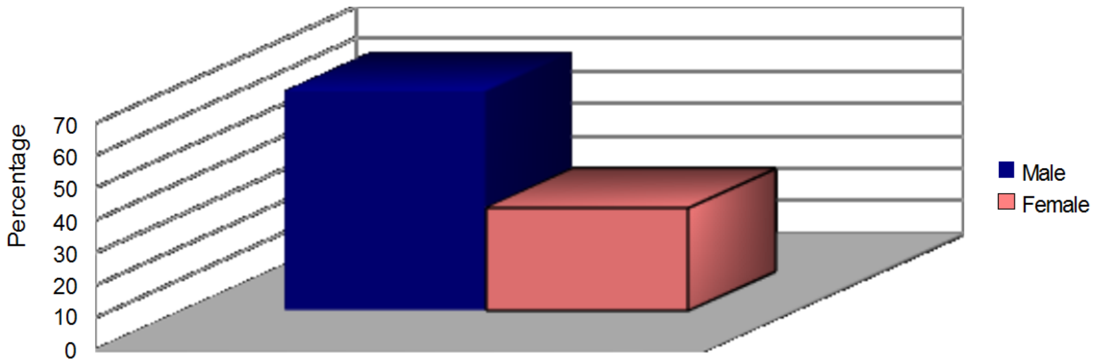
APPENDIX 1: Survey

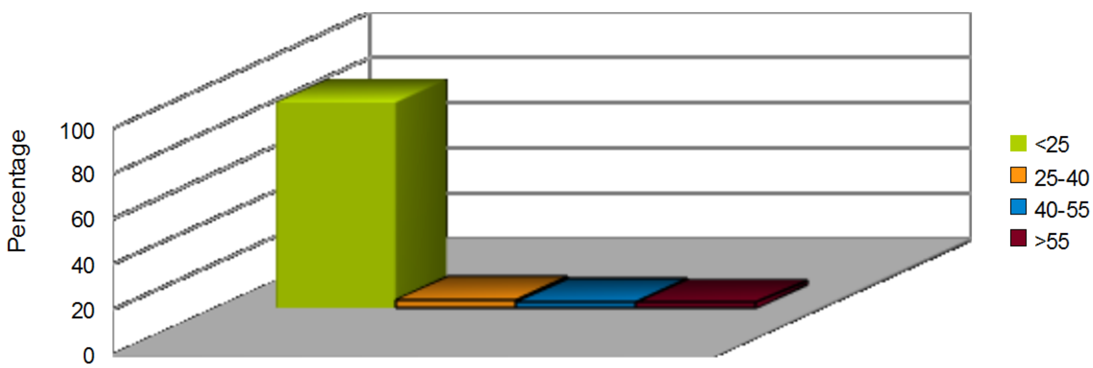
A. Overall Data

A.1 - What is your gender?



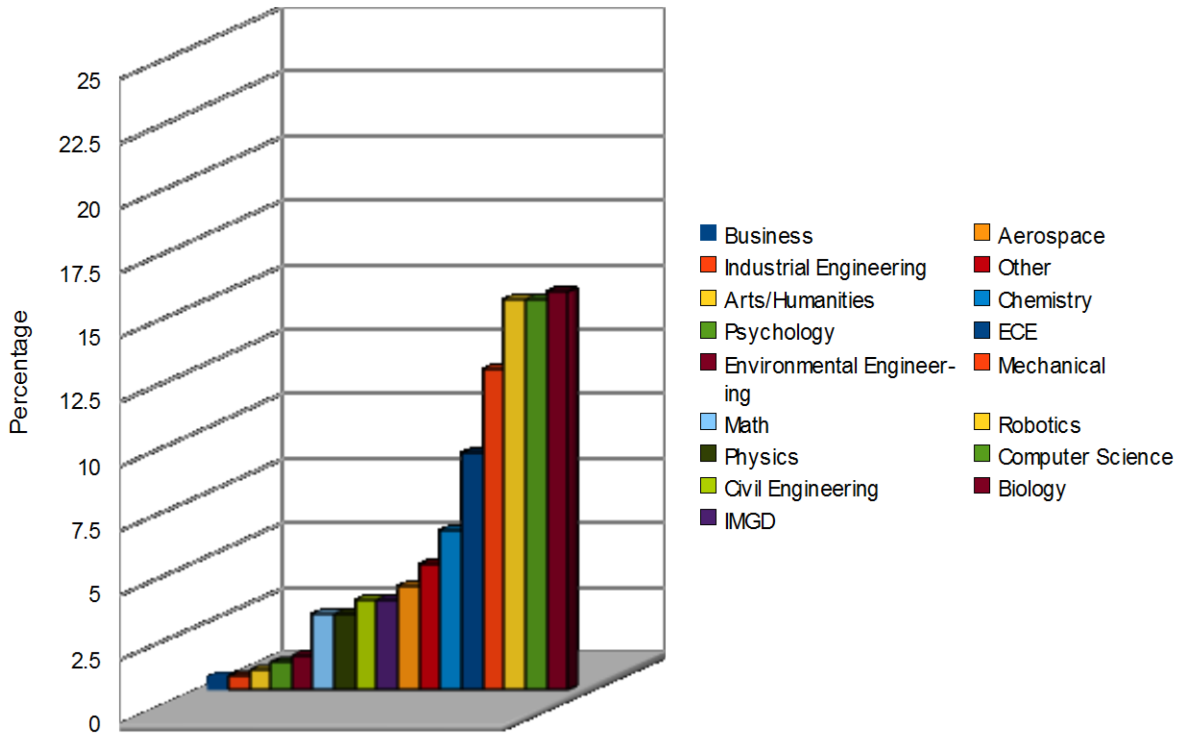
	Male	Female	Total
People (%)	251 (68.02%)	118 (31.93%)	369

A.2 - What is your age?



	<25	25-40	40-55	>55	Total
People (%)	336 (91.06%)	14 (3.79%)	10 (2.71%)	9 (2.44%)	369

A.3 - What is your area of study/interest?

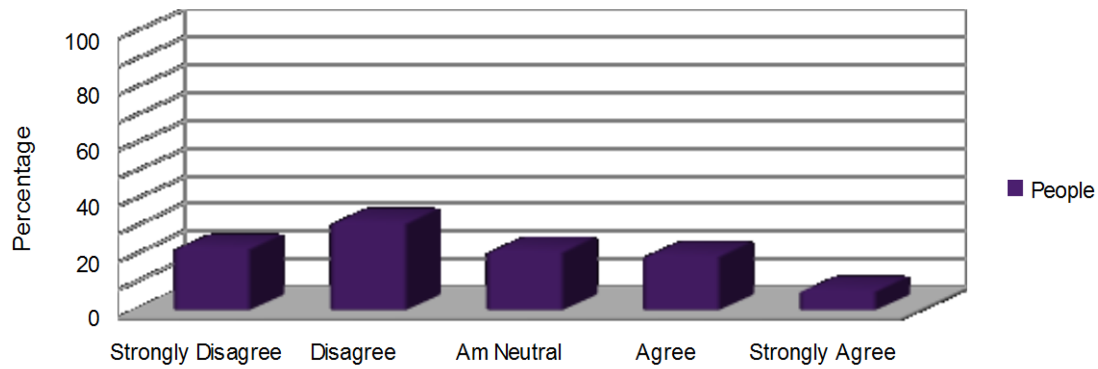


	Business	Ind. Eng.	Arts/ Hum.	Psych.	Env. Eng.	Math	Physics
Responses	2 (.54%)	2 (.54%)	3 (.81%)	4 (1.08%)	5 (1.36%)	11 (2.98%)	11 (2.95%)

	Civil Eng.	IMGD	Aerospace	Other	Chemistry	ECE	Mech. Eng.
Responses	13 (3.52%)	13 (3.52%)	15 (4.07%)	18 (4.88%)	23 (6.23%)	34 (9.21%)	46 (12.47%)

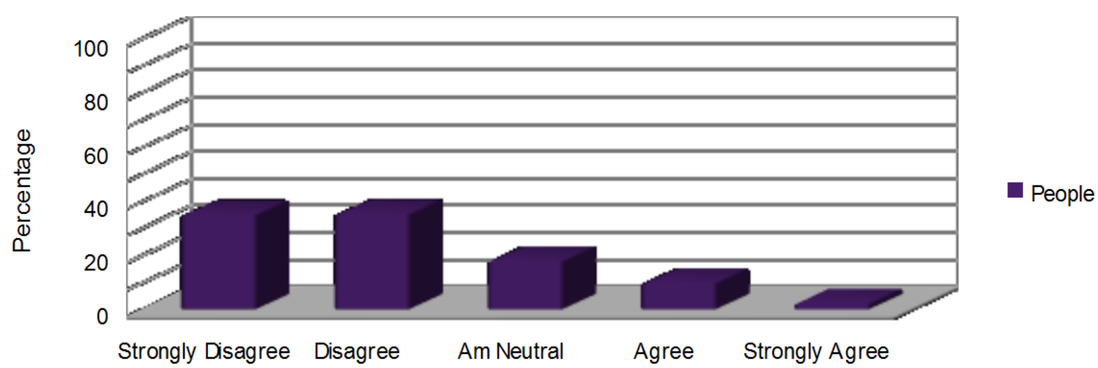
	Robotics	Computer Science	Biology				Grant Total
Responses	56 (15.18%)	56 (15.18%)	57 (15.45%)				369

A.4 - I have extensive knowledge of current robot technology:



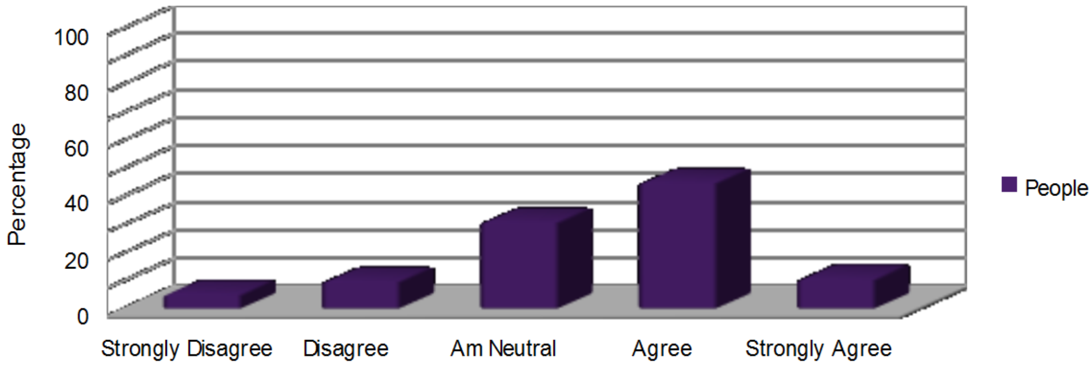
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	81 (22.0%)	115 (31.2%)	77 (20.9%)	71 (19.2%)	25 (6.8%)	369	2.58

A.5 - I have extensive knowledge of recent developments in space mining:



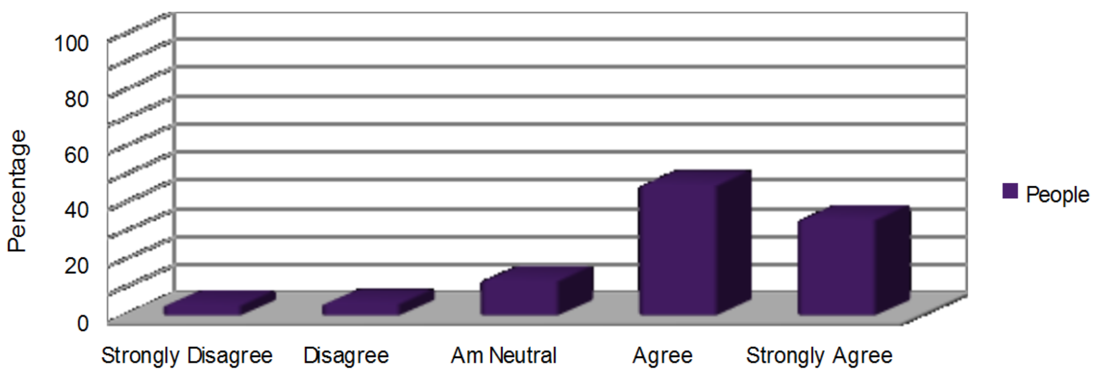
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	129 (35.0%)	130 (35.2%)	66 (17.9%)	36 (9.8%)	8 (2.2%)	369	2.09

A.6 - Current research and development of space mining technologies is of interest to me:



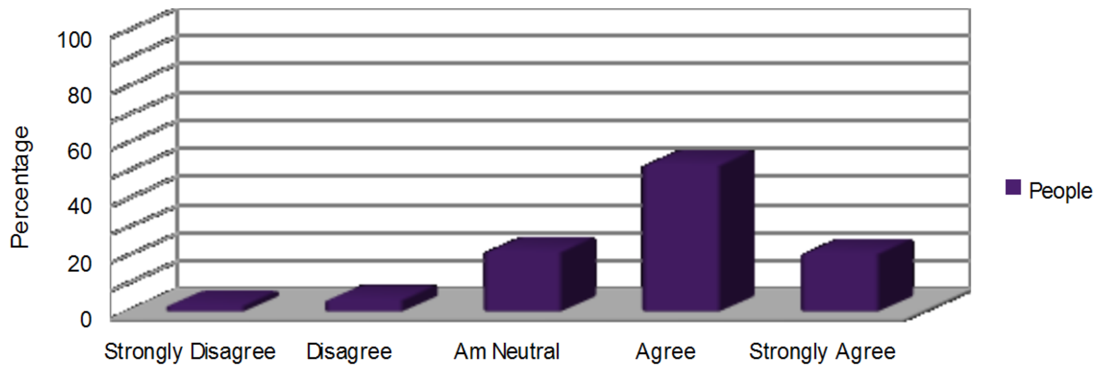
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	18 (4.9%)	35 (9.5%)	113 (30.6%)	165 (44.7%)	38 (10.3%)	369	3.46

A.7 - I believe space exploration is important to society:



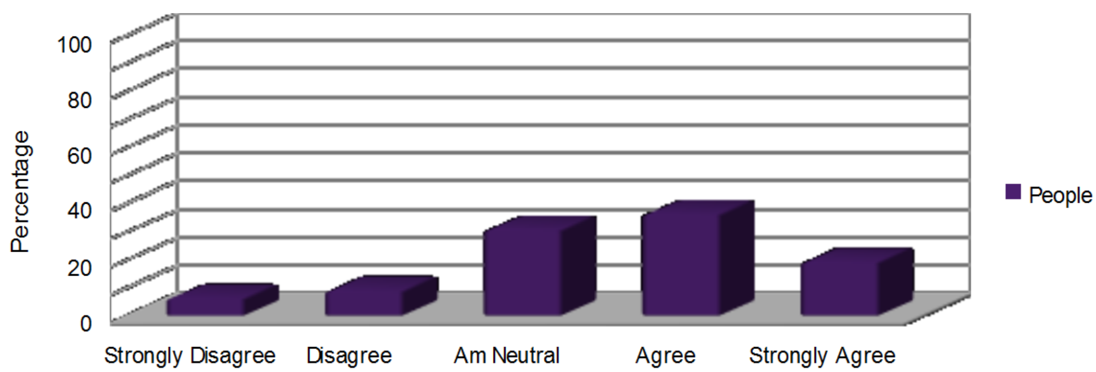
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	13 (3.5%)	15 (4.1%)	45 (12.2%)	170 (46.2%)	125 (34.0%)	368 (1 Skipped)	4.03

A.8 - I believe mining on Earth is important:



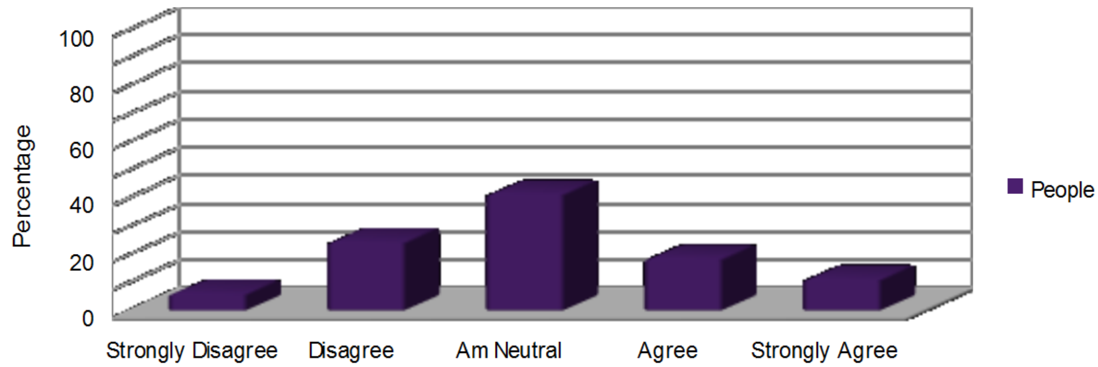
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	8 (2.2%)	15 (4.1%)	78 (21.1%)	192 (52.0%)	76 (20.6%)	369	3.85

A.9 - I believe mining on extraterrestrial (non-Earth) surfaces is important:



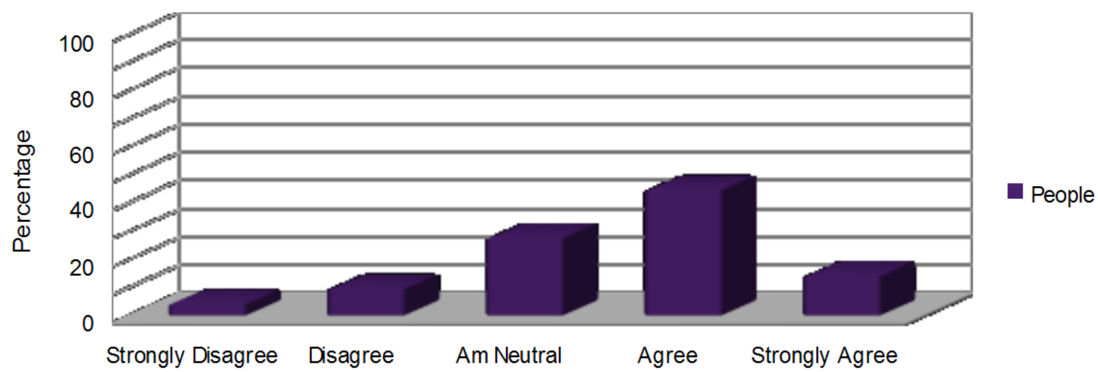
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	22 (6.0%)	32 (8.6%)	112 (30.4%)	133 (36.0%)	70 (19.0%)	369	3.53

A.10 - I believe funding for space mining would be better spent elsewhere:



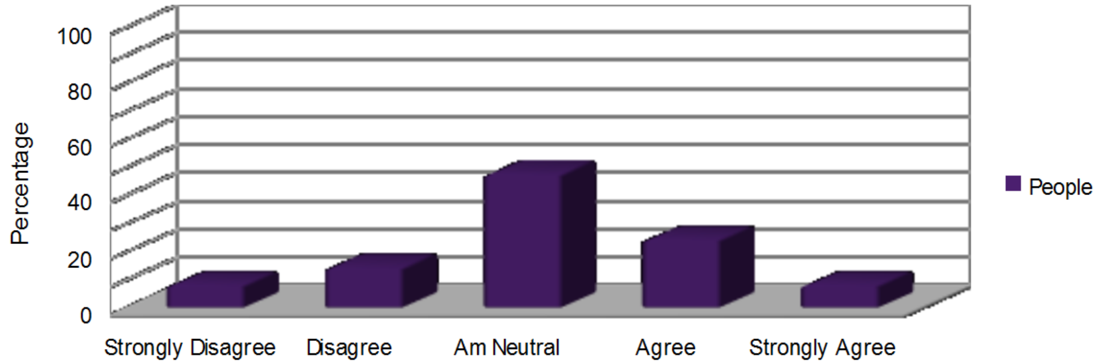
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	21 (5.7%)	89 (24.1%)	152 (41.2%)	67 (18.2%)	40 (10.8)	369	3.04

A.11 - I believe that robotic space mining needs to be given more media exposure:



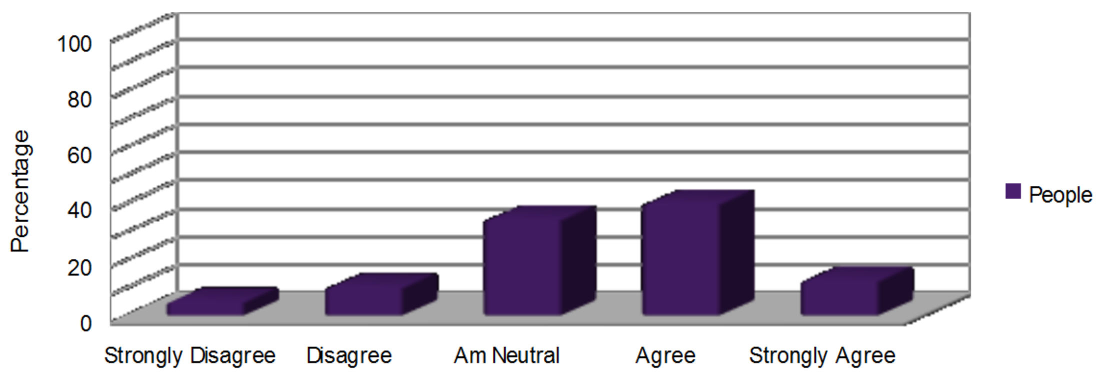
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	15 (4.1%)	35 (9.5%)	102 (27.6%)	165 (44.7%)	52 (14.1%)	369	3.55

A.12 - I believe that robotic space mining needs to be given more financial backing:



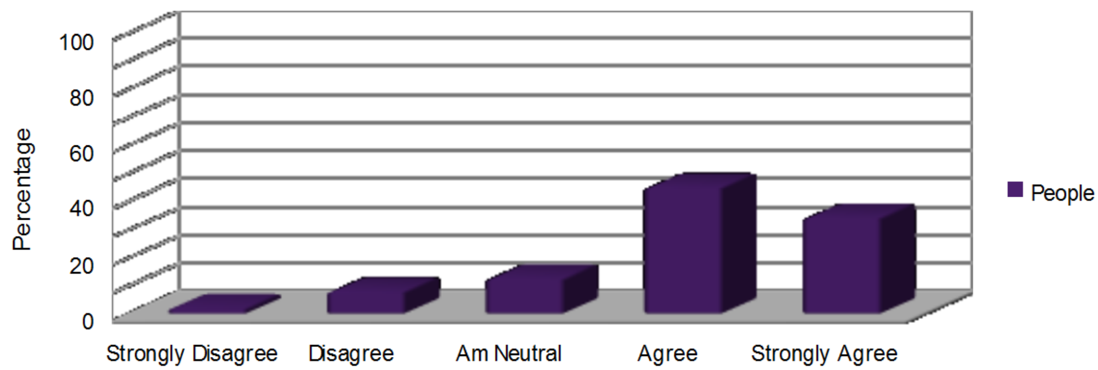
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	28 (7.6%)	51 (13.8%)	174 (47.2%)	88 (23.8%)	28 (7.6%)	369	3.1

A.13 - I believe we are in need of more (minable) resources:



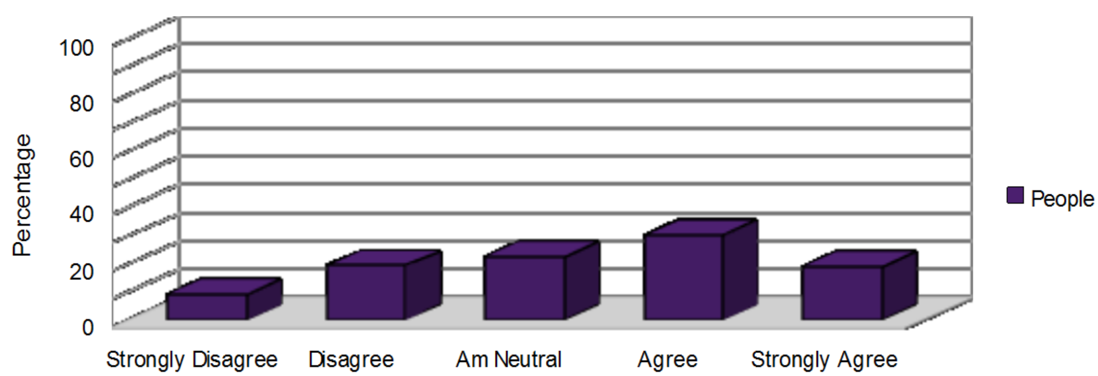
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	17 (4.6%)	36 (9.8%)	125 (33.9%)	146 (39.6%)	45 (12.2%)	369	3.45

A.14 - I think that exhaustive mining of Earth is inappropriate:



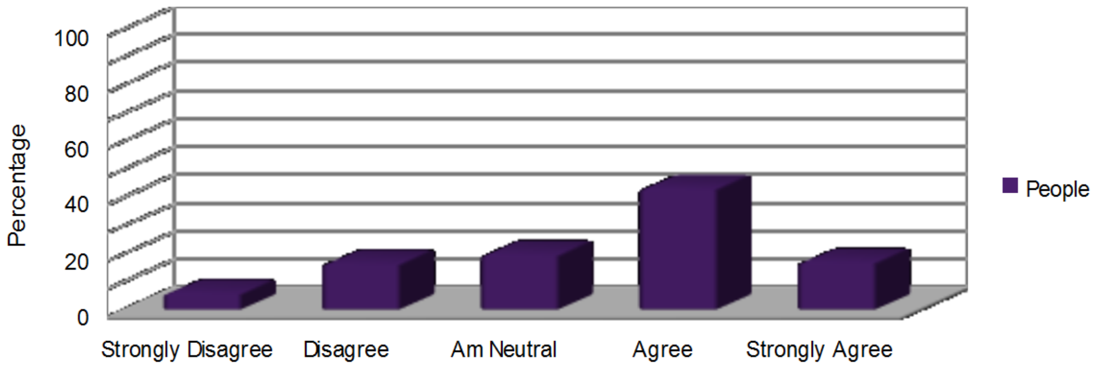
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	6 (1.6%)	28 (7.6%)	45 (12.2%)	165 (44.7%)	125 (33.9%)	369	4.02

A.15 - I think that exhaustive mining of the moon is inappropriate:



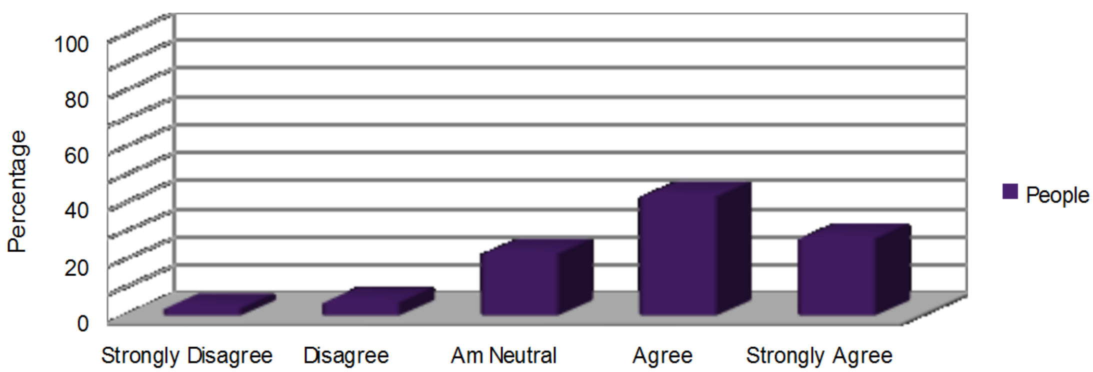
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	34 (9.2%)	71 (19.2%)	83 (22.5%)	111 (30.1%)	70 (19.0%)	369	3.3

A.16 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:



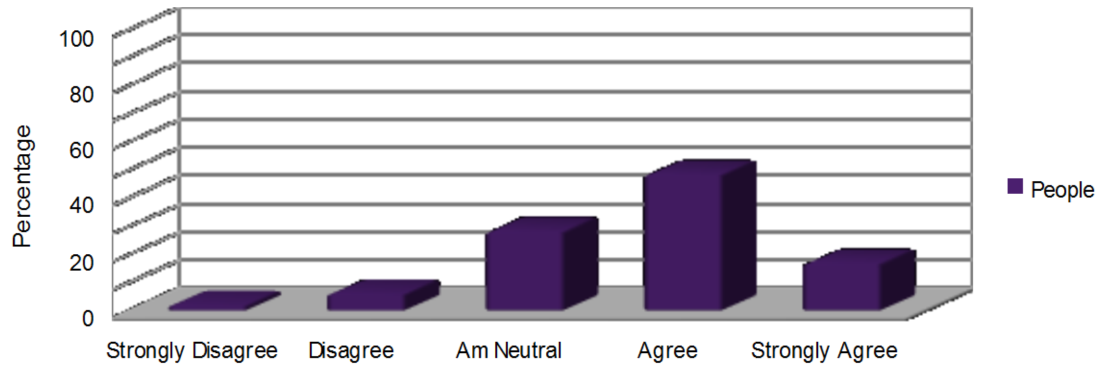
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	20 (5.4%)	59 (16.0%)	71 (19.2%)	158 (42.8%)	61 (16.5%)	369	3.49

A.17 - I think it would be more cost effective to send robots to space in place of humans:



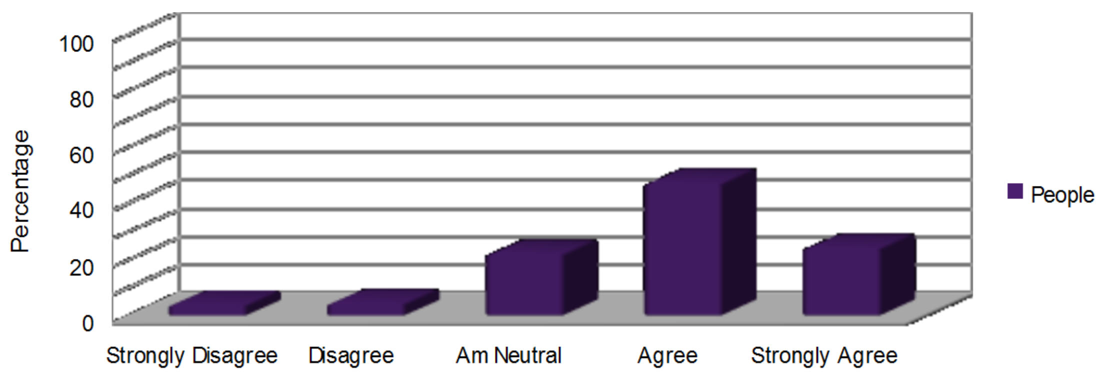
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	10 (2.7%)	18 (4.9%)	82 (22.2%)	157 (42.5%)	102 (27.6%)	369	3.88

A.18 - I think that mineral mining in space can currently be done by robots:



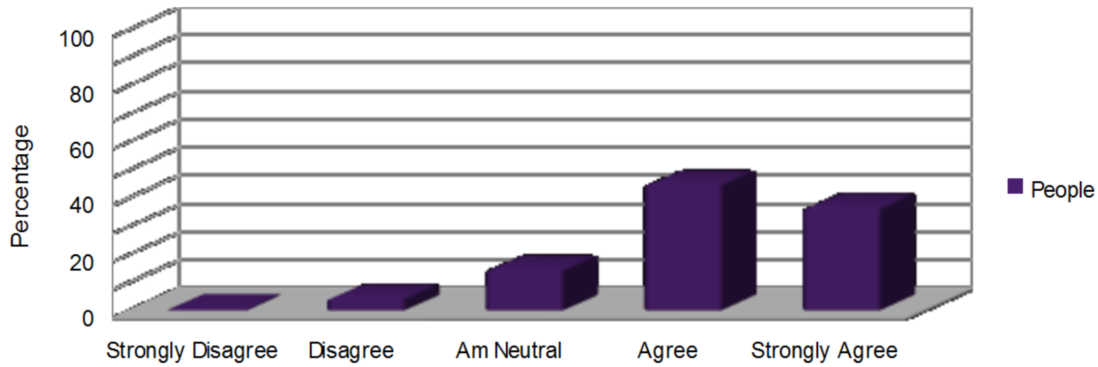
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	6 (1.6%)	21 (5.7%)	103 (27.9%)	178 (48.2%)	61 (16.5%)	369	3.72

A.19 - I think that mineral mining in space should be done by robots:



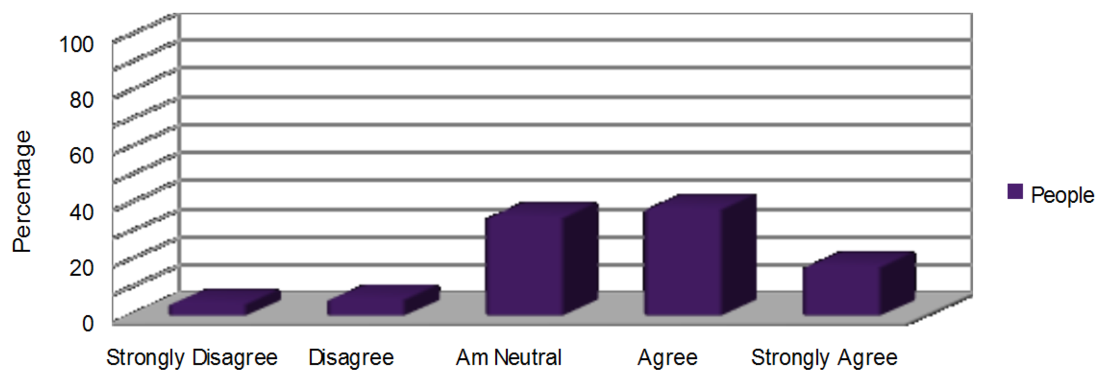
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	13 (3.5%)	15 (4.1%)	80 (21.7%)	173 (46.9%)	88 (23.8%)	369	3.83

A.20 - I think space exploration has a positive impact on society:



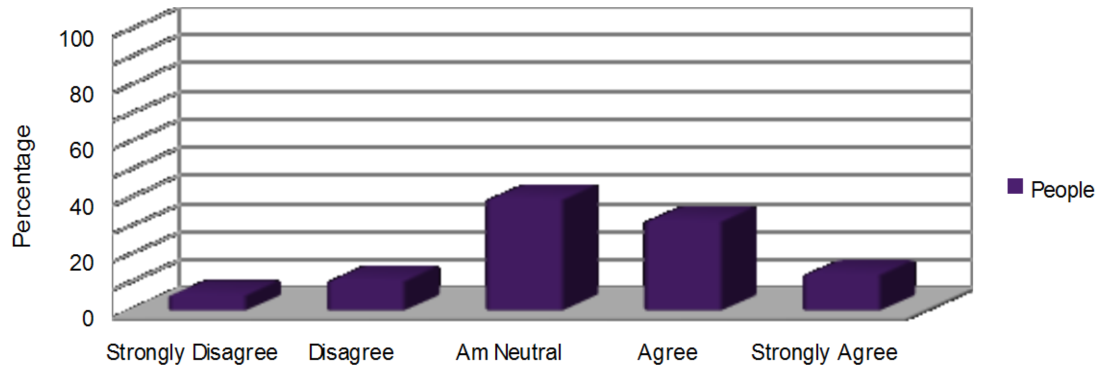
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	2 (.5%)	15 (4.1%)	53 (14.4%)	165 (44.7%)	134 (36.3%)	369	4.12

A.21 - I think space mining will have a positive impact on society:



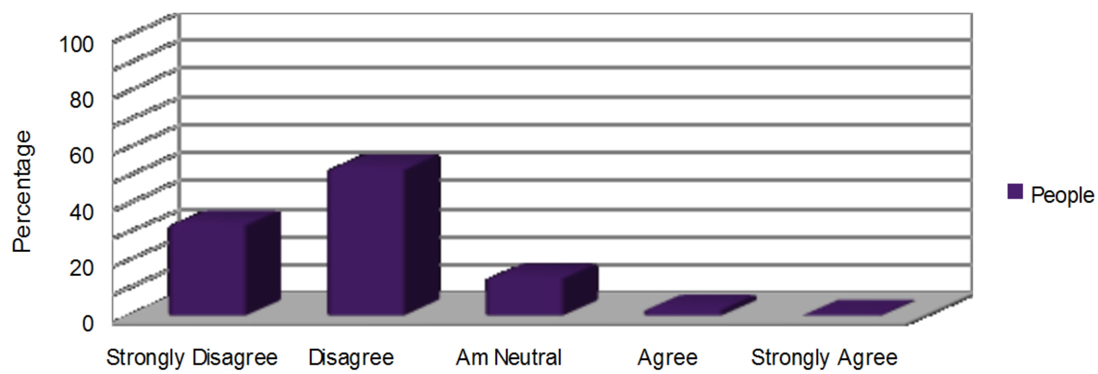
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	15 (4.1%)	21 (5.7%)	129 (35.0%)	140 (37.9%)	64 (17.3%)	369	3.59

A.22 - I think space mining would be financially beneficial:



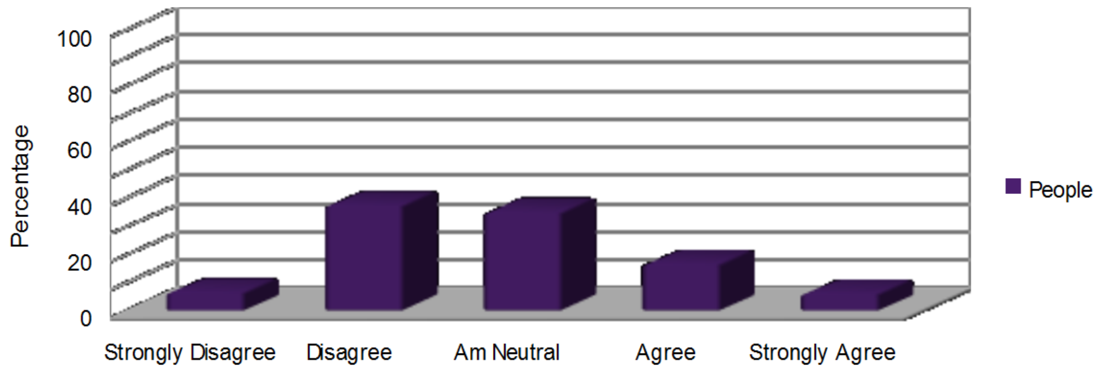
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	20 (5.4%)	39 (10.6%)	146 (39.6%)	117 (31.7%)	47 (12.7%)	369	3.36

A.23 - I believe that sending <u>only people</u> is the best choice for space mining operations:



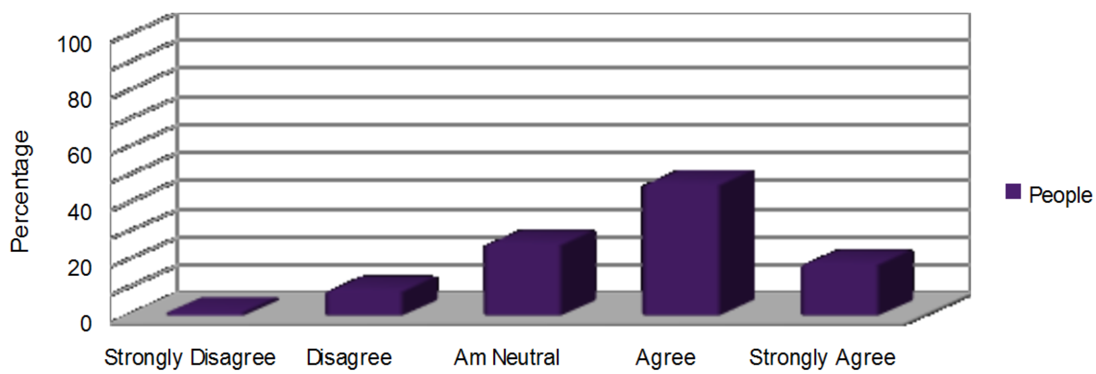
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	119 (32.2%)	192 (52.0%)	49 (13.3%)	8 (2.2%)	1 (.3%)	369	1.86

A.24 I believe that sending <u>only robots</u> is the best choice for space mining operations:



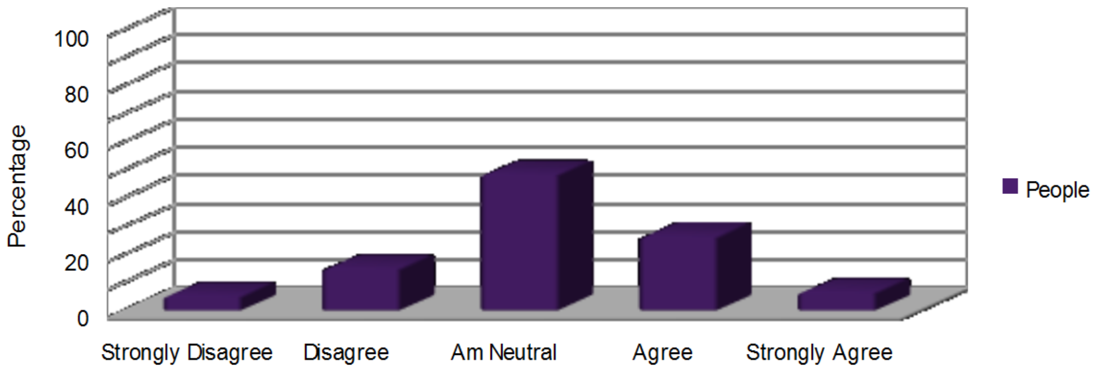
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	23 (6.2%)	137 (37.1%)	128 (34.7%)	60 (16.3%)	21 (5.7%)	369	2.78

A.25 - I believe that sending <u>both people and robots</u> is the best choice for space mining operations:



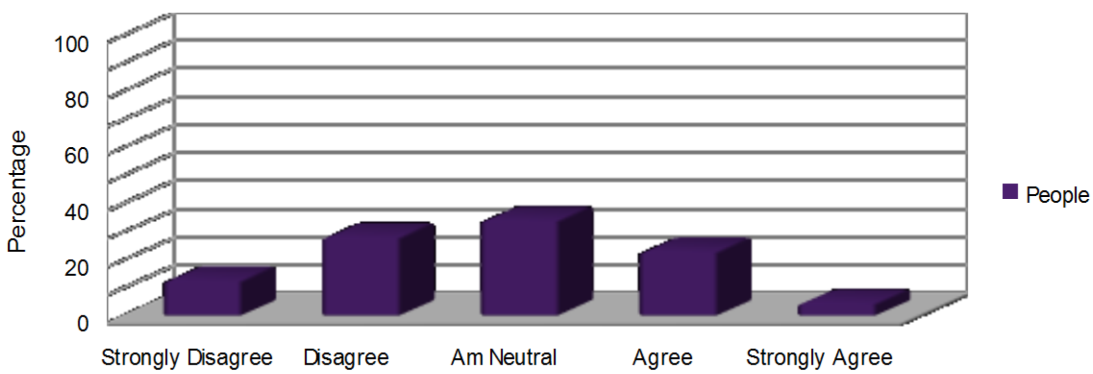
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	5 (1.4%)	32 (8.7%)	93 (25.2%)	172 (46.6%)	67 (18.2%)	369	3.72

A.26 - I think it would be more cost effective to process the mined minerals on Earth



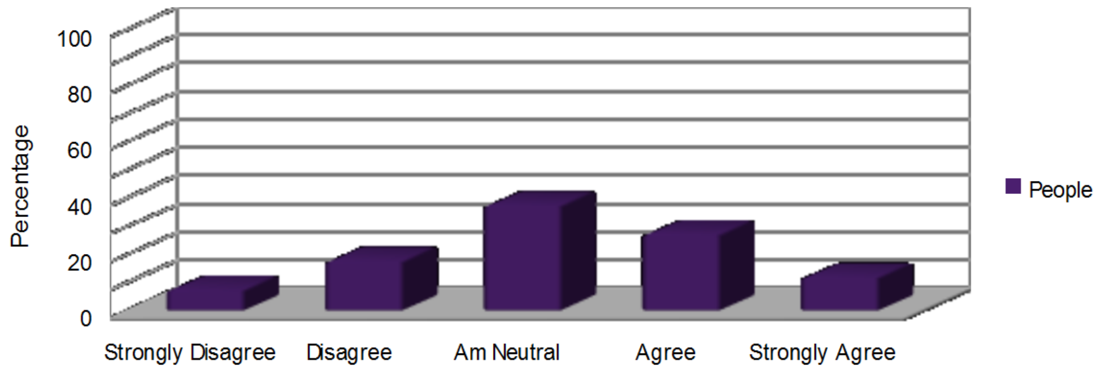
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	18 (4.9%)	54 (14.6%)	178 (48.2%)	96 (26.0%)	23 (6.2%)	369	3.14

A.27 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:



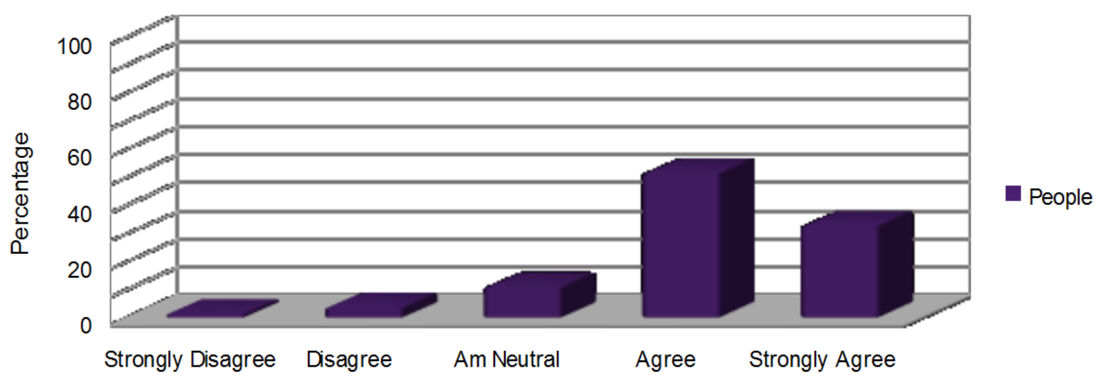
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	45 (12.2%)	102 (27.6%)	124 (33.6%)	83 (22.5%)	15 (4.1%)	369	2.79

A.28 - I think it would be financially beneficial to build a lunar base:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	26 (7.0%)	64 (17.3%)	137 (37.1%)	99 (26.8%)	43 (11.7%)	369	3.19

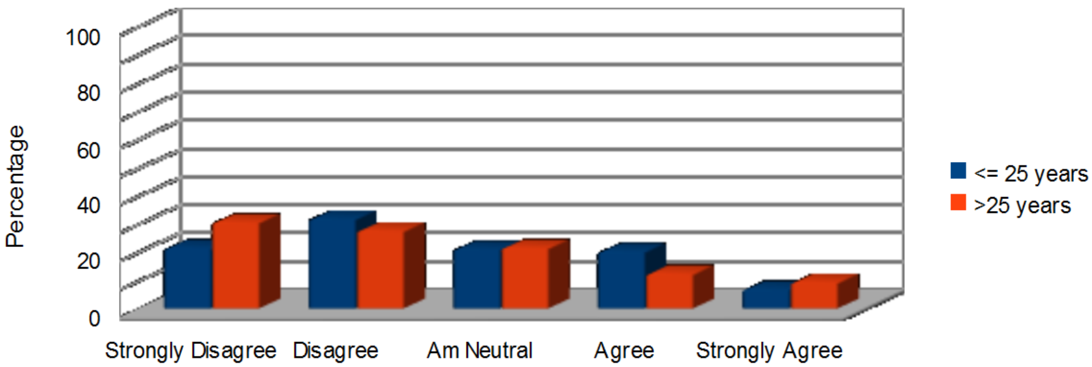
A.29 - I think that building a lunar base would lay the groundwork for expansion into space:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean
People (%)	5 (1.4%)	13 (3.5%)	40 (10.8%)	190 (51.5%)	121 (32.8%)	369	4.11

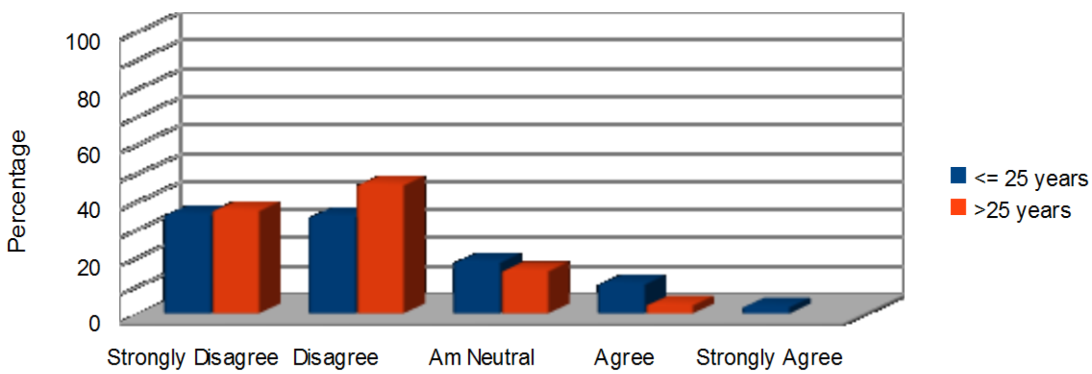
B. Age Groups

B.1 - I have extensive knowledge of current robot technology:



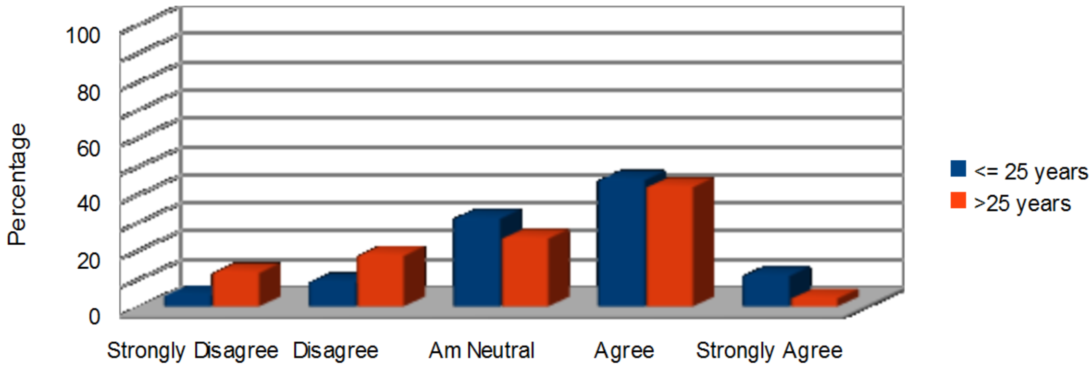
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	71 (21.1%)	106 (31.5%)	70 (20.8%)	67 (19.9%)	22 (6.5%)	336	2.59	1.21
> 25 years (%)	10 (30.3%)	9 (27.3%)	7 (21.2%)	4 (12.1%)	3 (9.1%)	33	2.42	1.28

B.2 - I have extensive knowledge of recent developments in space mining:



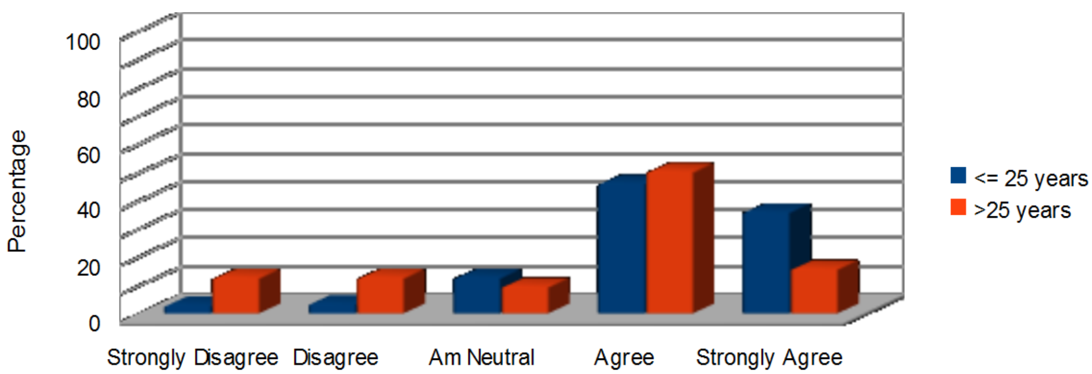
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	117 (34.8%)	115 (34.2%)	61 (18.2%)	35 (10.4%)	8 (2.4%)	336	2.11	1.07
> 25 years (%)	12 (36.4%)	15 (45.5%)	5 (15.2%)	1 (3.0%)	0 (0.0%)	33	1.85	0.78

B.3 - Current research and development of space mining technologies is of interest to me:



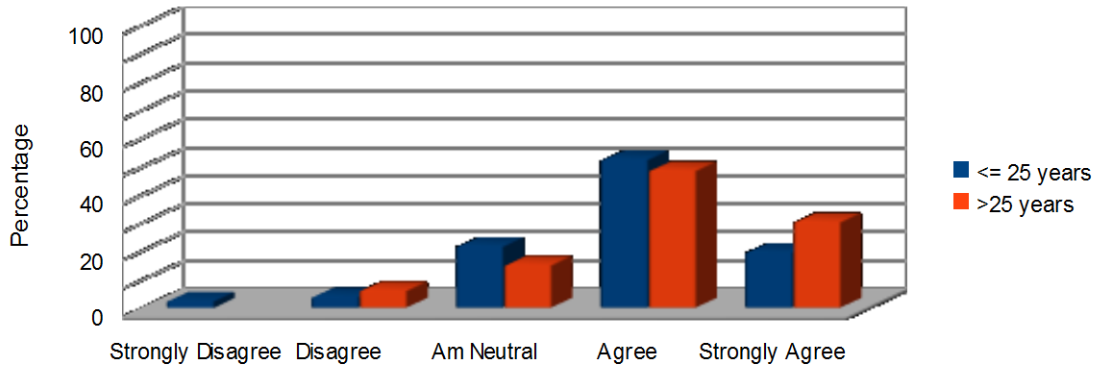
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	14 (4.2%)	29 (8.6%)	105 (31.3%)	151 (44.9%)	37 (11.0%)	336	3.5	0.94
> 25 years (%)	4 (12.1%)	6 (18.2%)	8 (24.2%)	14 (42.4%)	1 (3.0%)	33	3.06	1.1

B.4 - I believe space exploration is important to society:



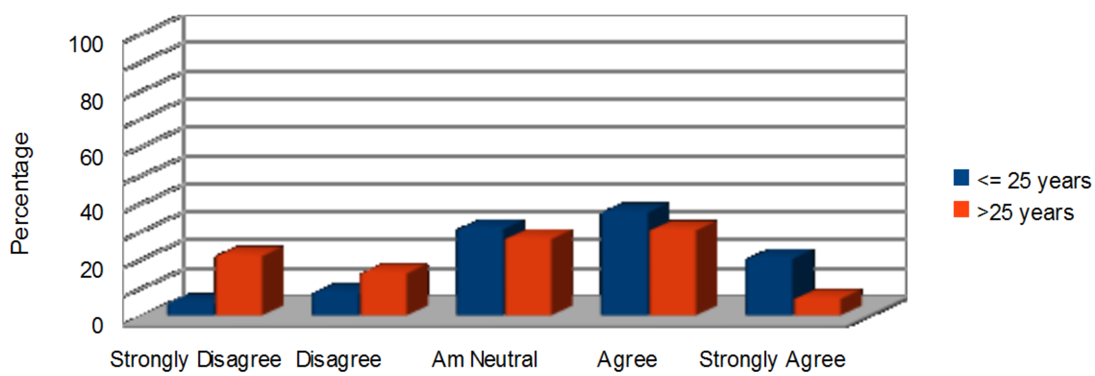
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	9 (2.7%)	11 (3.3%)	42 (12.5%)	154 (45.8%)	120 (35.7%)	336	4.09	0.92
> 25 years (%)	4 (12.5%)	4 (12.5%)	3 (9.4%)	16 (50.0%)	5 (15.6%)	32 (1 skipped)	3.44	1.25

B.5 - I believe mining on Earth is important:



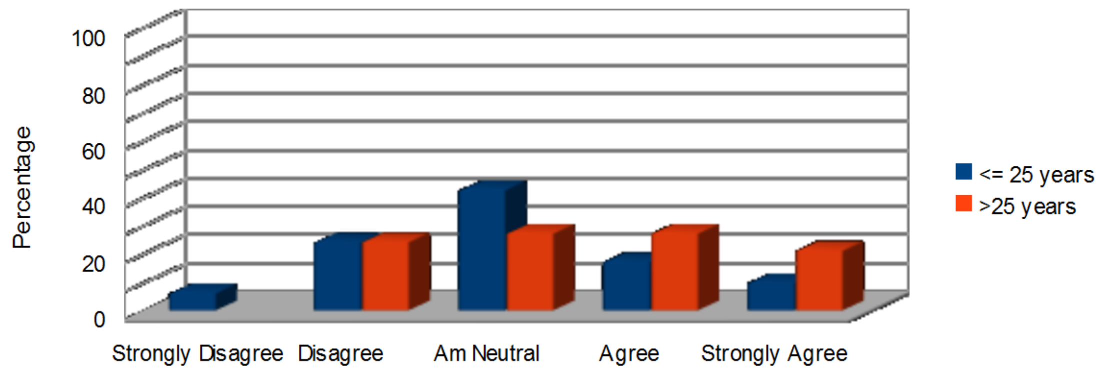
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	8 (2.4%)	13 (3.9%)	73 (21.7%)	176 (52.4%)	66 (19.6%)	336	3.83	0.87
> 25 years (%)	0 (0.0%)	2 (6.1%)	5 (15.2%)	16 (48.5%)	10 (30.3%)	33	4.03	0.83

B.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:



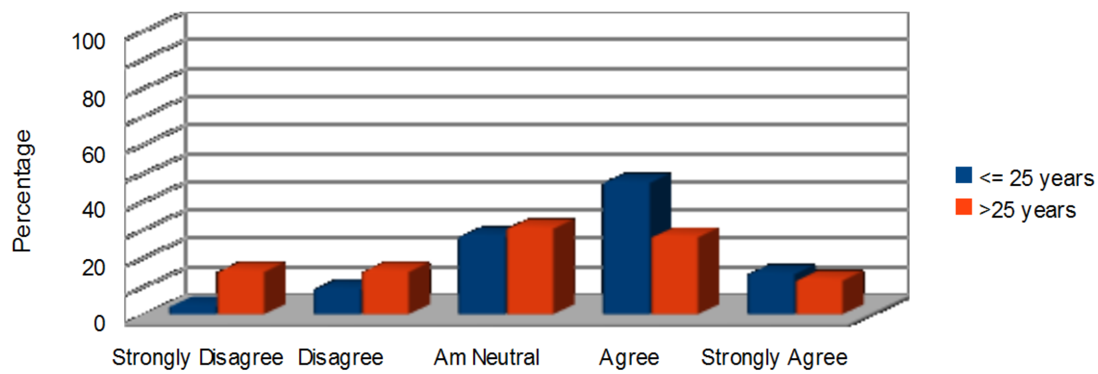
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	15 (4.5%)	27 (8.0%)	103 (30.7%)	123 (36.6%)	68 (20.2%)	336	3.6	1.04
> 25 years (%)	7 (21.2%)	5 (15.2%)	9 (27.3%)	10 (30.3%)	2 (6.1%)	33	2.85	1.23

B.7 - I believe funding for space mining would be better spent elsewhere:



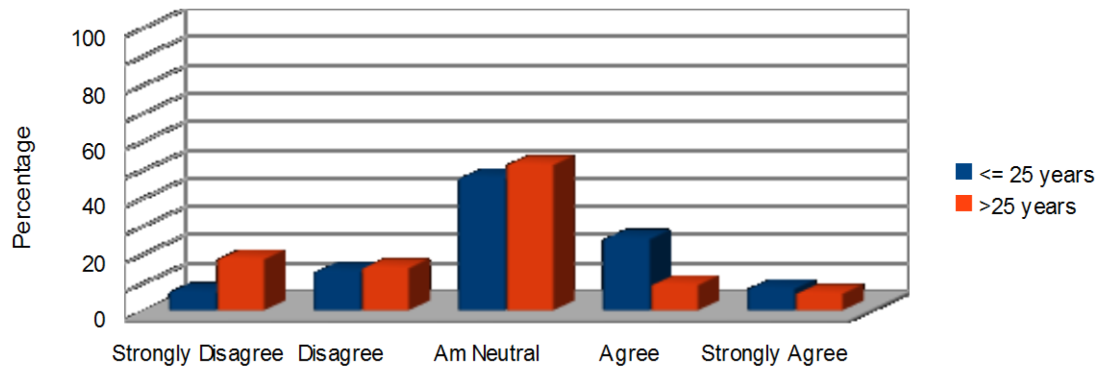
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	21 (6.3%)	81 (24.1%)	143 (42.6%)	58 (17.3%)	33 (9.8%)	336	3	1.03
> 25 years (%)	0 (0.0%)	8 (24.2%)	9 (27.3%)	9 (27.3%)	7 (21.2%)	33	3.45	1.08

B.8 I believe that robotic space mining needs to be given more media exposure:



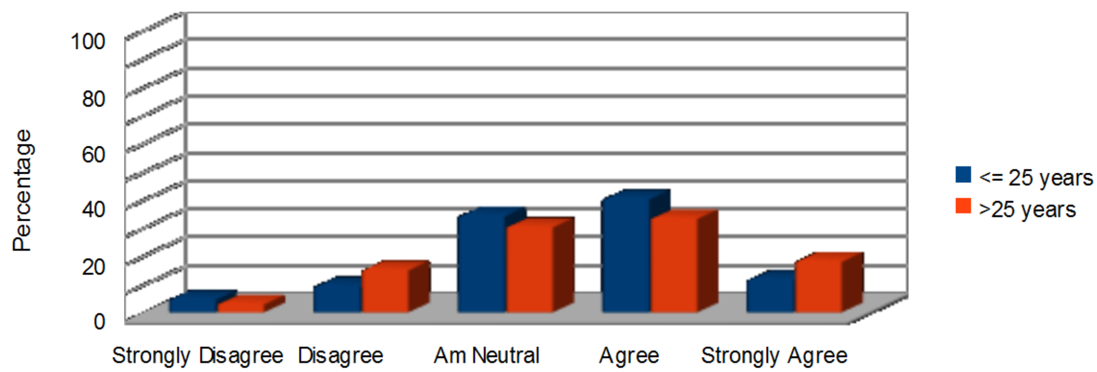
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	10 (3.0%)	30 (8.9%)	92 (27.4%)	156 (46.4%)	48 (14.3%)	336	3.6	0.94
> 25 years (%)	5 (15.2%)	5 (15.2%)	10 (30.3%)	9 (27.3%)	4 (12.1%)	33	3.06	1.23

B.9 - I believe that robotic space mining needs to be given more financial backing:



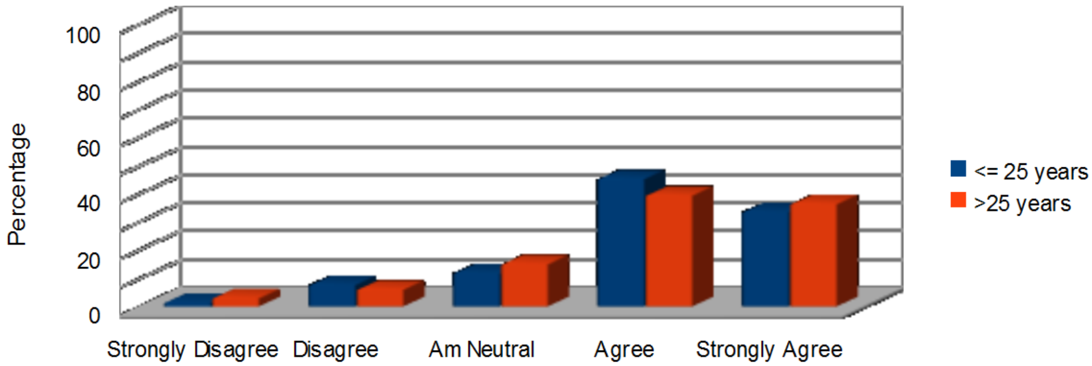
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	22 (6.5%)	46 (13.7%)	157 (46.7%)	85 (25.3%)	26 (7.7%)	336	3.14	0.97
> 25 years (%)	6 (18.2%)	5 (15.2%)	17 (51.5%)	3 (9.1%)	2 (6.1%)	33	2.7	1.06

B.10 - I believe we are in need of more (minable) resources:



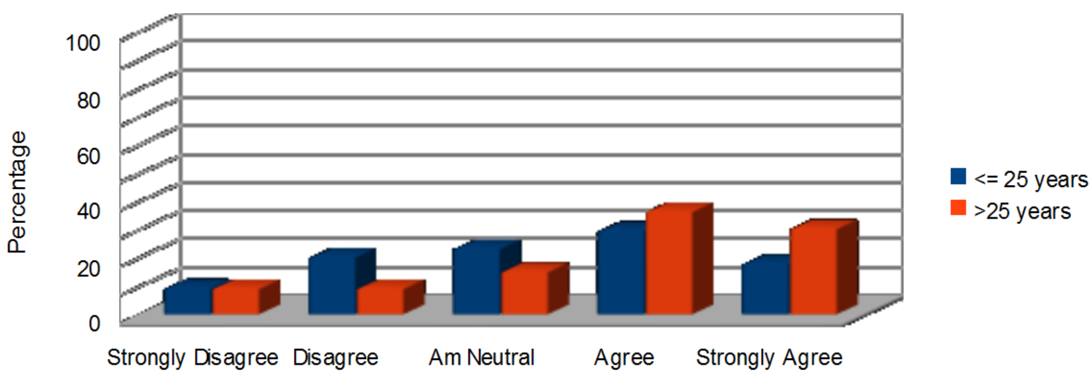
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years Old (%)	16 (4.8%)	31 (9.2%)	115 (34.2%)	135 (40.2%)	39 (11.6%)	336	3.45	0.97
> 25 years Old (%)	1 (3.0%)	5 (15.2%)	10 (30.3%)	11 (33.3%)	6 (18.2%)	33	3.48	1.05

B.11 - I think that exhaustive mining of Earth is inappropriate:



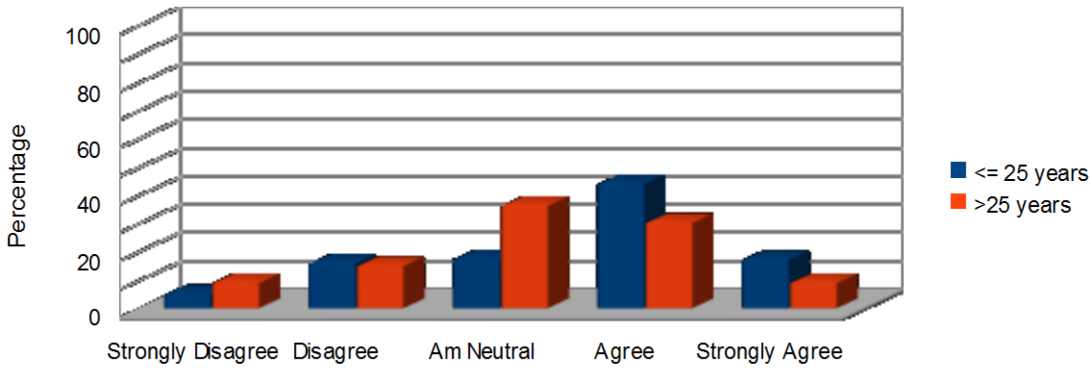
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	5 (1.5%)	26 (7.7%)	40 (11.9%)	152 (45.2%)	113 (33.6%)	336	4.02	0.95
> 25 years (%)	1 (3.0%)	2 (6.1%)	5 (15.2%)	13 (39.4%)	12 (36.4%)	33	4	1.02

B.12 - I think that exhaustive mining of the moon is inappropriate:



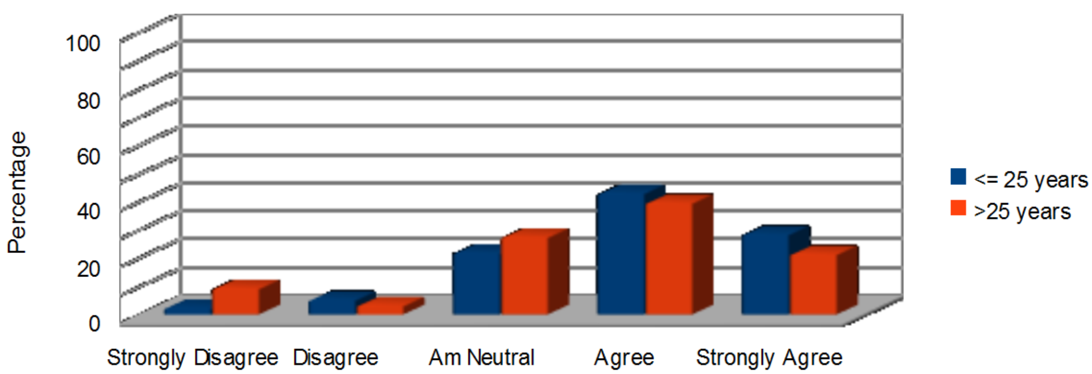
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	31 (9.2%)	69 (20.2%)	78 (23.2%)	99 (29.5%)	60 (17.9%)	336	3.26	1.23
> 25 years (%)	3 (9.1%)	3 (9.1%)	5 (15.2%)	12 (36.4%)	10 (30.3%)	33	3.7	1.24

B.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:



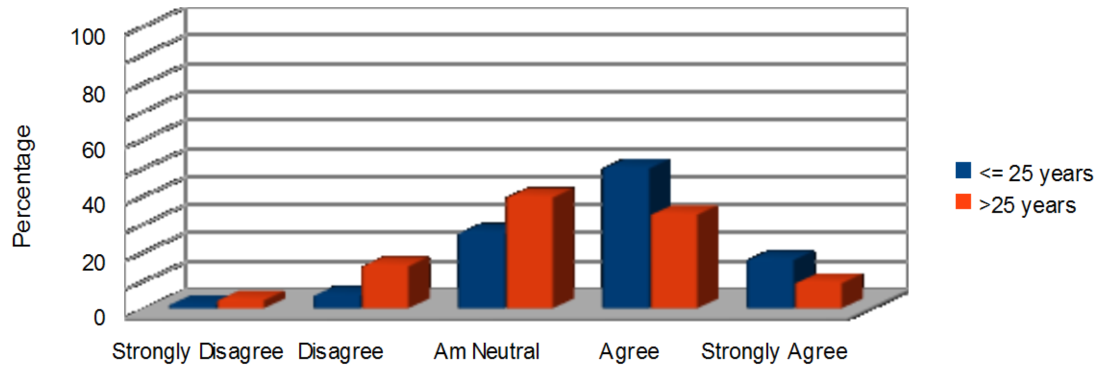
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	17 (5.1%)	54 (16.1%)	59 (17.6%)	148 (44.0%)	58 (17.3%)	336	3.52	1.1
> 25 years (%)	3 (9.1%)	5 (15.2%)	12 (36.4%)	10 (30.3%)	3 (9.1%)	33	3.15	1.08

B.14 - I think it would be more cost effective to send robots to space in place of humans:



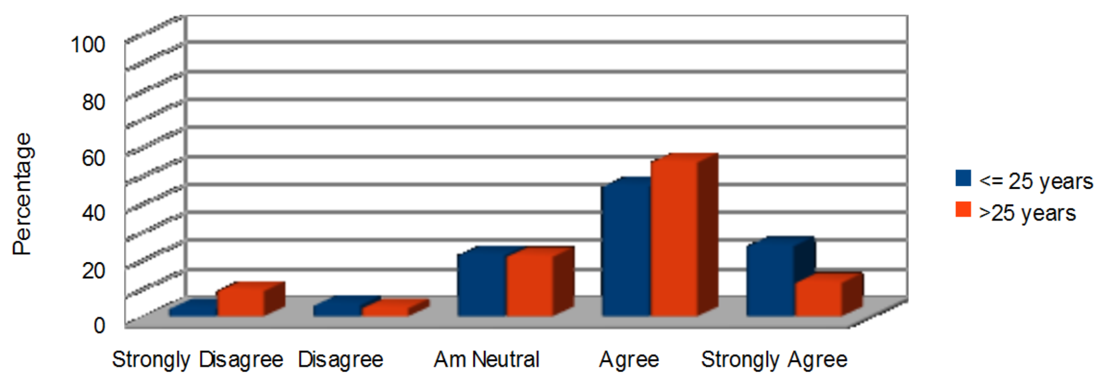
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	7 (2.1%)	17 (5.1%)	73 (21.7%)	144 (42.9%)	95 (28.3%)	336	3.9	0.94
> 25 years (%)	3 (9.1%)	1 (3.0%)	9 (27.3%)	13 (39.4%)	7 (21.2%)	33	3.61	1.12

B.15 - I think that mineral mining in space can currently be done by robots:



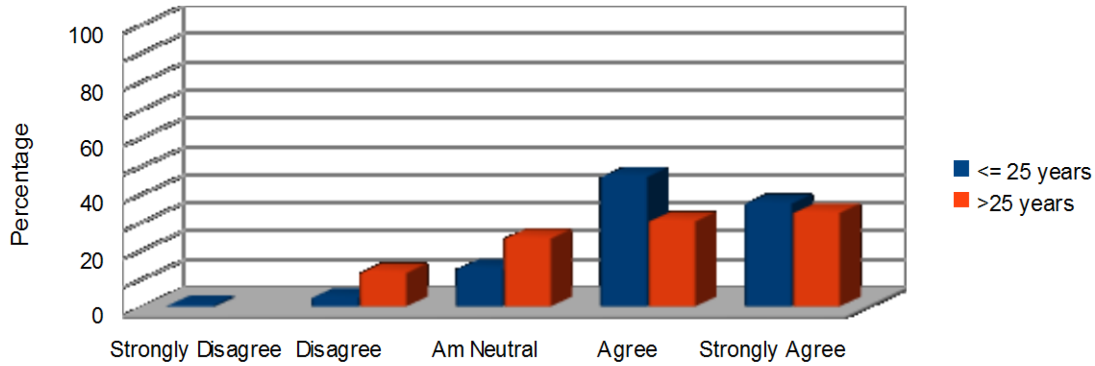
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	5 (1.5%)	16 (4.8%)	90 (26.8%)	167 (49.7%)	58 (17.3%)	336	3.76	0.84
> 25 years (%)	1 (3.0%)	5 (15.2%)	13 (39.4%)	11 (33.3%)	3 (9.1%)	33	3.3	0.94

B.16 - I think that mineral mining in space should be done by robots:



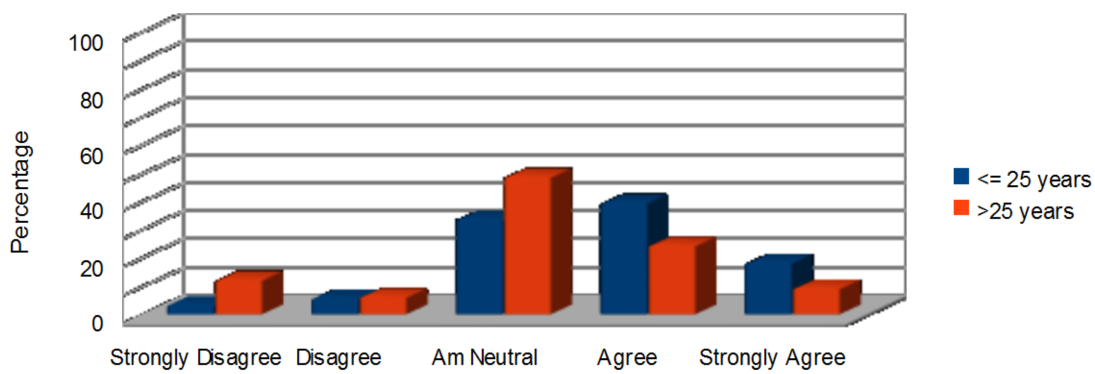
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	10 (3.0%)	14 (4.2%)	73 (21.7%)	155 (46.1%)	84 (25.0%)	336	3.86	0.94
> 25 years (%)	3 (9.1%)	1 (3.0%)	7 (21.2%)	18 (54.5%)	4 (12.1%)	33	3.58	1.05

B.17 - I think space exploration has a positive impact on society:



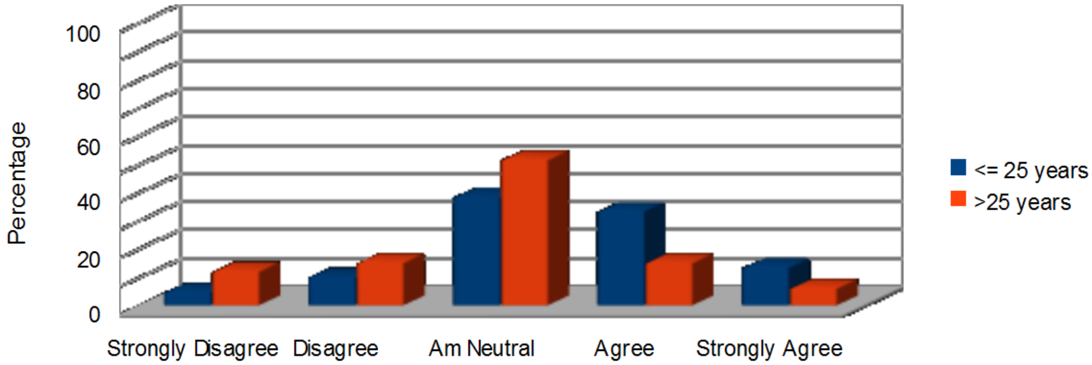
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	2 (.6%)	11 (3.3%)	45 (13.4%)	155 (46.1%)	123 (36.6%)	336	4.15	0.81
> 25 years (%)	0 (0.0%)	4 (12.1%)	8 (24.2%)	10 (30.3%)	11 (33.3%)	33	3.85	1.02

B.18 - I think space mining will have a positive impact on society:



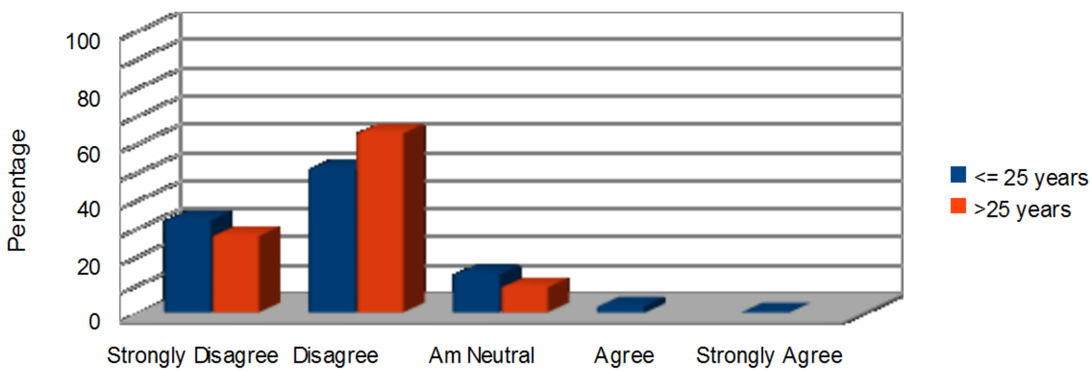
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	11 (3.3%)	19 (5.7%)	113 (33.6%)	132 (39.3%)	61 (18.2%)	336	3.63	0.95
> 25 years (%)	4 (12.1%)	2 (6.1%)	16 (48.5%)	8 (24.2%)	3 (9.1%)	33	3.12	1.07

B.19 - I think space mining would be financially beneficial:



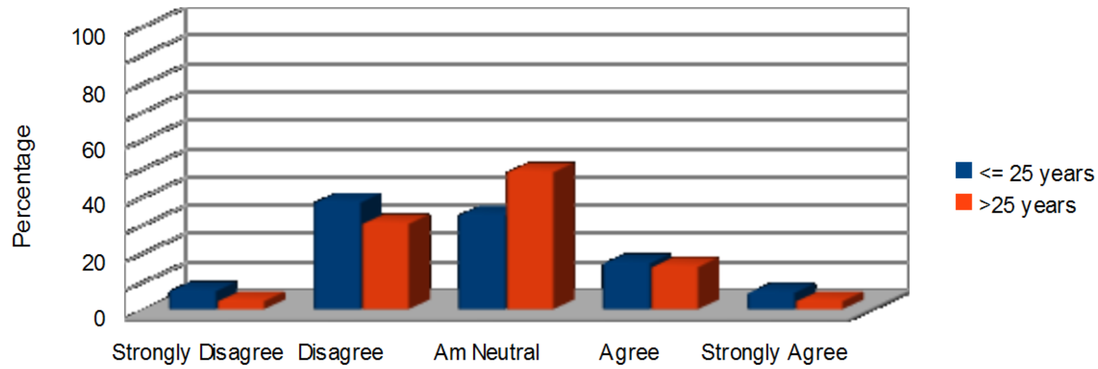
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	16 (4.8%)	34 (10.1%)	129 (38.4%)	112 (33.3%)	45 (13.4%)	336	3.4	1
> 25 years (%)	4 (12.1%)	5 (15.2%)	17 (51.5%)	5 (15.2%)	2 (6.1%)	33	2.88	1.01

B.20 - I believe that sending <u>only people</u> is the best choice for space mining operations:



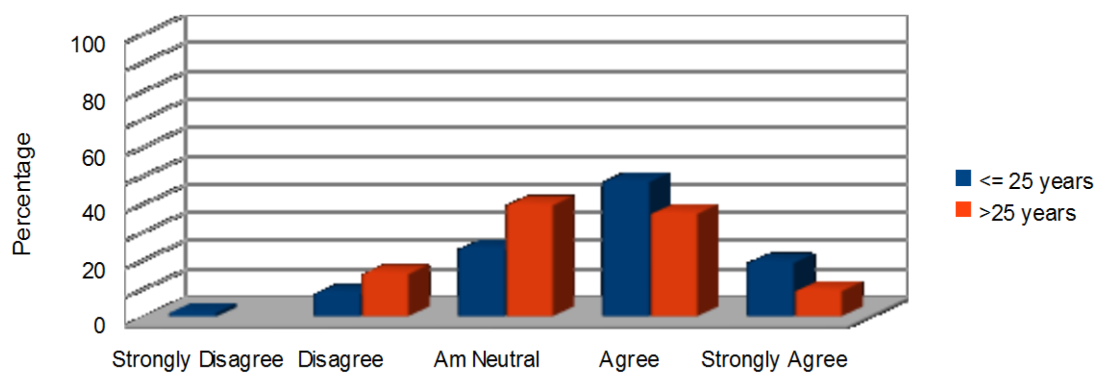
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	110 (32.7%)	171 (50.9%)	46 (13.7%)	8 (2.4%)	1 (.3%)	336	1.87	0.75
> 25 years (%)	9 (27.3%)	21 (63.6%)	3 (9.1%)	0 (0.0%)	0 (0.0%)	33	1.82	0.57

B.21 - I believe that sending only robots is the best choice for space mining operations:



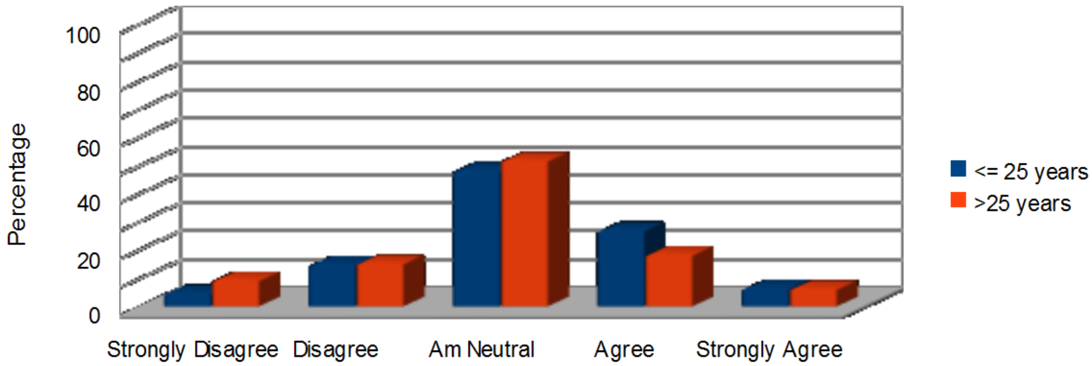
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	22 (6.5%)	127 (37.8%)	112 (33.3%)	55 (16.4%)	20 (6.0%)	336	2.77	1
> 25 years (%)	1 (3.0%)	10 (30.3%)	16 (48.5%)	5 (15.2%)	1 (3.0%)	33	2.85	0.82

B.22 - I believe that sending both people and robots is the best choice for space mining operations:



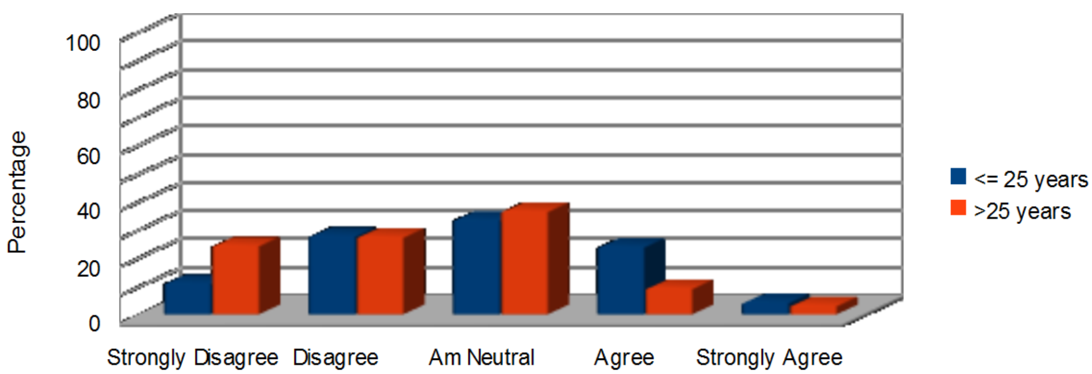
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	5 (1.5%)	27 (8.0%)	80 (23.8%)	160 (47.6%)	64 (19.0%)	336	3.75	0.91
> 25 years Old (%)	0 (0.0%)	5 (15.2%)	13 (39.4%)	12 (36.4%)	3 (9.1%)	33	3.39	0.85

B.23 - I think it would be more cost effective to process the mined minerals on Earth:



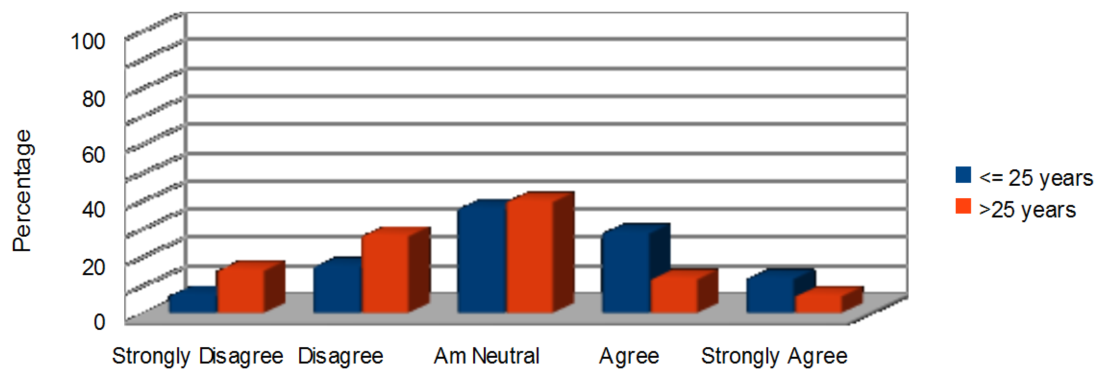
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	15 (4.5%)	49 (14.6%)	161 (47.9%)	90 (26.8%)	21 (6.3%)	336	3.16	0.9
> 25 years (%)	3 (9.1%)	5 (15.2%)	17 (51.5%)	6 (18.2%)	2 (6.1%)	33	2.97	0.97

B.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:



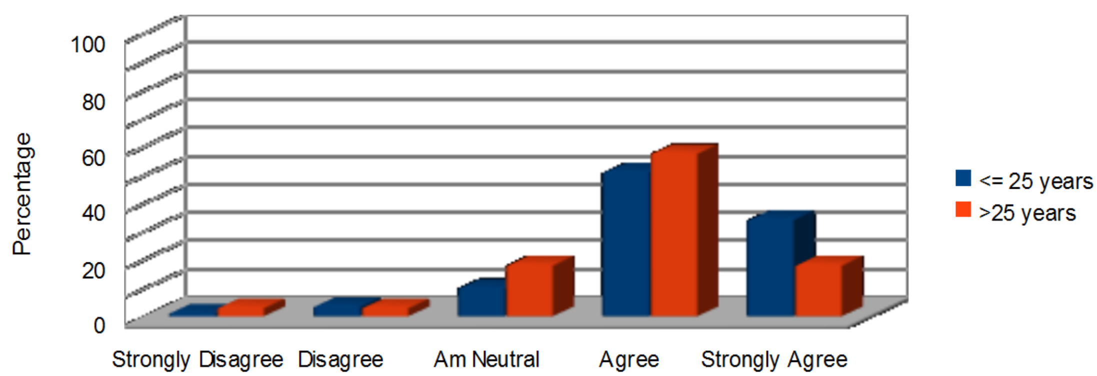
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	37 (11.0%)	93 (27.7%)	112 (33.3%)	80 (23.8%)	14 (4.2%)	336	2.82	1.04
> 25 years (%)	8 (24.2%)	9 (27.3%)	12 (36.4%)	3 (9.1%)	1 (3.0%)	33	2.39	1.04

B.25 - I think it would be financially beneficial to build a lunar base:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	21 (6.3%)	55 (16.4%)	124 (36.9%)	95 (28.3%)	41 (12.2%)	336	3.24	1.06
> 25 years (%)	5 (15.2%)	9 (27.3%)	13 (39.4%)	4 (12.1%)	2 (6.1%)	33	2.67	1.06

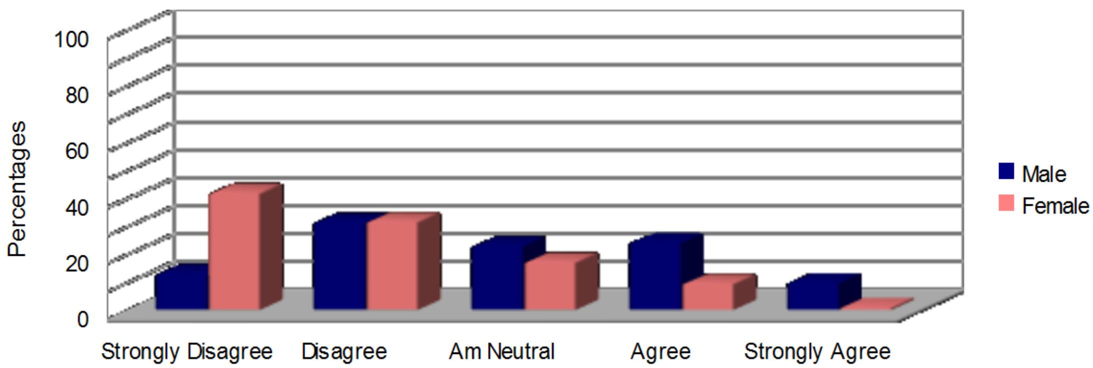
B.26 - I think that building a lunar base would lay the groundwork for expansion into space:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
<= 25 Years (%)	4 (1.2%)	12 (3.6%)	34 (10.1%)	171 (50.9%)	115 (34.2%)	336	4.13	0.82
> 25 years (%)	1 (3.0%)	1 (3.0%)	6 (18.2%)	19 (57.6%)	6 (18.2%)	33	3.85	0.86

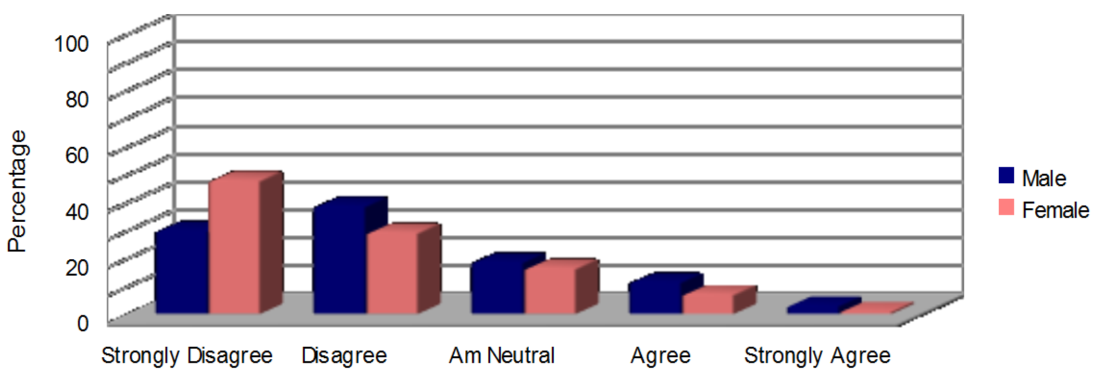
C. Gender

C.1 - I have extensive knowledge of current robot technology:



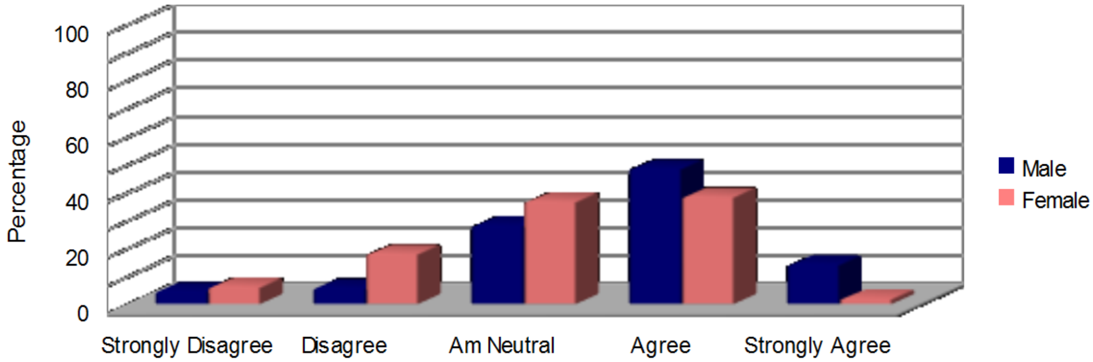
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	32 (12.7%)	78 (31.1%)	57 (22.7%)	60 (23.9%)	24 (9.6%)	251	2.86	1.19
Female (%)	49 (41.5%)	37 (31.4%)	20 (16.9%)	11 (9.3%)	1 (0.8%)	118	1.97	1.02

C.2 - I have extensive knowledge of recent developments in space mining:



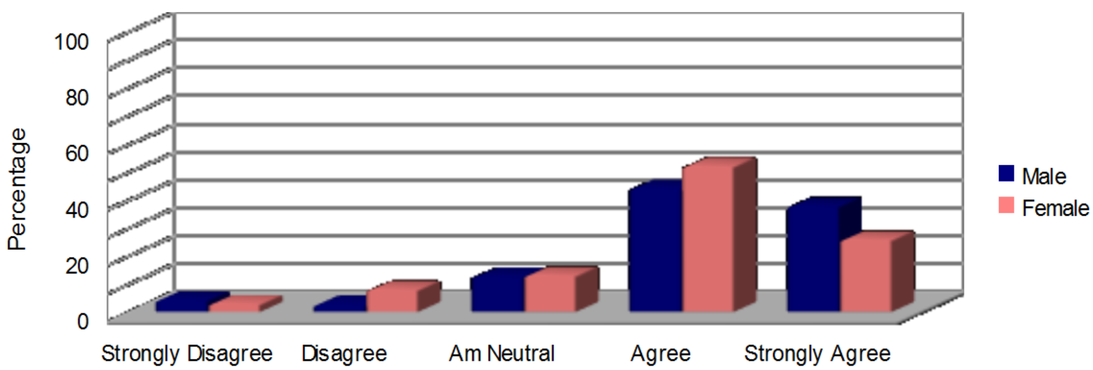
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	74 (29.5%)	96 (38.2%)	46 (18.3%)	28 (11.2%)	7 (2.8%)	251	2.2	1.07
Female (%)	56 (47.5%)	34 (28.8%)	19 (16.1%)	8 (6.8%)	1 (0.8%)	118	1.85	0.98

C.3 - Current research and development of space mining technologies is of interest to me:



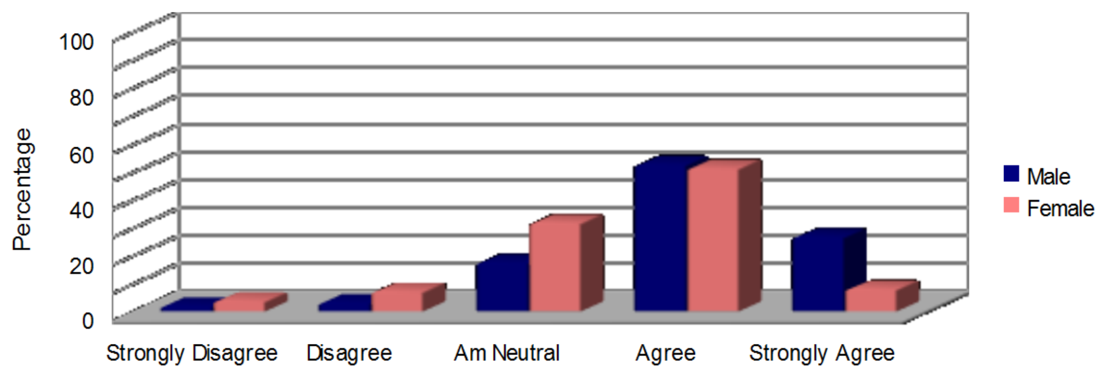
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	11 (4.4%)	14 (5.6%)	70 (27.9%)	121 (48.2%)	35 (13.9%)	251	3.62	0.94
Female (%)	7 (5.9%)	21 (17.8%)	43 (36.4%)	45 (38.1%)	2 (1.7%)	118	3.12	0.92

C.4 - I believe space exploration is important to society:



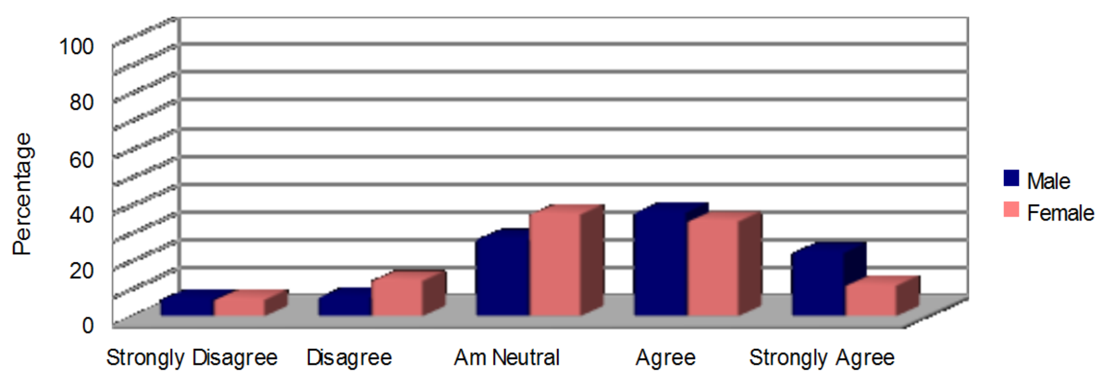
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	10 (4.0%)	6 (2.4%)	31 (12.4%)	109 (43.8%)	94 (37.5%)	250	4.08	0.97
Female (%)	3 (2.5%)	9 (7.6%)	15 (12.7%)	61 (51.7%)	30 (25.4%)	118	3.9	0.95

C.5 - I believe mining on Earth is important:



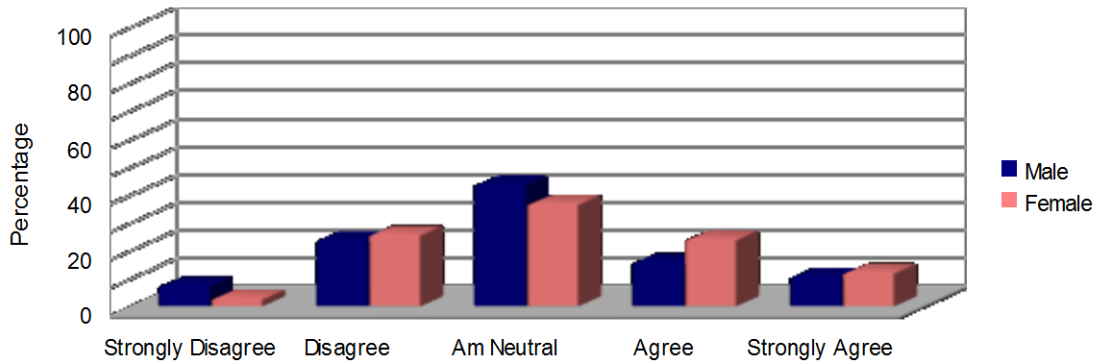
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	4 (1.6%)	7 (2.8%)	43 (17.1%)	131 (52.2%)	66 (26.3%)	251	3.99	0.83
Female (%)	4 (3.4%)	8 (6.8%)	37 (31.4%)	60 (50.8%)	9 (7.6%)	118	3.53	0.86

QC.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:



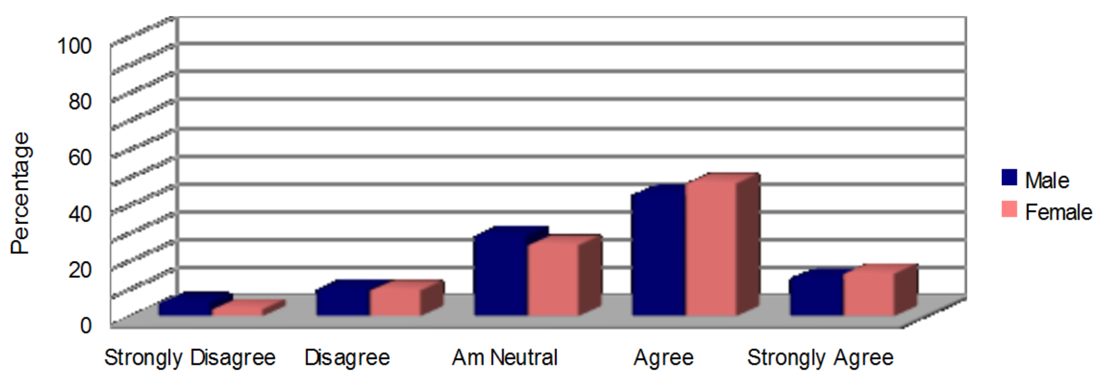
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	15 (6.0%)	17 (6.8%)	69 (27.5%)	93 (37.1%)	57 (22.7%)	251	3.64	1.09
Female (%)	7 (5.9%)	15 (12.7%)	43 (36.4%)	40 (33.9%)	13 (11.0%)	118	3.31	1.02

C.7 - I believe funding for space mining would be better spent elsewhere:



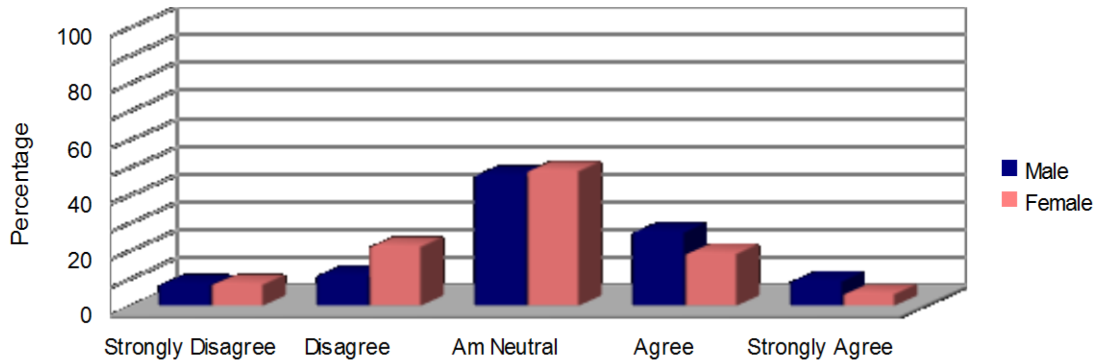
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	18 (7.2%)	59 (23.5%)	109 (43.4%)	39 (15.5%)	26 (10.4%)	251	2.98	1.04
Female (%)	3 (2.5%)	30 (25.4%)	43 (36.4%)	28 (23.7%)	14 (11.9%)	118	3.17	1.02

C.8 - I believe that robotic space mining needs to be given more media exposure:



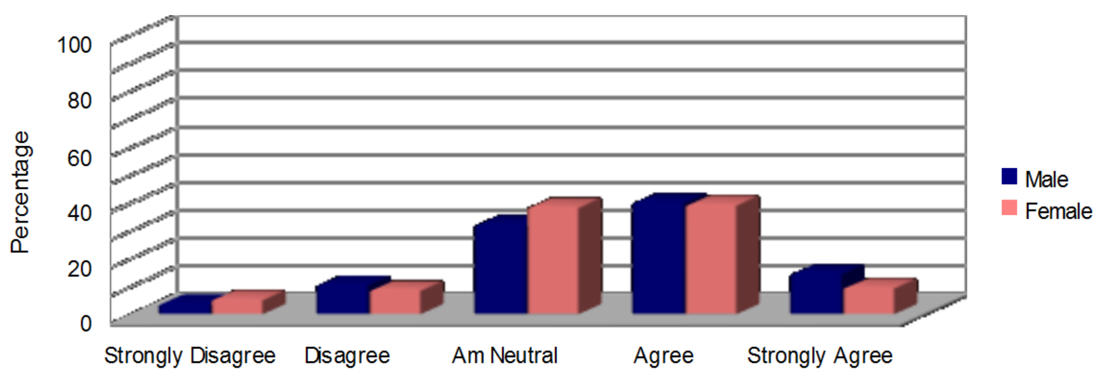
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	12 (4.8%)	24 (9.6%)	72 (28.7%)	109 (43.4%)	34 (13.5%)	251	3.51	1
Female (%)	3 (2.5%)	11 (9.3%)	30 (25.4%)	56 (47.5%)	18 (15.3%)	118	3.64	0.94

C.9 - I believe that robotic space mining needs to be given more financial backing:



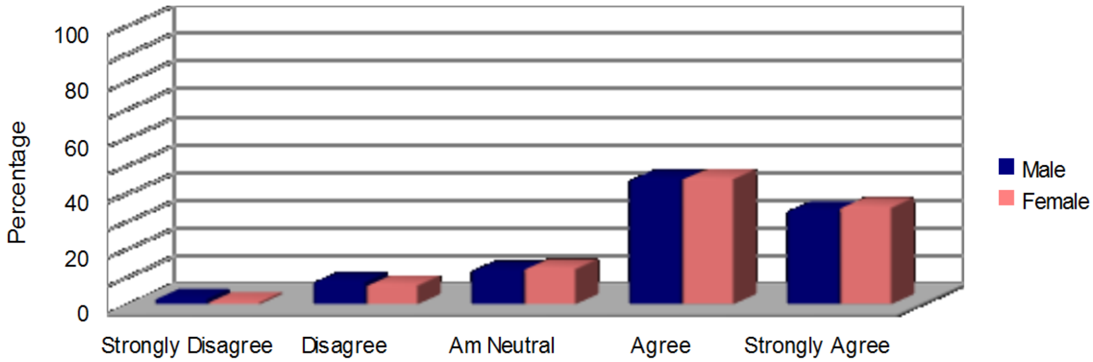
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	19 (7.6%)	27 (10.8%)	117 (46.6%)	66 (26.3%)	22 (8.8%)	251	3.18	1
Female (%)	9 (7.6%)	25 (21.1%)	57 (48.3%)	22 (18.6%)	5 (4.2%)	118	2.91	0.93

C.10 - I believe we are in need of more (minable) resources:



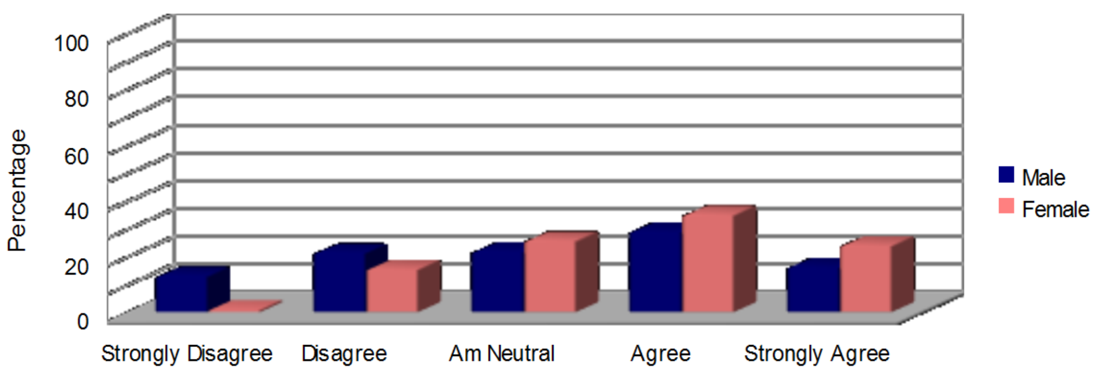
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	9 (3.6%)	26 (10.4%)	80 (31.9%)	100 (39.8%)	36 (14.3%)	251	3.51	0.98
Female (%)	6 (5.1%)	10 (8.5%)	45 (38.1%)	46 (39.0%)	11 (9.3%)	118	3.39	0.95

C.11 - I think that exhaustive mining of Earth is inappropriate:



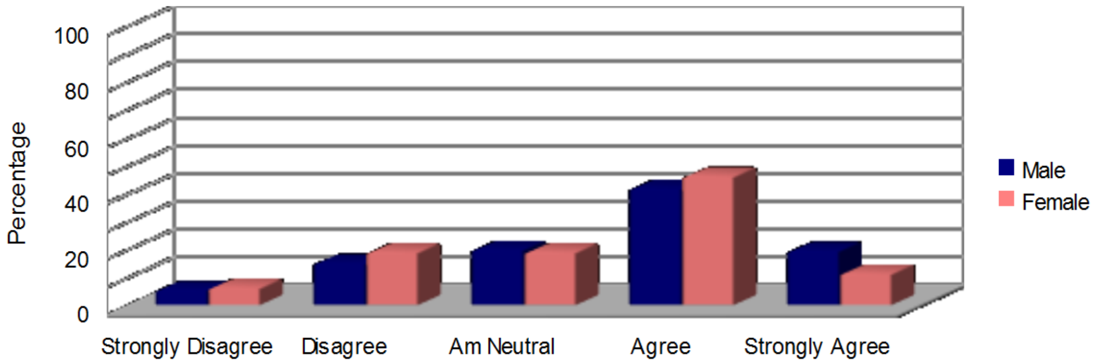
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	5 (2.0%)	20 (8.0%)	30 (12.0%)	112 (44.6%)	84 (33.5%)	251	4	0.98
Female (%)	1 (0.8%)	8 (6.8%)	15 (12.7%)	53 (44.9%)	41 (34.7%)	118	4.06	0.9

C.12 - I think that exhaustive mining of the moon is inappropriate:



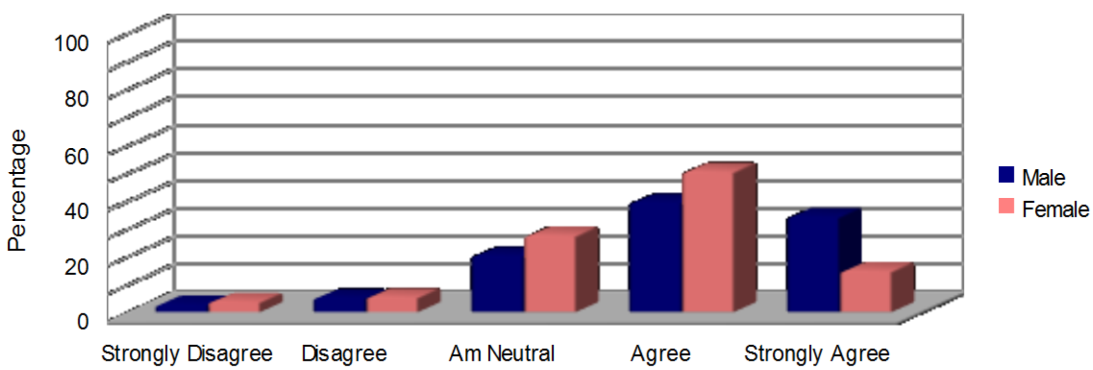
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	32 (12.7%)	53 (21.1%)	54 (21.5%)	72 (28.7%)	40 (15.9%)	251	3.14	1.28
Female (%)	1 (0.8%)	18 (15.3%)	30 (25.4%)	41 (34.7%)	28 (23.7%)	118	3.65	1.03

C.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:



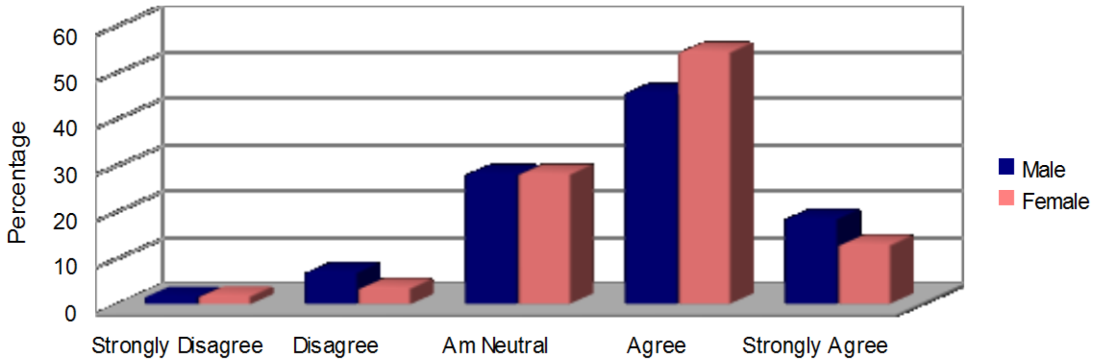
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	13 (5.2%)	37 (14.7%)	49 (19.5%)	104 (41.4%)	48 (19.1%)	251	3.55	1.11
Female (%)	7 (5.9%)	22 (18.6%)	22 (18.6%)	54 (45.8%)	13 (11.0%)	118	3.37	1.09

C.14 - I think it would be more cost effective to send robots to space in place of humans:



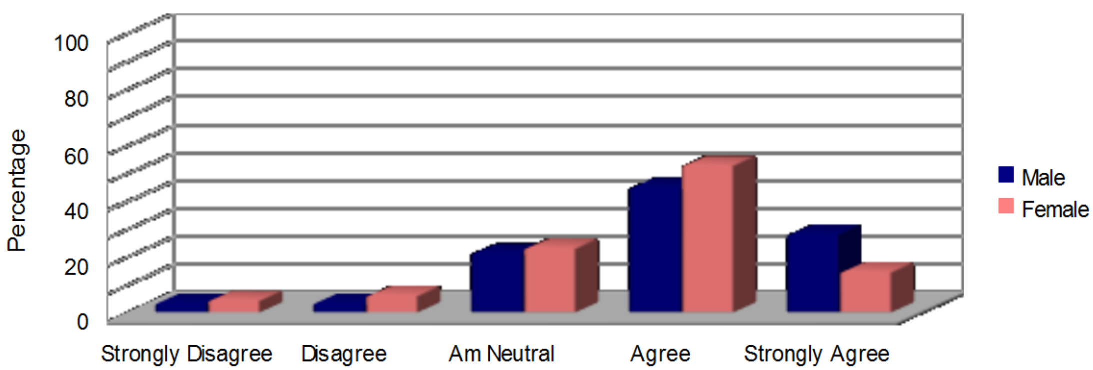
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	6 (2.4%)	12 (4.8%)	50 (19.9%)	98 (39.0%)	85 (33.9%)	251	3.97	0.97
Female (%)	4 (3.4%)	6 (5.1%)	32 (27.1%)	59 (50.0%)	17 (14.4%)	118	3.67	0.9

C.15 - I think that mineral mining in space can currently be done by robots:



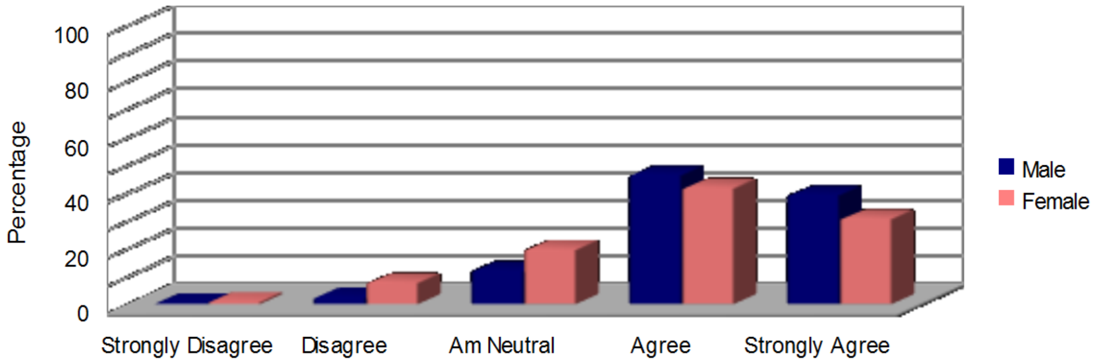
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	4 (1.6%)	17 (6.8%)	70 (27.9%)	114 (45.4%)	46 (18.3%)	251	3.72	0.89
Female (%)	2 (1.7%)	4 (3.4%)	33 (28.0%)	64 (54.2%)	15 (12.7%)	118	3.73	0.79

C.16 - I think that mineral mining in space should be done by robots:



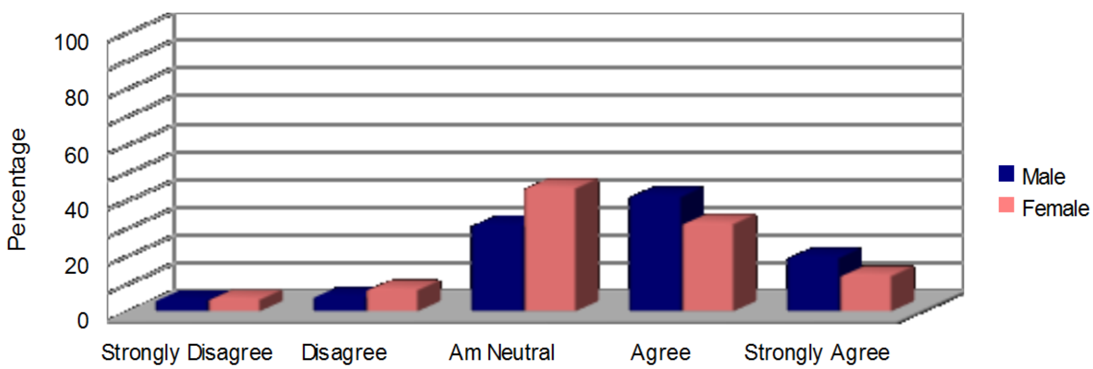
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	8 (3.2%)	8 (3.2%)	53 (21.1%)	112 (44.6%)	70 (27.9%)	251	3.91	0.95
Female (%)	5 (4.2%)	7 (5.9%)	27 (22.9%)	62 (52.5%)	17 (14.4%)	118	3.67	0.94

C.17 - I think space exploration has a positive impact on society:



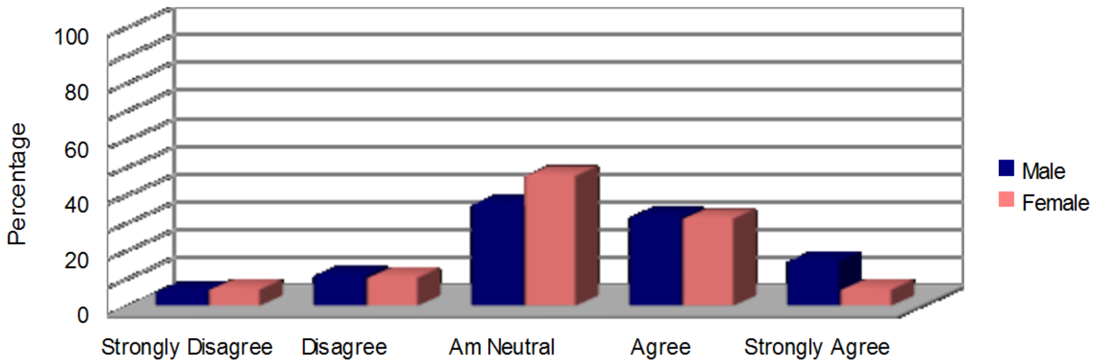
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	1 (0.4%)	6 (2.4%)	30 (12.0%)	116 (46.2%)	98 (39.0%)	251	4.21	0.77
Female (%)	1 (0.8%)	9 (7.6%)	23 (19.5%)	49 (41.5%)	36 (30.5%)	118	3.93	0.94

C.18 - I think space mining will have a positive impact on society:



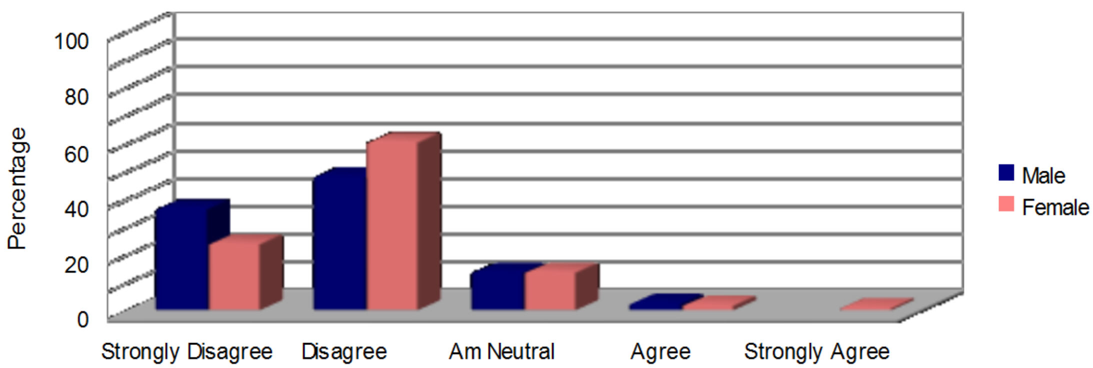
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	10 (4.0%)	13 (5.2%)	77 (30.7%)	103 (41.0%)	48 (19.1%)	251	3.66	0.97
Female (%)	5 (4.2%)	9 (7.6%)	52 (44.1%)	37 (31.4%)	15 (12.7%)	118	3.41	0.95

C.19 - I think space mining would be financially beneficial:



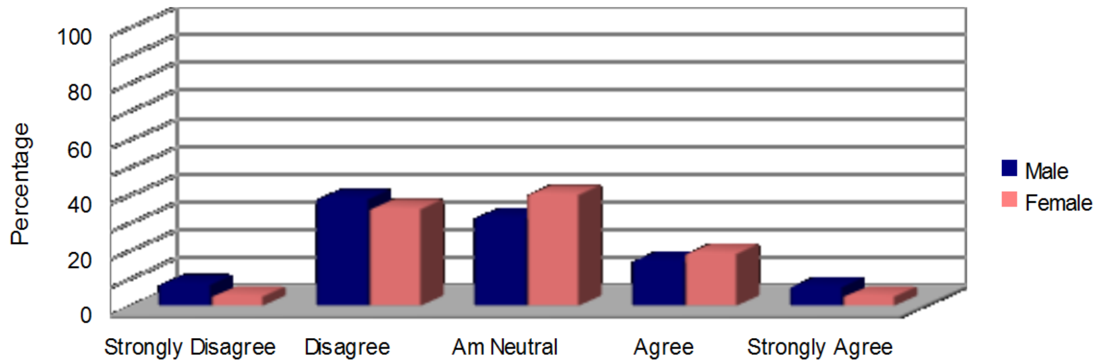
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	13 (5.2%)	27 (10.8%)	91 (36.3%)	80 (31.9%)	40 (15.9%)	251	3.43	1.04
Female (%)	7 (5.9%)	12 (10.2%)	55 (46.6%)	37 (31.4%)	7 (5.9%)	118	3.21	0.92

C.20 - I believe that sending <u>only people</u> is the best choice for space mining operations:



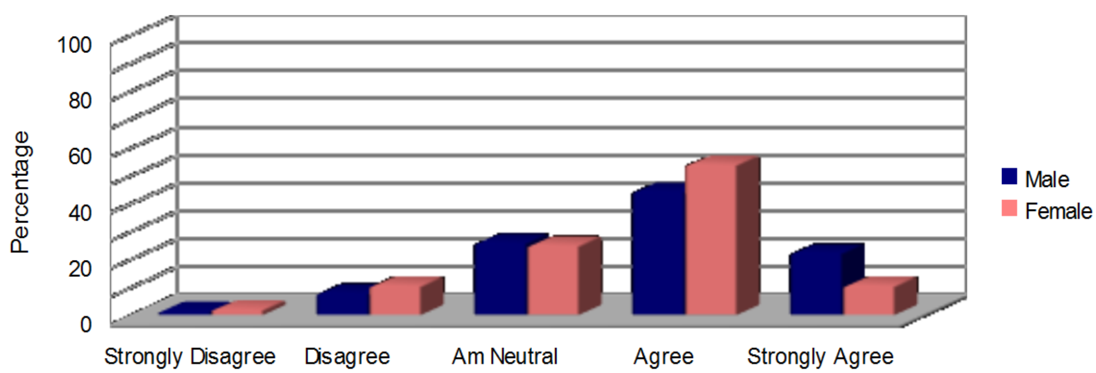
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	91 (36.3%)	120 (47.8%)	34 (13.5%)	6 (2.4%)	0 (0.0%)	251	1.82	0.75
Female (%)	28 (23.7%)	71 (60.2%)	16 (13.6%)	2 (1.7%)	1 (0.8%)	118	1.96	0.72

C.21 - I believe that sending only robots is the best choice for space mining operations:



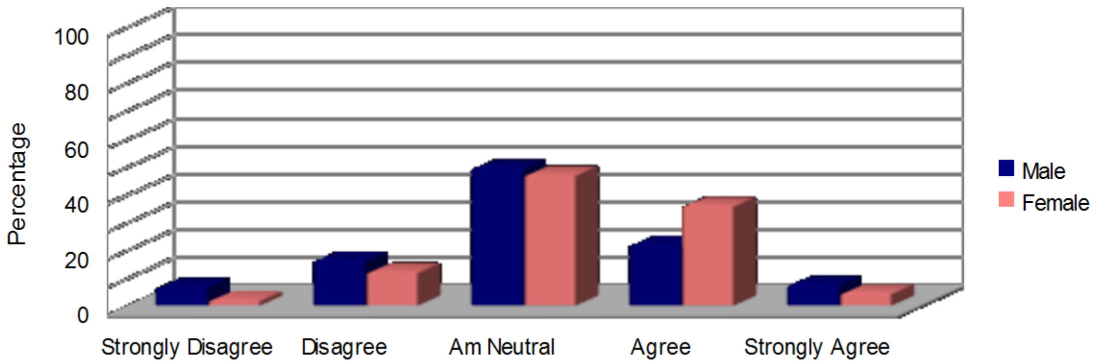
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	19 (7.6%)	96 (38.2%)	79 (31.5%)	40 (15.9%)	17 (6.8%)	251	2.76	1.03
Female (%)	4 (3.4%)	41 (34.7%)	47 (39.8%)	22 (18.6%)	4 (3.4%)	118	2.84	0.88

C.22 - I believe that sending both people and robots is the best choice for space mining operations:



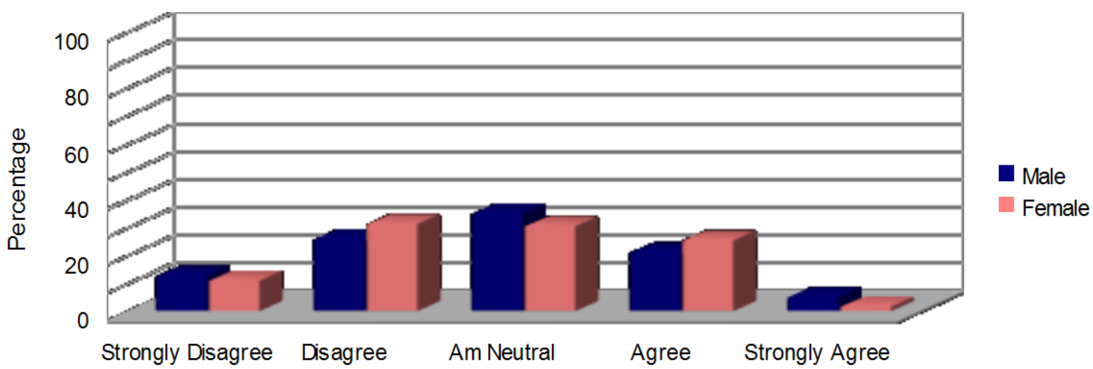
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	3 (1.2%)	19 (7.6%)	64 (25.5%)	110 (43.8%)	55 (21.9%)	251	3.78	0.91
Female (%)	2 (1.7%)	12 (10.2%)	29 (24.6%)	63 (53.4%)	12 (10.2%)	118	3.6	0.86

C.23 - I think it would be more cost effective to process the mined minerals on Earth:



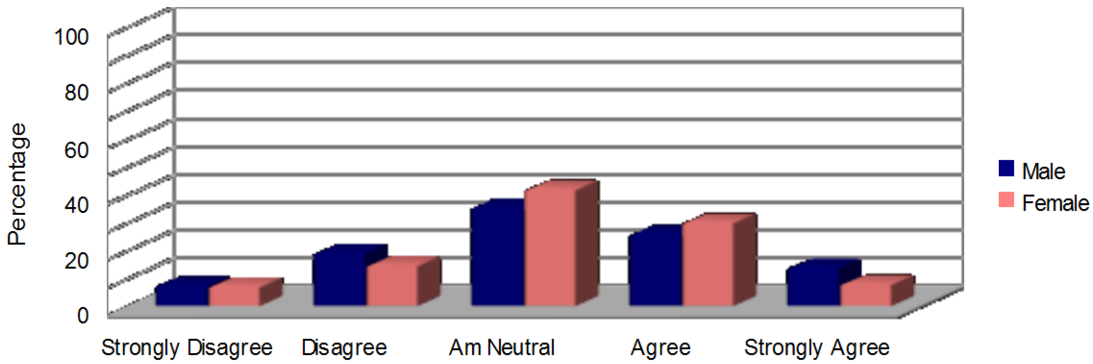
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	16 (6.4%)	40 (15.9%)	123 (49.0%)	54 (21.5%)	18 (7.2%)	251	3.07	0.95
Female (%)	2 (1.7%)	14 (11.9%)	55 (46.6%)	42 (35.6%)	5 (4.2%)	118	3.29	0.79

C.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:



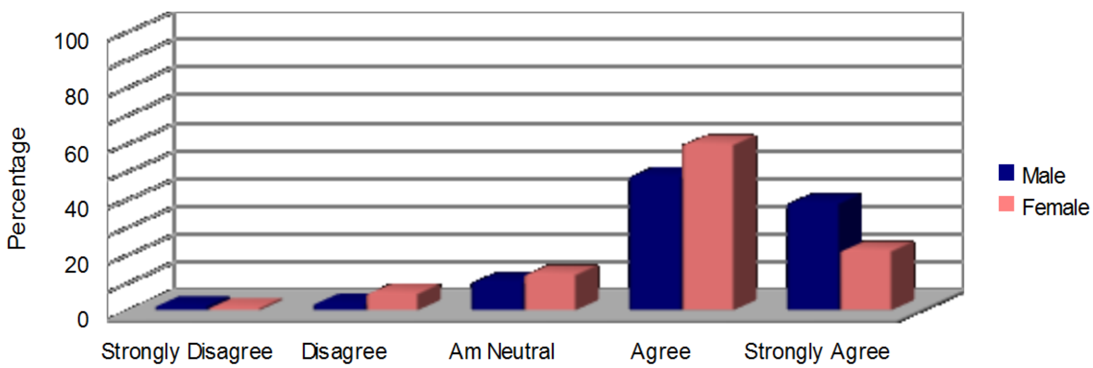
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	32 (12.7%)	65 (25.9%)	88 (35.1%)	53 (25.5%)	13 (13.5%)	251	2.8	1.07
Female (%)	13 (11.0%)	37 (31.4%)	36 (30.5%)	30 (25.4%)	2 (1.7%)	118	2.75	1.01

C.25 - I think it would be financially beneficial to build a lunar base:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	18 (7.2%)	47 (18.7%)	88 (35.1%)	64 (25.5%)	34 (13.5%)	251	3.2	1.11
Female (%)	8 (6.8%)	17 (14.4%)	49 (41.5%)	35 (29.7%)	9 (7.6%)	118	3.17	0.99

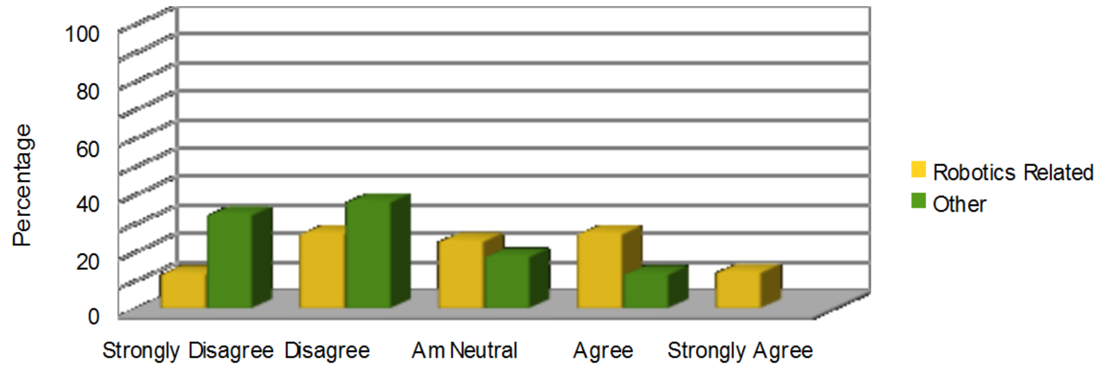
C.26 - I think that building a lunar base would lay the groundwork for expansion into space:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Male (%)	4 (1.6%)	6 (2.4%)	25 (10.0%)	120 (47.8%)	96 (38.2%)	251	4.19	0.83
Female (%)	1 (0.8%)	7 (5.9%)	15 (12.7%)	70 (59.3%)	25 (21.2%)	118	3.94	0.81

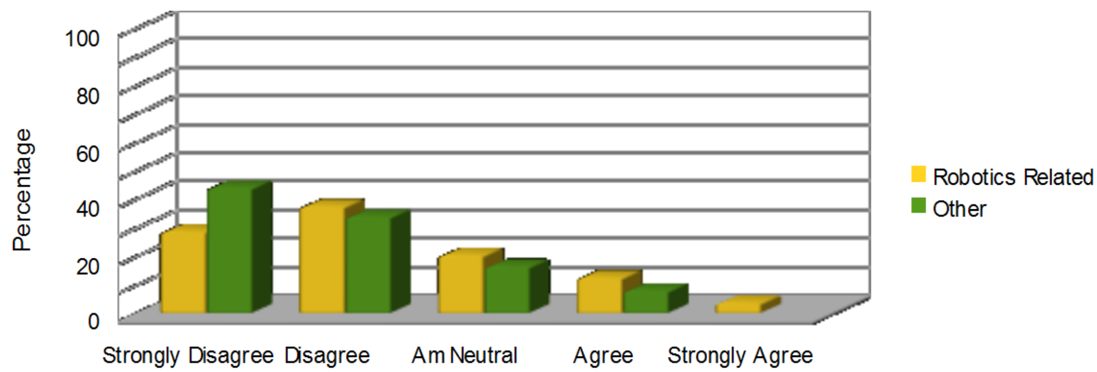
D. Area of Study

D.1 - I have extensive knowledge of current robot technology:



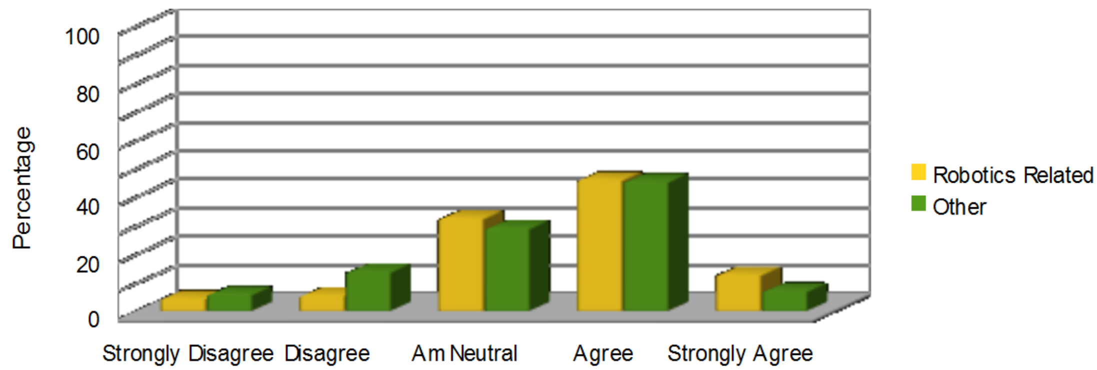
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	23 (12.0%)	50 (26.0%)	45 (23.4%)	50 (26.0%)	24 (12.5%)	192	3.01	1.22
Other (%)	58 (32.8%)	66 (37.3%)	32 (18.1%)	21 (11.9%)	0 (0.0%)	177	2.09	0.99

D.2 - I have extensive knowledge of recent developments in space mining:



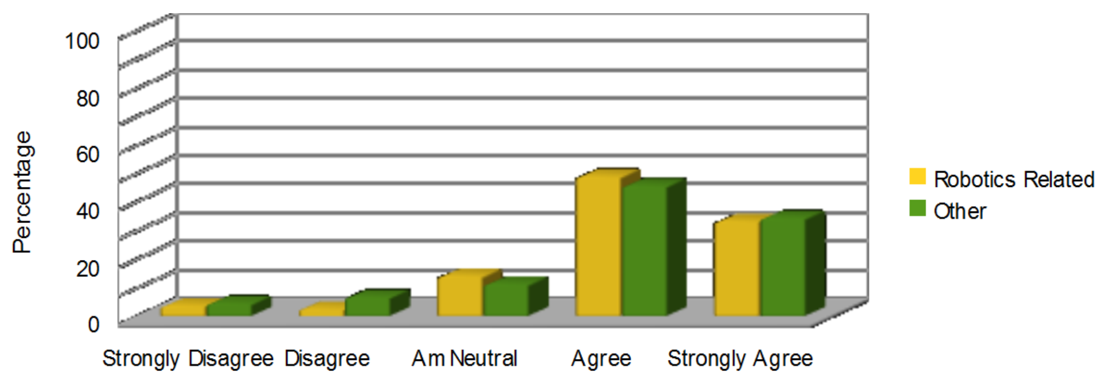
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	54 (28.1%)	71 (37.0%)	38 (19.8%)	23 (12.0%)	6 (3.1%)	192	2.25	1.08
Other (%)	77 (43.5%)	59 (33.3%)	28 (15.8%)	13 (7.3%)	0 (0.0%)	177	1.87	0.93

D.3 - Current research and development of space mining technologies is of interest to me:



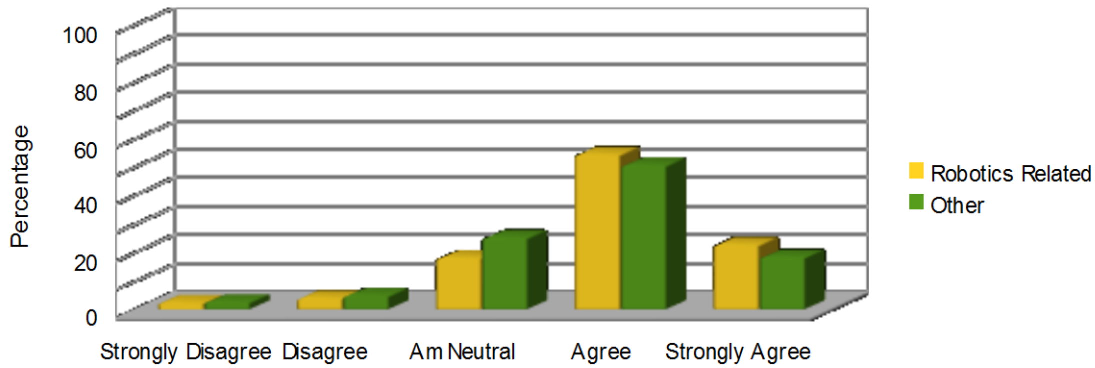
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	8 (4.2%)	10 (5.2%)	62 (32.3%)	88 (45.8%)	24 (12.5%)	192	3.57	0.92
Other (%)	10 (5.6%)	24 (13.6%)	51 (28.8%)	80 (45.2%)	12 (6.8%)	177	3.34	0.98

D.4 - I believe space exploration is important to society:



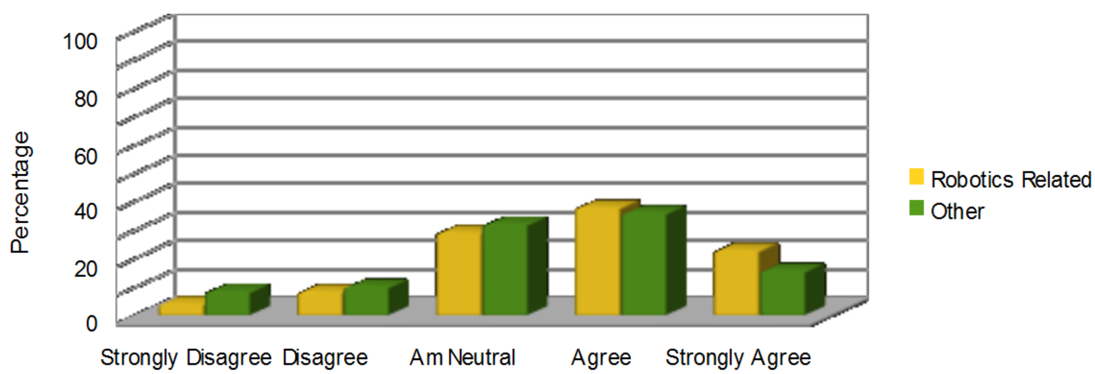
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	6 (3.1%)	4 (2.1%)	26 (13.5%)	93 (48.4%)	63 (32.8%)	192	4.06	0.91
Other (%)	7 (4.0%)	11 (6.2%)	19 (10.7%)	79 (45.2%)	60 (33.9%)	176	3.99	1.03

D.5 - I believe mining on Earth is important:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	4 (2.1%)	7 (3.6%)	34 (17.7%)	104 (54.2%)	43 (22.4%)	192	3.91	0.85
Other (%)	4 (2.3%)	8 (4.5%)	44 (24.9%)	89 (50.3%)	32 (18.1%)	177	3.77	0.87

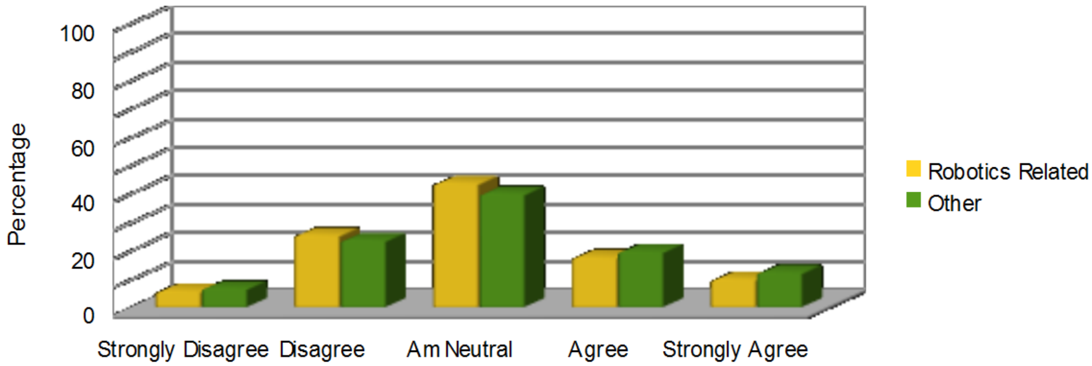
D.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	7 (3.6%)	15 (7.8%)	55 (28.6%)	72 (37.5%)	43 (22.4%)	192	3.67	1.02
Other	14	17	56	63	27	177	3.41	1.1

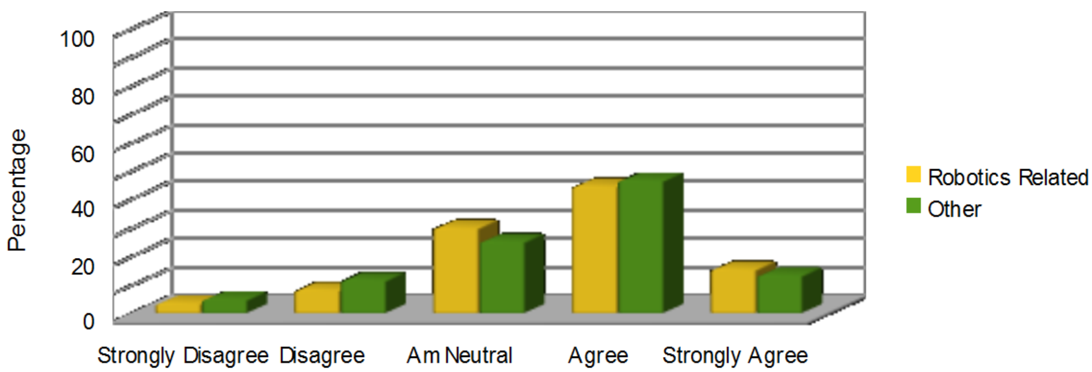
(%)	(7.9%)	(9.6%)	(31.6%)	(35.6%)	(15.3%)			

D.7 - I believe funding for space mining would be better spent elsewhere:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	10 (5.2%)	48 (25.0%)	83 (43.2%)	33 (17.2%)	18 (9.4%)	192	3.01	1
Other (%)	11 (6.2%)	41 (23.2%)	70 (39.5%)	34 (19.2%)	21 (11.9%)	177	3.07	1.07

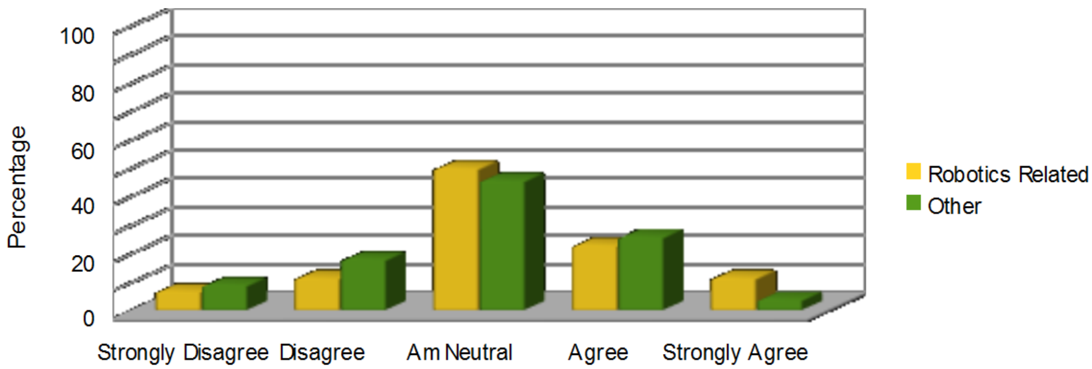
D.8 - I believe that robotic space mining needs to be given more media exposure:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	6 (3.1%)	15 (7.8%)	57 (29.7%)	85 (44.3%)	29 (15.1%)	192	3.6	0.94

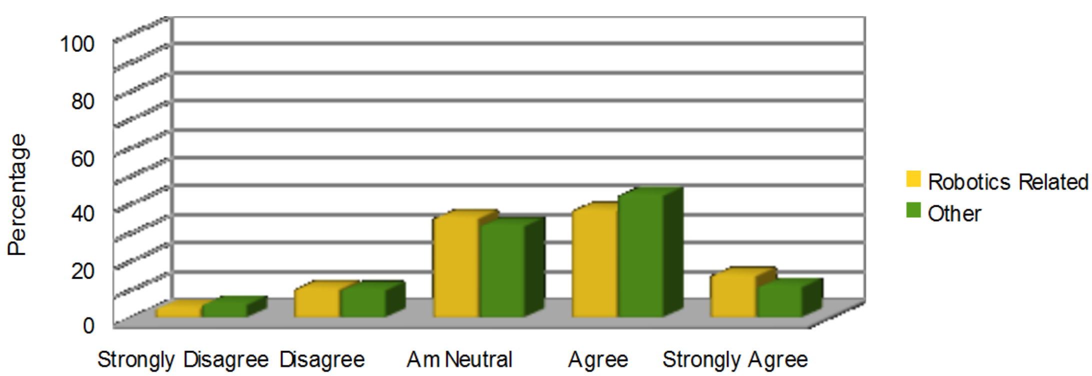
Other (%)	8 (4.5%)	20 (11.3%)	44 (24.9%)	82 (46.3%)	23 (13.0%)	177	3.52	1

D.9 - I believe that robotic space mining needs to be given more financial backing:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	12 (6.3%)	21 (10.9%)	95 (49.5%)	43 (22.4%)	21 (10.9%)	192	3.21	0.99
Other (%)	15 (8.5%)	31 (17.5%)	80 (45.2%)	45 (25.4%)	6 (3.4%)	177	2.98	0.95

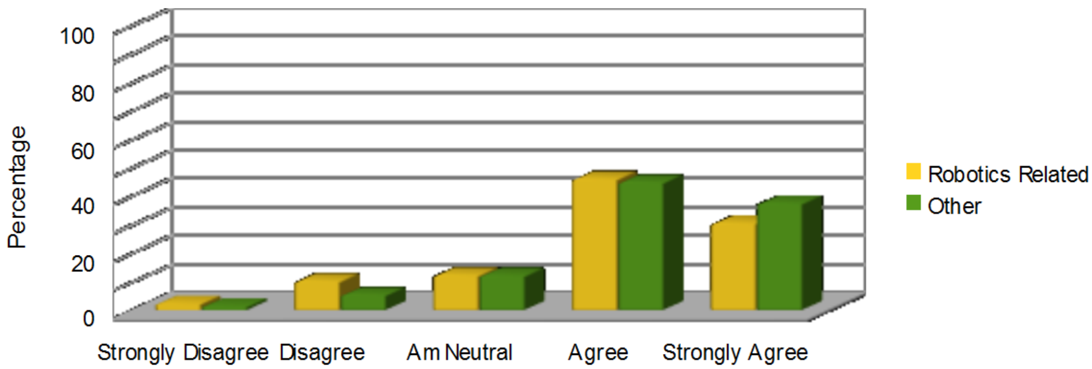
D.10 - I believe we are in need of more (minable) resources:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	6 (3.1%)	19 (9.9%)	67 (34.9%)	72 (37.5%)	28 (14.6%)	192	3.51	0.96

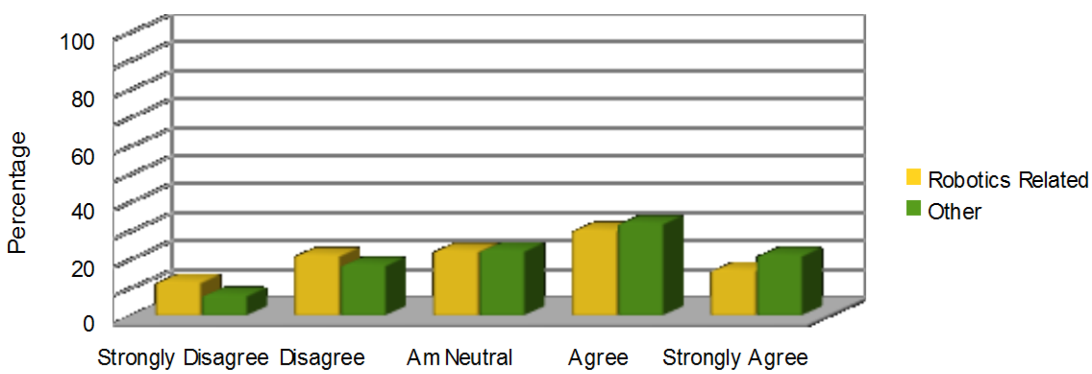
Other (%)	8 (4.5%)	17 (9.6%)	57 (32.2%)	76 (42.9%)	19 (10.7%)	177	3.46	0.96

D.11 - I think that exhaustive mining of Earth is inappropriate:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	4 (2.1%)	19 (9.9%)	23 (12.0%)	88 (45.8%)	58 (30.2%)	192	3.92	1
Other (%)	2 (1.1%)	9 (5.1%)	21 (11.9%)	79 (44.6%)	66 (37.3%)	177	4.11	0.88

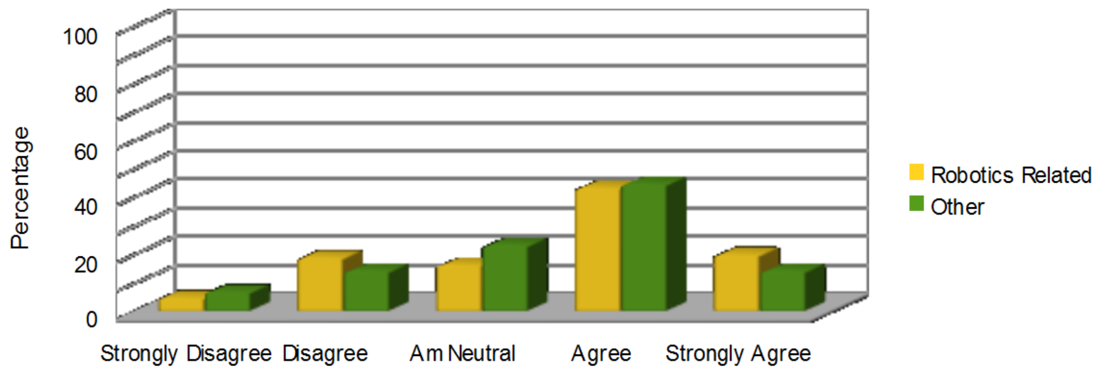
D.12 - I think that exhaustive mining of the moon is inappropriate:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	22 (11.5%)	40 (20.8%)	43 (22.4%)	57 (29.7%)	30 (15.6%)	192	3.17	1.25

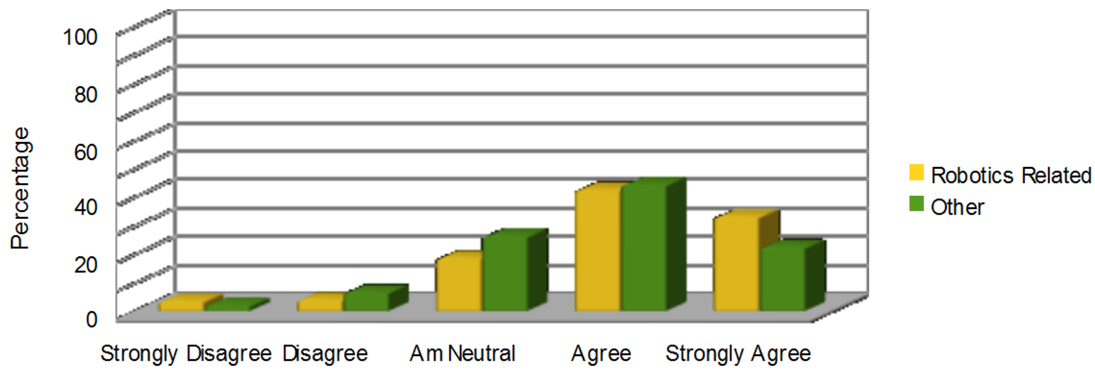
Other (%)	12 (6.8%)	31 (17.5%)	40 (22.6%)	57 (32.2%)	37 (20.9%)	177	3.43	1.19

D.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	8 (4.2%)	35 (18.2%)	30 (15.6%)	82 (42.7%)	37 (19.3%)	192	3.55	1.12
Other (%)	11 (6.2%)	24 (13.6%)	40 (22.6%)	78 (44.1%)	24 (13.6%)	177	3.45	1.08

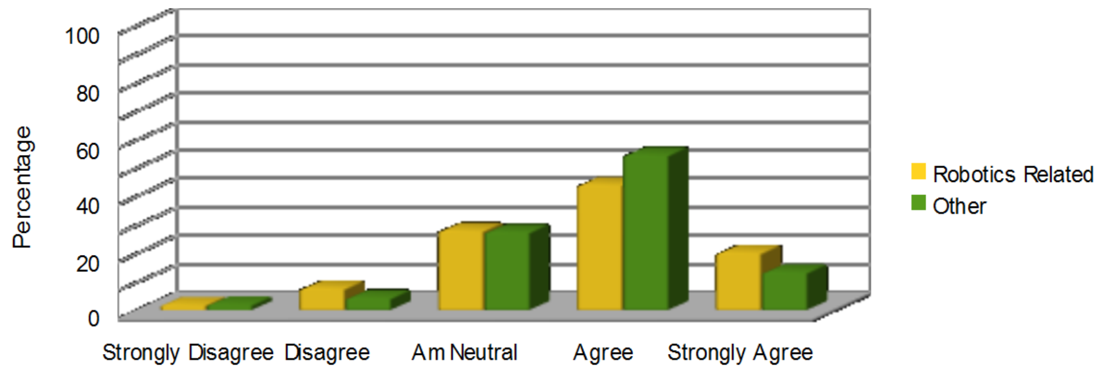
D.14 - I think it would be more cost effective to send robots to space in place of humans:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	6 (3.1%)	7 (3.6%)	35 (18.2%)	81 (42.2%)	63 (32.8%)	192	3.98	0.97

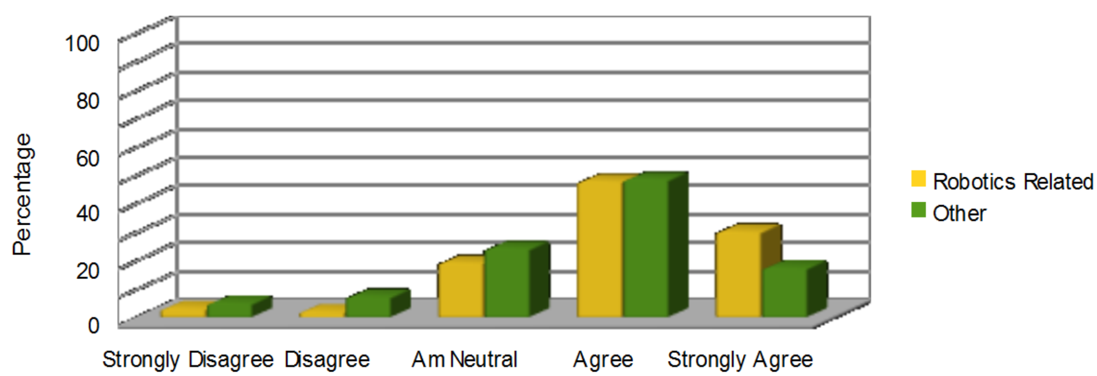
Other (%)	3 (1.7%)	11 (6.2%)	46 (26.0%)	78 (44.1%)	39 (22.0%)	177	3.79	0.91

D.15 - I think that mineral mining in space can currently be done by robots:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	3 (1.6%)	14 (7.3%)	53 (27.6%)	84 (43.8%)	38 (19.8%)	192	3.73	0.91
Other (%)	3 (1.7%)	7 (4.0%)	48 (27.1%)	96 (48.0%)	23 (16.9%)	177	3.73	0.8

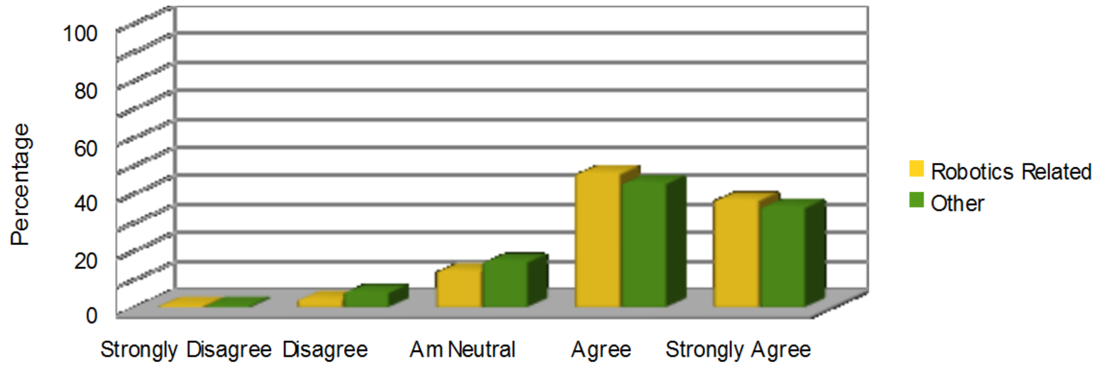
D.16 - I think that mineral mining in space should be done by robots:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	5 (2.6%)	3 (1.6%)	36 (18.8%)	91 (47.4%)	57 (29.7%)	192	4	0.88
Other	8	12	42	85	30	177	3.66	0.98

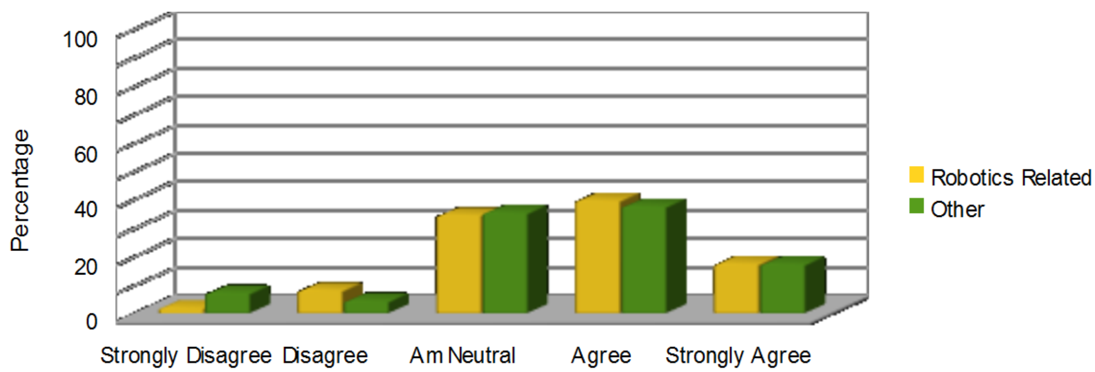
(%)	(4.5%)	(6.8%)	(23.7%)	(48.0%)	(16.9%)			

D.17 - I think space exploration has a positive impact on society:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	1 (0.5%)	5 (2.6%)	24 (12.5%)	90 (46.9%)	72 (37.5%)	192	4.18	0.79
Other (%)	1 (0.6%)	9 (5.1%)	28 (15.8%)	77 (43.5%)	62 (35.0%)	177	4.07	0.87

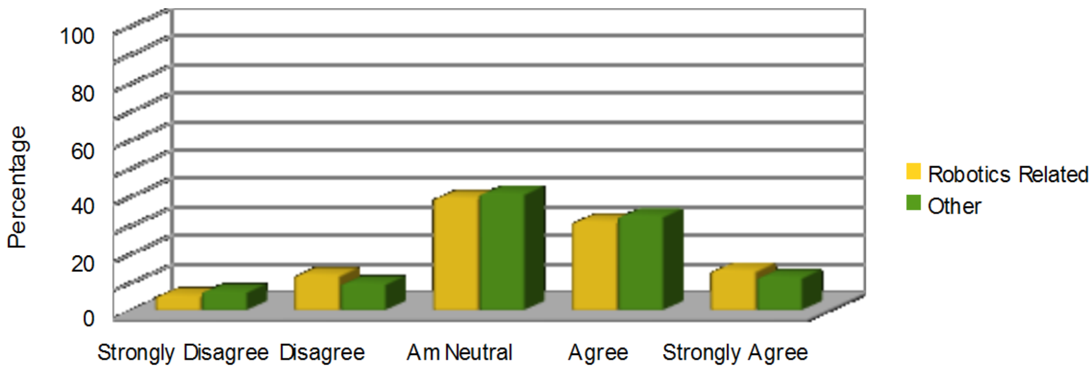
D.18 - I think space mining will have a positive impact on society:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	3 (1.6%)	15 (7.8%)	66 (34.4%)	75 (39.1%)	33 (17.2%)	192	3.63	0.91

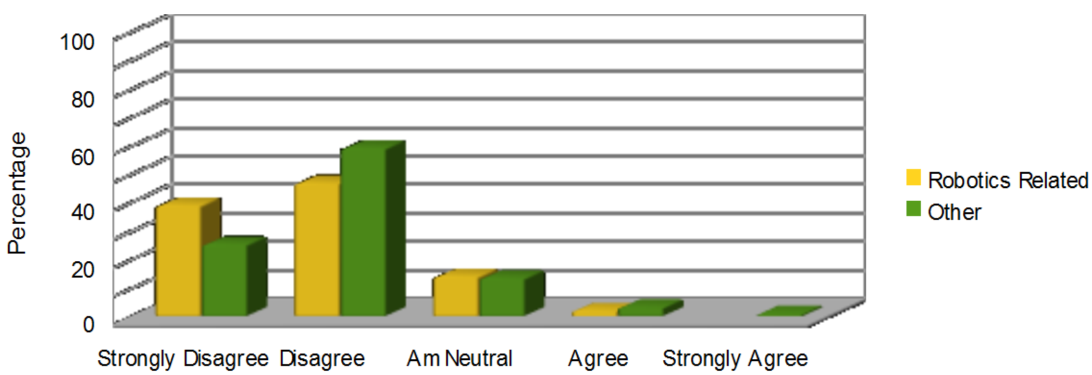
Other (%)	12 (6.8%)	7 (4.0%)	62 (35.0%)	66 (37.3%)	30 (16.9%)	177	3.54	1.04

D.19 - I think space mining would be financially beneficial:



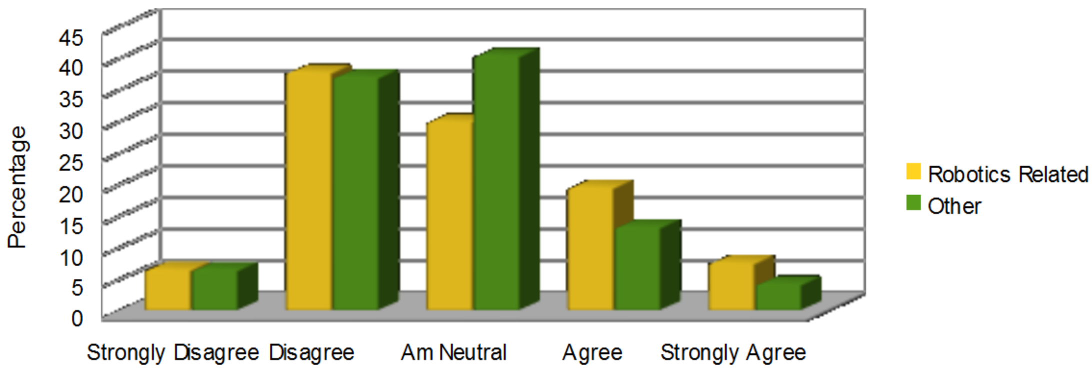
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	9 (4.7%)	23 (12.0%)	75 (39.1%)	59 (30.7%)	26 (13.5%)	192	3.36	1.01
Other (%)	11 (6.2%)	16 (9.0%)	72 (40.7%)	58 (32.8%)	20 (11.3%)	177	3.34	1

D.20 - I believe that sending <u>only people</u> is the best choice for space mining operations:



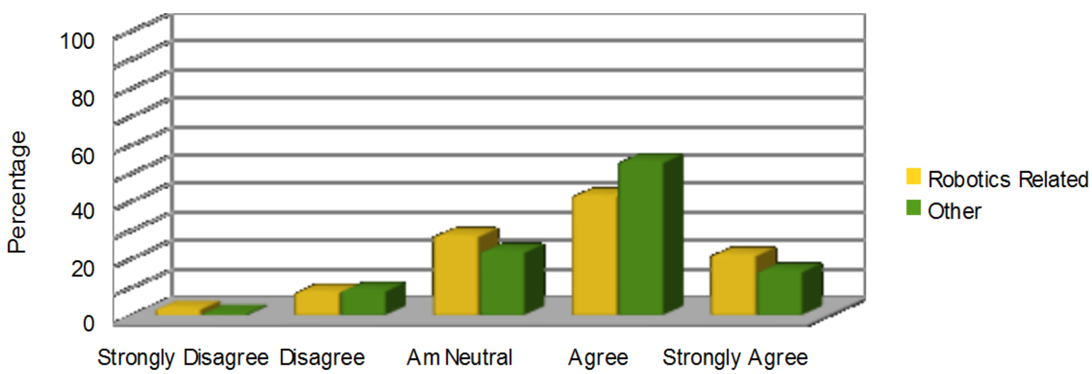
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	74 (38.5%)	89 (46.4%)	26 (13.5%)	3 (1.6%)	0 (0.0%)	192	1.78	0.73
Other (%)	44 (24.9%)	104 (58.8%)	23 (13.0%)	5 (2.8%)	1 (.6%)	177	1.95	0.74

D.21 - I believe that sending <u>only robots</u> is the best choice for space mining operations:



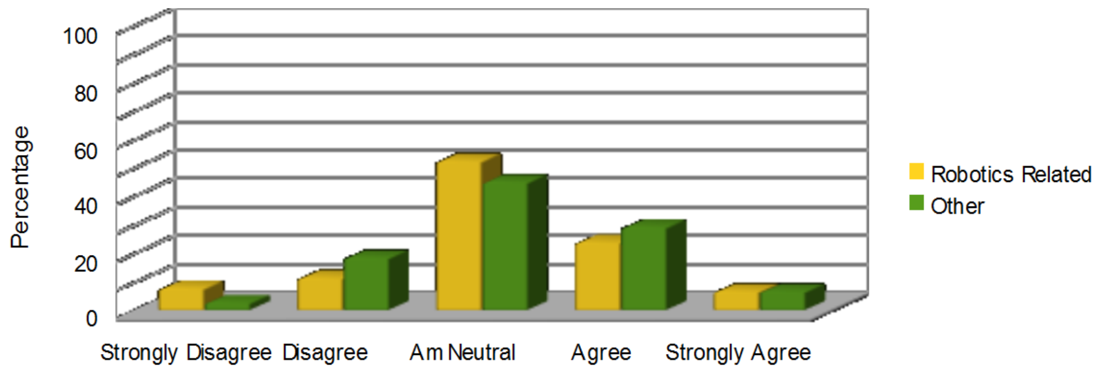
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	12 (6.3%)	72 (37.5%)	57 (29.7%)	37 (19.3%)	14 (7.3%)	192	2.84	1.04
Other (%)	11 (6.2%)	65 (36.7%)	71 (40.1%)	23 (13.0%)	7 (4.0%)	177	2.72	0.91

D.22 - I believe that sending <u>both people and robots</u> is the best choice for space mining operations:



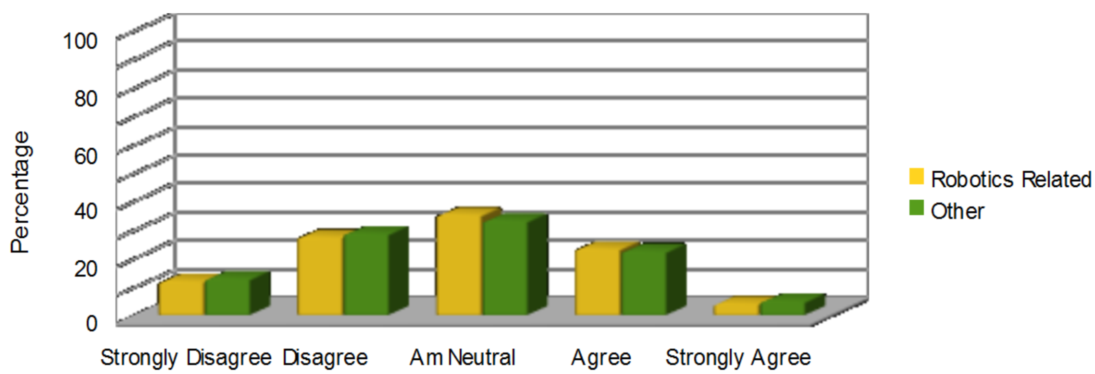
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	4 (2.1%)	15 (7.8%)	53 (27.6%)	80 (41.7%)	40 (20.8%)	192	3.71	0.95
Other (%)	1 (.6%)	15 (8.5%)	39 (22.0%)	95 (53.7%)	27 (15.3%)	177	3.75	0.84

D.23 - I think it would be more cost effective to process the mined minerals on Earth:



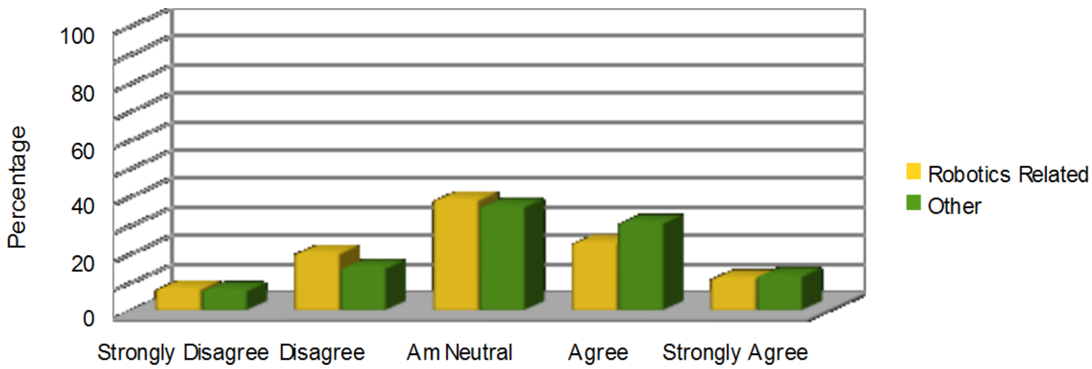
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	14 (7.3%)	21 (10.9%)	100 (52.1%)	45 (23.4%)	12 (6.3%)	192	3.1	0.94
Other (%)	4 (2.3%)	32 (18.1%)	79 (44.6%)	51 (28.8%)	11 (6.2%)	177	3.19	0.88

D.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:



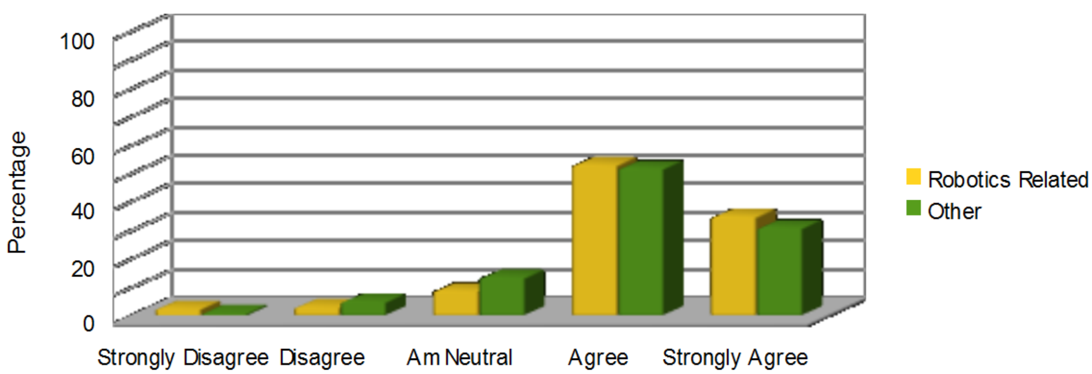
	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	22 (11.5%)	52 (27.1%)	67 (34.9%)	44 (22.9%)	7 (3.6%)	192	2.8	1.03
Other (%)	22 (12.4%)	50 (28.2%)	58 (32.8%)	39 (22.0%)	8 (4.5%)	177	2.78	1.06

D.25 - I think it would be financially beneficial to build a lunar base:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	14 (7.3%)	38 (19.8%)	74 (38.5%)	45 (23.4%)	21 (10.9%)	192	3.11	1.07
Other	12 (6.8%)	26 (14.7%)	64 (36.2%)	54 (30.5%)	21 (11.9%)	177	3.26	1.06

D.26 - I think that building a lunar base would lay the groundwork for expansion into space:



	Strongly Disagree (1)	Disagree (2)	Am Neutral (3)	Agree (4)	Strongly Agree (5)	Total	Mean	Standard Deviation
Robotics related (%)	4 (2.1%)	5 (2.6%)	16 (8.3%)	101 (52.6%)	66 (34.4%)	192	4.15	0.84
Other	1 (.6%)	8 (4.5%)	23 (13.0%)	91 (51.4%)	54 (30.5%)	177	4.07	0.81

E. Tables (Overall Data)

E.1 - I have extensive knowledge of current robot technology:

	Mean	Median	Mode	Standard Deviation
Result	2.58	2	2	1.21

E.2 - I have extensive knowledge of recent developments in space mining:

	Mean	Median	Mode	Standard Deviation
Result	2.08	2	1.5	1.05

E.3 - Current research and development of space mining technologies is of interest to me:

	Mean	Median	Mode	Standard Deviation
Result	3.46	4	4	0.96

E.4 - I believe space exploration is important to society:

	Mean	Median	Mode	Standard Deviation
Result	4.02	4	4	0.97

E.5 - I believe mining on Earth is important:

	Mean	Median	Mode	Standard Deviation
Result	3.84	4	4	0.87

E.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:

	Mean	Median	Mode	Standard Deviation
Result	3.53	4	4	1.08

E.7 - I believe funding for space mining would be better spent elsewhere:

	Mean	Median	Mode	Standard Deviation
Result	3.04	3	3	1.04

E.8 - I believe that robotic space mining needs to be given more media exposure:

	Mean	Median	Mode	Standard Deviation
Result	3.55	4	4	0.98

E.9 - I believe that robotic space mining needs to be given more financial backing:

	Mean	Median	Mode	Standard Deviation
Result	3.09	3	3	0.98

E.10 - I believe we are in need of more (minable) resources:

	Mean	Median	Mode	Standard Deviation
Result	3.47	4	4	0.97

E.11 - I think that exhaustive mining of Earth is inappropriate:

	Mean	Median	Mode	Standard Deviation
Result	4.02	4	4	0.95

E.12 - I think that exhaustive mining of the moon is inappropriate:

	Mean	Median	Mode	Standard Deviation
Result	3.3	3	4	1.23

E.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:

	Mean	Median	Mode	Standard Deviation
Result	3.49	4	4	1.11

E.14 - I think it would be more cost effective to send robots to space in place of humans:

	Mean	Median	Mode	Standard Deviation
Result	3.88	4	4	0.96

E.15 - I think that mineral mining in space <u>can</u> currently be done by robots:

	Mean	Median	Mode	Standard Deviation
Result	3.72	4	4	0.86

E.16 - I think that mineral mining in space <u>should</u> be done by robots:

	Mean	Median	Mode	Standard Deviation
Result	3.83	4	4	0.95

E.17 - I think space exploration has a positive impact on society:

	Mean	Median	Mode	Standard Deviation
Result	4.12	4	4	0.84

E.18 - I think space mining will have a positive impact on society:

	Mean	Median	Mode	Standard Deviation
Result	3.58	4	4	0.97

E.19 - I think space mining would be financially beneficial:

	Mean	Median	Mode	Standard Deviation
Result	3.36	3	3	1.01

E.20 - I believe that sending only people is the best choice for space mining operations:

	Mean	Median	Mode	Standard Deviation
Result	1.86	2	2	0.74

E.21 - I believe that sending only robots is the best choice for space mining operations:

	Mean	Median	Mode	Standard Deviation
Result	2.79	3	2	0.99

E.22 - I believe that sending both people and robots is the best choice for space mining operations:

	Mean	Median	Mode	Standard Deviation
Result	3.72	4	4	0.9

E.23 - I think it would be more cost effective to process the mined minerals on Earth

	Mean	Median	Mode	Standard Deviation
Result	3.14	3	3	0.91

E.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:

	Mean	Median	Mode	Standard Deviation
Result	2.79	3	3	1.05

E.25 - I think it would be financially beneficial to build a lunar base:

	Mean	Median	Mode	Standard Deviation
Result	3.19	3	3	1.07

E.26 - I think that building a lunar base would lay the groundwork for expansion into space:

	Mean	Median	Mode	Standard Deviation
Result	4.11	4	4	0.83

F. 95% Confidence Intervals for Mean: Overall

F.1 - I have extensive knowledge of current robot technology:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	2.58	1.21	± 0.12	2.46 to 2.75

F.2 - I have extensive knowledge of recent developments in space mining:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	2.08	1.05	± 0.11	1.97 to 2.19

F.3 - Current research and development of space mining technologies is of interest to me:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.46	0.96	± 0.1	3.36 to 3.56

F.4 - I believe space exploration is important to society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	368	4.02	0.97	± 0.1	3.92 to 4.12

F.5 - I believe mining on Earth is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.84	0.87	± 0.09	3.75 to 3.93

F.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.53	1.08	± 0.11	3.42 to 3.64

F.7 - I believe funding for space mining would be better spent elsewhere:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.04	1.04	± 0.11	2.93 to 3.15

F.8 - I believe that robotic space mining needs to be given more media exposure:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.55	0.98	± 0.1	3.45 to 3.65

F.9 - I believe that robotic space mining needs to be given more financial backing:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.09	0.98	± 0.1	2.99 to 3.19

F.10 - I believe we are in need of more (minable) resources:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.47	0.97	± 0.1	3.37 to 3.57

F.11 - I think that exhaustive mining of Earth is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean

Result	369	4.02	0.95	± 0.1	3.92 to 4.12

F.12 - I think that exhaustive mining of the moon is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.3	1.23	± 0.13	3.17 to 3.43

F.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.49	1.11	± 0.11	3.38 to 3.6

F.14 - I think it would be more cost effective to send robots to space in place of humans:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.88	0.96	± 0.1	3.78 to 3.98

F.15 - I think that mineral mining in space <u>can</u> currently be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.72	0.86	± 0.09	3.63 to 3.81

F.16 - I think that mineral mining in space <u>should</u> be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.83	0.95	± 0.1	3.73 to 3.93

F.17 - I think space exploration has a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	4.12	0.84	± 0.09	4.03 to 4.21

F.18 - I think space mining will have a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.58	0.97	± 0.1	3.48 to 3.68

F.19 - I think space mining would be financially beneficial:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.36	1.01	± 0.1	3.26 to 3.46

F.20 - I believe that sending only people is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	1.86	0.74	± 0.08	1.78 to 1.94

F.21 - I believe that sending only robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	2.79	0.99	± 0.1	2.69 to 2.89

F.22 - I believe that sending both people and robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.72	0.9	± 0.09	3.63 to 3.81

F.23 - I think it would be more cost effective to process the mined minerals on Earth

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.14	0.91	± 0.09	3.05 to 3.23

F.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	2.79	1.05	± 0.11	2.68 to 2.9

F.25 - I think it would be financially beneficial to build a lunar base:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	3.19	1.07	± 0.11	3.08 to 3.3

F.26 - I think that building a lunar base would lay the groundwork for expansion into space:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Result	369	4.11	0.83	± 0.08	4.03 to 4.19

G. 95% Confidence Intervals for Means: Age Groups

G.1 - I have extensive knowledge of current robot technology:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	2.59	1.21	± 0.13	2.46 to 2.72
> 25 years	33	2.42	1.28	± 0.44	1.98 to 2.86

G.2 - I have extensive knowledge of recent developments in space mining:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	2.11	1.07	± 0.11	2 to 2.22
> 25 years	33	1.85	0.78	± 0.27	1.58 to 2.12

G.3 - Current research and development of space mining technologies is of interest to me:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.5	0.94	± 0.1	3.4 to 3.6
> 25 years	33	3.06	1.1	± 0.38	2.68 to 3.44

G.4 - I believe space exploration is important to society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	4.09	0.92	± 0.1	3.99 to 4.19
> 25 years	32	3.44	1.25	± 0.43	3.01 to 3.87

G.5 - I believe mining on Earth is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.83	0.87	± 0.09	3.74 to 3.92
> 25 years	33	4.03	0.83	± 0.28	3.75 to 4.31

G.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.6	1.04	± 0.11	3.49 to 3.71
> 25 years	33	2.85	1.23	± 0.42	2.43 to 3.27

G.7 - I believe funding for space mining would be better spent elsewhere:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3	1.03	± 0.11	2.89 to 3.11
> 25 years	33	3.45	1.08	± 0.37	3.08 to 3.82

G.8 - I believe that robotic space mining needs to be given more media exposure:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.6	0.94	± 0.1	3.5 to 3.7
> 25 years	33	3.06	1.23	± 0.42	2.64 to 3.48

G.9 - I believe that robotic space mining needs to be given more financial backing:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.14	0.97	± 0.1	3.04 to 3.24
> 25 years	33	2.7	1.06	± 0.36	2.34 to 3.06

G.10 - I believe we are in need of more (minable) resources:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.45	0.97	± 0.1	3.35 to 3.55
> 25 years	33	3.48	1.05	± 0.36	3.12 to 3.84

G.11 - I think that exhaustive mining of Earth is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	4.02	0.95	± 0.1	3.92 to 4.12
> 25 years	33	4	1.02	± 0.35	3.65 to 4.35

G.12 - I think that exhaustive mining of the moon is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.26	1.23	± 0.13	3.13 to 3.39
> 25 years	33	3.7	1.24	± 0.42	3.28 to 4.12

G.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.52	1.1	± 0.12	3.4 to 3.64
> 25 years	33	3.15	1.08	± 0.37	2.78 to 3.52

G.14 - I think it would be more cost effective to send robots to space in place of humans:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.9	0.94	± 0.1	3.8 to 4
> 25 years	33	3.61	1.12	± 0.38	3.23 to 3.99

G.15 - I think that mineral mining in space <u>can</u> currently be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.76	0.84	± 0.09	3.67 to 3.85
> 25 years	33	3.3	0.94	± 0.32	2.98 to 3.62

G.16 - I think that mineral mining in space <u>should</u> be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.86	0.94	± 0.1	3.76 to 3.96
> 25 years	33	3.58	1.05	± 0.36	3.22 to 3.94

G.17 - I think space exploration has a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	4.15	0.81	± 0.09	4.06 to 4.24
> 25 years	33	3.85	1.02	± 0.35	3.5 to 4.2

G.18 - I think space mining will have a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.63	0.95	± 0.1	3.53 to 3.73
> 25 years	33	3.12	1.07	± 0.37	2.75 to 3.49

G.19 - I think space mining would be financially beneficial:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.4	1	± 0.11	3.29 to 3.51
> 25 years	33	2.88	1.01	± 0.34	2.54 to 3.22

G.20 - I believe that sending only people is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	1.87	0.75	± 0.08	1.79 to 1.95
> 25 years	33	1.82	0.57	± 0.19	1.63 to 2.01

G.21 - I believe that sending only robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	2.77	1	± 0.11	2.66 to 2.88
> 25 years	33	2.85	0.82	± 0.28	2.57 to 3.13

G.22 - I believe that sending both people and robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.75	0.91	± 0.1	3.65 to 3.85
> 25 years	33	3.39	0.85	± 0.29	3.1 to 3.68

G.23 - I think it would be more cost effective to process the mined minerals on Earth

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.16	0.9	± 0.1	3.06 to 3.26
> 25 years	33	2.97	0.97	± 0.33	2.64 to 3.3

G.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	2.82	1.04	± 0.11	2.71 to 2.93
> 25 years	33	2.39	1.04	± 0.35	2.04 to 2.74

G.25 - I think it would be financially beneficial to build a lunar base:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	3.24	1.06	± 0.11	3.13 to 3.35
> 25 years	33	2.67	1.06	± 0.36	2.31 to 3.03

G.26 - I think that building a lunar base would lay the groundwork for expansion into space:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
<= 25 Years	336	4.13	0.82	± 0.09	4.04 to 4.22
> 25 years	33	3.85	0.86	± 0.29	3.56 to 4.14

H. 95% Confidence Intervals for Means: Gender

H.1 - I have extensive knowledge of current robot technology:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	2.86	1.19	± 0.15	2.71 to 3.01
Female	118	1.97	1.02	± 0.18	1.79 to 2.15

H.2 - I have extensive knowledge of recent developments in space mining:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	2.2	1.07	± 0.13	2.07 to 2.33
Female	118	1.85	0.98	± 0.18	1.67 to 2.03

H.3 - Current research and development of space mining technologies is of interest to me:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.62	0.94	± 0.12	3.5 to 3.74
Female	118	3.12	0.92	± 0.17	2.95 to 3.29

H.4 - I believe space exploration is important to society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	250	4.08	0.97	± 0.12	3.96 to 4.2
Female	118	3.9	0.95	± 0.17	3.73 to 4.07

H.5 - I believe mining on Earth is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.99	0.83	± 0.1	3.89 to 4.09
Female	118	3.53	0.86	± 0.16	3.37 to 3.69

H.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.64	1.09	± 0.13	3.51 to 3.77
Female	118	3.31	1.02	± 0.18	3.13 to 3.49

H.7 - I believe funding for space mining would be better spent elsewhere:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	2.98	1.04	± 0.13	2.85 to 3.11
Female	118	3.17	1.02	± 0.18	2.99 to 3.35

H.8 - I believe that robotic space mining needs to be given more media exposure:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.51	1	± 0.12	3.39 to 3.63
Female	118	3.64	0.94	± 0.17	3.47 to 3.81

H.9 - I believe that robotic space mining needs to be given more financial backing:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.18	1	± 0.12	3.06 to 3.3

Female	118	2.91	0.93	± 0.17	2.74 to 3.08

H.10 - I believe we are in need of more (minable) resources:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.51	0.98	± 0.12	3.39 to 3.63
Female	118	3.39	0.95	± 0.17	3.22 to 3.56

H.11 - I think that exhaustive mining of Earth is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	4	0.98	± 0.12	3.88 to 4.12
Female	118	4.06	0.9	± 0.16	3.9 to 4.22

H.12 - I think that exhaustive mining of the moon is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.14	1.28	± 0.16	2.98 to 3.3
Female	118	3.65	1.03	± 0.19	3.46 to 3.84

H.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.55	1.11	± 0.14	3.41 to 3.69
Female	118	3.37	1.09	± 0.2	3.17 to 3.57

H.14 - I think it would be more cost effective to send robots to space in place of humans:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean

Male	251	3.97	0.97	± 0.12	3.85 to 4.09
Female	118	3.67	0.9	± 0.16	3.51 to 3.83

H.15 - I think that mineral mining in space <u>can</u> currently be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.72	0.89	± 0.11	3.61 to 3.83
Female	118	3.73	0.79	± 0.14	3.59 to 3.87

H.16 - I think that mineral mining in space <u>should</u> be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.91	0.95	± 0.12	3.79 to 4.03
Female	118	3.67	0.94	± 0.17	3.5 to 3.84

H.17 - I think space exploration has a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	4.21	0.77	± 0.1	4.11 to 4.31
Female	118	3.93	0.94	± 0.17	3.76 to 4.1

H.18 - I think space mining will have a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.66	0.97	± 0.12	3.54 to 3.78
Female	118	3.41	0.95	± 0.17	3.24 to 3.58

H.19 - I think space mining would be financially beneficial:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean

Male	251	3.43	1.04	± 0.13	3.3 to 3.56
Female	118	3.21	0.92	± 0.17	3.04 to 3.38

H.20 - I believe that sending only people is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	1.82	0.75	± 0.09	1.73 to 1.91
Female	118	1.96	0.72	± 0.13	1.83 to 2.09

H.21 - I believe that sending only robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	2.76	1.03	± 0.13	2.63 to 2.89
Female	118	2.84	0.88	± 0.16	2.68 to 3

H.22 - I believe that sending both people and robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.78	0.91	± 0.11	3.67 to 3.89
Female	118	3.6	0.86	± 0.16	3.44 to 3.76

H.23 - I think it would be more cost effective to process the mined minerals on Earth

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.07	0.95	± 0.12	2.95 to 3.19
Female	118	3.29	0.79	± 0.14	3.15 to 3.43

H.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	2.8	1.07	± 0.13	2.67 to 2.93
Female	118	2.75	1.01	± 0.18	2.57 to 2.93

H.25 - I think it would be financially beneficial to build a lunar base:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	3.2	1.11	± 0.14	3.06 to 3.34
Female	118	3.17	0.99	± 0.18	2.99 to 3.35

H.26 - I think that building a lunar base would lay the groundwork for expansion into space:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Male	251	4.19	0.83	± 0.1	4.09 to 4.29
Female	118	3.94	0.81	± 0.15	3.79 to 4.09

I. 95% Confidence Intervals for Means: Majors

I.1 - I have extensive knowledge of current robot technology:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.01	1.22	± 0.17	2.84 to 3.18
Other	177	2.09	0.99	± 0.15	1.94 to 2.24

I.2 - I have extensive knowledge of recent developments in space mining:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	2.25	1.08	± 0.15	2.1 to 2.4
Other	177	1.87	0.93	± 0.14	1.73 to 2.01

I.3 - Current research and development of space mining technologies is of interest to me:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.57	0.92	± 0.13	3.44 to 3.7
Other	177	3.34	0.98	± 0.14	3.2 to 3.48

I.4 - I believe space exploration is important to society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	4.06	0.91	± 0.13	3.93 to 4.19
Other	176	3.99	1.03	± 0.15	3.84 to 4.14

I.5 - I believe mining on Earth is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.91	0.85	± 0.12	3.79 to 4.03
Other	177	3.77	0.87	± 0.13	3.64 to 3.9

I.6 - I believe mining on extraterrestrial (non-Earth) surfaces is important:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.67	1.02	± 0.14	3.53 to 3.81
Other	177	3.41	1.1	± 0.16	3.25 to 3.57

I.7 - I believe funding for space mining would be better spent elsewhere:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.01	1	± 0.14	2.87 to 3.15
Other	177	3.07	1.07	± 0.16	2.91 to 3.23

I.8 - I believe that robotic space mining needs to be given more media exposure:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.6	0.94	± 0.13	3.47 to 3.73
Other	177	3.52	1	± 0.15	3.37 to 3.67

I.9 - I believe that robotic space mining needs to be given more financial backing:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.21	0.99	± 0.14	3.07 to 3.35
Other	177	2.98	0.95	± 0.14	2.84 to 3.12

I.10 - I believe we are in need of more (minable) resources:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.51	0.96	± 0.14	3.37 to 3.65
Other	177	3.46	0.96	± 0.14	3.32 to 3.6

I.11 - I think that exhaustive mining of Earth is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.92	1	± 0.14	3.78 to 4.06
Other	177	4.11	0.88	± 0.13	3.98 to 4.24

I.12 - I think that exhaustive mining of the moon is inappropriate:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.17	1.25	± 0.18	2.99 to 3.35
Other	177	3.43	1.19	± 0.18	3.25 to 3.61

I.13 - One of the biggest concerns of mining on Earth is the destruction of wildlife habitats. Because there is no life on the moon, I think it is more morally responsible to mine there:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.55	1.12	± 0.16	3.39 to 3.71
Other	177	3.45	1.08	± 0.16	3.29 to 3.61

I.14 - I think it would be more cost effective to send robots to space in place of humans:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.98	0.97	± 0.14	3.84 to 4.12

Other	177	3.79	0.91	± 0.13	3.66 to 3.92

I.15 - I think that mineral mining in space can currently be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.73	0.91	± 0.13	3.6 to 3.86
Other	177	3.73	0.8	± 0.12	3.61 to 3.85

I.16 - I think that mineral mining in space should be done by robots:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	4	0.88	± 0.12	3.88 to 4.12
Other	177	3.66	0.98	± 0.14	3.52 to 3.8

I.17 - I think space exploration has a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	4.18	0.79	± 0.11	4.07 to 4.29
Other	177	4.07	0.87	± 0.13	3.94 to 4.2

I.18 - I think space mining will have a positive impact on society:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.63	0.91	± 0.13	3.5 to 3.76
Other	177	3.54	1.04	± 0.15	3.39 to 3.69

I.19 - I think space mining would be financially beneficial:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.36	1.01	± 0.14	3.22 to 3.5

Other	177	3.34	1	± 0.15	3.19 to 3.49

I.20 - I believe that sending only people is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	1.78	0.73	± 0.1	1.68 to 1.88
Other	177	1.95	0.74	± 0.11	1.84 to 2.06

I.21 - I believe that sending only robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	2.84	1.04	± 0.15	2.69 to 2.99
Other	177	2.72	0.91	± 0.13	2.59 to 2.85

I.22 - I believe that sending both people and robots is the best choice for space mining operations:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.71	0.95	± 0.13	3.58 to 3.84
Other	177	3.75	0.84	± 0.12	3.63 to 3.87

I.23 - I think it would be more cost effective to process the mined minerals on Earth

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.1	0.94	± 0.13	2.97 to 3.23
Other	177	3.19	0.88	± 0.13	3.06 to 3.32

I.24 - I think it would be worthwhile to continue space mining if the practice was shown not to be profitable:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean

Robotics Related	192	2.8	1.03	± 0.15	2.65 to 2.95
Other	177	2.78	1.06	± 0.16	2.62 to 2.94

I.25 - I think it would be financially beneficial to build a lunar base:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	3.11	1.07	± 0.15	2.96 to 3.26
Other	177	3.26	1.06	± 0.16	3.10 to 3.42

I.26 - I think that building a lunar base would lay the groundwork for expansion into space:

	Total	Mean	Standard Deviation	Confidence Interval	True Population Mean
Robotics Related	192	4.15	0.84	± 0.12	4.03 to 4.27
Other	177	4.07	0.81	± 0.12	3.95 to 4.19

APPENDIX 2: Interview Transcripts

A. Professor Sanbonmatsu

Q: What is your expertise with robotics?

Sanbonmatsu: I've seen Blade Runner. Let's see in all serious I don't have expertise in robotics per se. I do philosophy and am interested in the philosophy of technology and that's probably my next book actually. So, I've thought a lot about it—about the question.

Q: What do you think of the current state of robotics?

Sanbonmatsu: I think it is too advanced. I think it should be slowed down, possibly halted—before it's too late.

Q: Why is that exactly?

Sanbonmatsu: Because our technologies are evolving much faster than we are as moral creatures and social creatures, which is to say that we are developing and have developed extraordinarily powerful machines of various kinds, robotics among them, and we don't have sufficient democratic control over these technics, these technologies or machines . So my feeling is that especially with robotics which is mostly funded by the military that's commanded up pretty soon being used to dominate and subjugate people unjustly. But there is so much investment obviously in robotics research that it seems pretty unstoppable, but I'm pretty concerned about it.

Q: What do you think about the role of robots in space exploration?

Sanbonmatsu: Well, I suppose it depends on what the mission is. My general feeling is that we have a huge mess right here at home on the Earth and that we should be spending our spare dollars to house, clothe, and feed everybody before we take off into the heavens. So I'm not sure if that is the right priority right now for our species. How's this for a cynical view.

Q. Do you think that robotic autonomy is a good or bad thing?

Sanbonmatsu: Well, it depends what we mean by autonomy I suppose. I'm skeptical of claims of artificial intelligence or consciousness in machines. So if we mean autonomy in that sense then I am skeptical that that is even possible. If we mean setting machines up so that they can perform tasks without human input, again it would depend on the task. I know there is a lot of debate within the military about whether robots should be given autonomy to kill or to decide on what kinds of actions to take on a battlefield setting, and I would be very concerned about that. Even without giving machines autonomy what has happened is we have become increasingly stripped of our moral autonomy, so that we you know kill people at a distance. Some CIA contractors in Virginia say are in a trailer and are using a Predator drone robot to kill people on the other side of the planet. They don't know anything about these people really, they can't even see them other than little specs on the ground and then yet they kill them. I think the drive to build autonomous robots again is coming primarily from the military and it can’t lead to anything good given the track record of the military in creating undemocratic and lethal technologies.

Q. Do you believe robots will ever become fully autonomous?

Sanbonmatsu: No, I don’t believe that. It’s funny I have a cousin in Los Alamos Laboratories and he thinks that we’re at the stage of, where the robots are going to take over the world pretty soon. Perhaps not literally, obviously you guys know there are extraordinary advances in robotics and it just seems like it’s accelerating. But yeah, I’m not sure autonomy is a goal that we should be striving for.

Q: Do you think having robots discover things in place of humans would possibly take away from the ‘ego’ of man?

Sanbonmatsu: I think that in order to answer any of these questions you need to look somewhat skeptically at the history of colonization. There were already people living in the Americas, they’ve been living here for thousands of years and the Europeans came and basically slaughtered them, gave them poison blankets and killed them off. I grew up watching Star Trek and you watch that kind of thing and you think of colonization as a benign process, but it wasn’t. Similarly human beings are colonizing the ecosystem in a way that is now endangering all the beings on the planet. So I don’t think that the model of colonization is a good model for space exploration given that the history of colonization is one of tremendous violence and extermination. That said, there is nothing wrong with… even if a machine “discovered something” that we humans did not discover, in fact it would still be our discovery because we built the machine that made the discovery, so I’m not that concerned the taking away from our ego—damaging our ego. But the other aspect is that when we think about discovery is the kind of false view of science in which the scientist essentially stumbles over existing facts, just goes out and “Oh here’s a fact and there’s another fact”, but the philosophy of science has shown pretty convincingly that humans beings including scientists have to interpret the world. They have to ascribe meaning to the world, they have to judgments about the world, and they bring values to that process of discovery. So unless we had robots that were capable of interpretation, giving meaning to things, ascribing values to those judgments, then I don’t think there is any danger that a robot or a machine is going to discover anything. Discovery will always be in the hand of or the minds of those who have consciousness and I think in order to have consciousness you have to have a body and apart from these cybernetic cyborg organisms being created that meld brain cells with machinery I don’t think a machine in itself will have consciousness.

Q: What is your expertise with mining?

Sanbonmatsu: I do not have any expertise in mining. But I do know of the dangers and hazards associated with it. So do you know of a film called Harlan County U.S.A? It’s in our library, you should check it out sometime, the DVD not the VHS. It’s about mining wars in Appalachia, it’s quite a fascinating document and one of the things it shows is the conditions of miners and certainly if there is to be an ethical case for the use of robots it would be in mining “here” let alone in space because it is so dangerous. The conditions for miners as you well know are terrible.

Q: What would be the implications of using robots to mine space?

Sanbonmatsu: Well, I'm sure you have seen the alien triptych, or quadruplic, whatever it is now where the Nostromo which was of course the ship used by Joseph Conrad in Heart of Darkness, which sort of has this overlay about the history of colonialism and space exploration as being a part of a violent legacy. If you look at the first alien faction, the Nostromo is awakened from its sleep and it's a mining operation supposedly returning home and it's put off course right to a foreign planet to essentially bring back an alien life form as a weapon. I am going into all this because as long as manufacturing is controlled by monopoly capital, as to say by these huge anonymous corporate bureaucracies they are not accountable to ordinary people, any kind of enterprise like that I think is going to be ethically fraught, it is going to be of questionable significance and value. I mean we are already mining the hell out of this planet. So to answer your question, the ethics of it really don't have to do from my perspective with robots themselves because it would almost certainly be more ethical than using human beings because it would be so dangerous. On the other hand the question, the ethical question is really , "Why the hell are we even thinking about mining other worlds rather than caretaking and stewarding the existing resources of planet?", which are quite sufficient to feed and clothe everybody. You may know that because of global warming the Arctic Caps are melting and the Arctic North Pole , the seas around the North Pole are now free of ice which is now enabling big companies to go in and start exploring and mining and oil exploration, which is the last thing we need. I mean it is precisely the mining and oil extraction that caused the global climate change in the first place. So that would be my answer, that I do not see the need for space mining. It is the wrong way to look at the ecological crisis. I mean that is basically the reason why people are promoting space mining right? Because we are running out of resources here, the answer it seems to me is not to go and use up resources somewhere else but to develop sustainable forms of economic and technological development.

Q: If the practice were to become normal should they use robots instead of humans?

Sanbonmatsu: Sure. But better to not use any at all, ideally.

Q: Do you think the funding we are allocating to space robotics is adequate?

Sanbonmatsu: As you can probably guess I think it is too much, I don't think we should be spending our resources on that right now.

Q: What about the man-space department?

Sanbonmatsu: Similarly I think we should have a moratorium on space exploration until we have gotten our house in order. Yeah, it is the case where there is enough resources probably to take care of our social needs as well as do space exploration but in a way I think in a way it's a kind of distraction and almost immoral given 1 out of 2 human beings doesn't have enough food and clothing. Half of humanity doesn't have the basics and then the big powerful nation states are off sending rockets, just seems a little mistaken—wronghanded I guess.

Q: Would you then say that space mining is not worth the effort?

Sanbonmatsu: Yes I would say that it is… well when you put it that way it sounds like a practical problem, I'm not saying that. Because I know there is a question about the amount of fuel it would take to send things up there and all that jazz.

Q: Well the effort, the research and the time.

Sanbonmatsu: I see what you mean. Yeah I guess then I would say no. I don't think it would be worth it.

Q: If we were to hypothetically take care of the problems we currently have on Earth, do you think then it would be reasonable to go to the moon to look for resources?

Sanbonmatsu: No, I don't think so. I mean if you look at other species, they have survived for millions of years. If it was a question of our survival on Earth or the survival of the ecosystem, then I would suppose yes. But in anything short of that kind of dire scenario, I mean basically why is mining happening now? Is it for stuff we need? Go to Wal-Mart, how much of that stuff is necessary—all the oil that went into it all the coal that was burned. As I was saying species have lived for millions of years in harmony with their environments; if we learned to do the same thing we wouldn't need to be exploiting other planets I think.

Q: If we were to create a lunar base would it possibly enable further missions?

Sanbonmatsu: I do not think there will ever be a long-term presence on the moon. I don't think that it is financially feasible. Basically the United States is headed towards bankruptcy and we are the only country that has the resources or the interest to do this sort of thing. If you look at the origins of the space program, it originated in the Cold War in Kennedy's desire to keep up with Russia after the Sputnik launch. It wasn't, well in spite of all the talk about the science—the scientists were earnestly interested in finding out stuff about the moon and space and the cosmos, but basically it was driven by the Cold War. And it was an enormously expensive venture and the reason why NASA has been cut back is because it's a very expensive thing and it does not serve a national purpose like it used to. So I am personally skeptical because we are spending so much money as a nation that we are really heading off a cliff. There's going to be less money even for space exploration. If the moon was simply awash with diamonds and oils just sitting on the surface then maybe we would do it, but the amount of effort it would take to go over and establish a stable atmosphere or whatever. I just don't think it is possible. It is just like the mortgage crisis which we have living beyond our means, let alone setting up another planet.

Q: (Explanation of the MoonRaker and the properties of Regolith) What do you think of NASA's future plans?

Sanbonmatsu: I just think that it is too expensive. I don't think that they can do it. I am very skeptical of it. The only thing that could drive it is if there was scarce mineral that the Pentagon needed then they would find a way to get it there. Yeah I just don't see it happening.
(Explanation of Helium-3)

Sanbonmatsu: Well, do you know about the most recent scarcity having to do with nuclear weapons detection, that's probably I mentioned it exactly, in the last week or two the US had distributed these new neutrino detectors at major ports to detect fissile nuclear material and the key ingredient is Helium-3 I believe and there is a shortage. It was a spin-off of tritium production and we do not have any left. So indeed if the Pentagon needed something like that or whatever then yeah maybe they would do it, but it wouldn't be economically feasible. It would be the same way the Pentagon gets the hundreds of billions of dollars that it needs to do what it does, but I don't think large scale mining would be feasible in itself.

Q: So you think it would be for the need of the product by itself rather than the money?

Sanbonmatsu: Yeah, not just the product itself. I think the only way it would be justified in this country is on national security grounds. If you look at these space missions, the space shuttles, I do not remember the percentage and it may even be classified but a pretty high percentage of NASA's budget and the energy department's budget are already military. There is a lot of research being done on the space station and so on.

Q: What do you think the effects of mastering nuclear fusion would be on economy and society?

Sanbonmatsu: I believe, as far as I know the only fusion reactors that have ever been contemplated are laser-based, which is to say they concentrate lasers on Helium to initiate the reaction. There is this guy named Langdon Winter, he wrote an interesting book called the Waylon Reactor and one of the things that Winter argues is that technology is not neutral, it is never neutral. That our artifacts have a politics. So if you think of a handgun, a handgun well it seems like any other tool but it isn't. If you place a handgun in a public place it would exude this kind of social force field and it would change people's behavior and it produces a kind of organization of society. In the same way he argues that nuclear reactors (fission) are not neutral, why? Well because they require an elaborate national security state apparatus to protect the fuel, to protect the reaction. It's a centralized bureaucratic form of energy. That means everybody becomes dependant on this one plant in the area which they don't have any control over and so forth. The trend right now is towards more decentralized forms of energy production, which I think is smarter and safer. Whenever you have a centralized power source like a fusion reactor you are dealing with terrorist threats, you're dealing with having to have massive security. I guess the answer is I do not think it is the solution to our energy needs. I think we should ween ourselves away from energy consumption and go to decentralized forms of energy such as solar and wind and so forth, which I say is tended to be the tendency. Because it is more human scale. When you have technologies that are human scale they tend to work out better. They are less prone to catastrophe. You guys are too young to remember the Three-Mile Island meltdown or the Chernobyl Meltdown but those are tremendous disasters, and it may be that fusion reaction is safe but scientists always say that it is safe and it turns out not to be half the time—more than half the time.

Q: Do you think it would be acceptable to have nuclear power robotic probes/vehicles?

Sanbonmatsu: You know my dad used to say if you run into a burning building and there is a Rembrandt there and a cat, then you would have to save the cat. I think that with any kind of technological decision I think the same thing applies, namely you do not endanger life in the pursuit of knowledge. Which is why the Brooke Haven Laboratory, there was concern with their collider there and so forth… you know there was an infinitesimal, there was a very small chance that it would lead to a black hole and swallow the Earth sort of thing. Probably there was no chance, but even if there was a tiny chance I do not think they should have done it. There has been a similar debate about putting fissile reactors on space probes. I do not think that it is a good idea because years ago I wrote an article in the paper about the space shuttle Challenger explosion, and the point I made in that article was that the Star Wars missile defense system was supposed to be foolproof, but no technology is foolproof—I used the space shuttle Challenger as an example. And since then there has been another space shuttle disaster. So the consequences of having a reactor burn up in the atmosphere and releasing nuclear material would be bad and we wouldn't really know it necessarily. Maybe it would lead to an increase of ten million cancers worldwide over fifty years. No one would know where they really got the cancer but it is just not worth it, it seems to me. So we should find safer ways of exploring the universe.

Q: What do you think of the recent discovery of water on the moon?

Sanbonmatsu: I don't know what to say about rather than it was interesting. It seems like it was a relatively harmless way of using our money. But again you know if you look at what the nation state and corporate capitalism is doing to this planet with its mining and so forth. Mountain top removal, where they just size off entire mountains and dump the poisonous pilings downstream and it kills all the fish and destroys peoples' livelihoods. I mean that is what will happen in outer space. Now if you are going to do that sort of thing in a place where there is no living thing, there is no ethical problem there. But then if you are going to move all that crap back to Earth then what's going to happen to it, that's the question. Because the people who are going to control it are the unscrupulous power elites and it's hard to see how something good will come of that.

Q: Do you predict any outcomes given the discovery of water on the moon?

Sanbonmatsu: Yeah, someone will probably bottle it and sell it for a lot of money. No, I don't know. You guys know more about it than I do. Maybe it is possible that they will find some way to colonize the moon, but I doubt it. As you know it takes an enormous amount of energy to break the Earth's gravitational pull. It's never been economical for us to do this, the only reason we are doing this again is for national security reasons so called.

Q: Is it even worth getting off Earth in order to survive?

Sanbonmatsu: That's another question is it worth surviving. It is philosophical. As Jesus said, "What profits a man if he should gain the whole world but lose his soul?". If we are the kind of species that are rapacious and predatorial and destroys its habitats and soils its habitats and tortures other creatures and kills itself, maybe we should just die with the sun. I mean I don't see any moral reason necessarily to continue the grand experiment in self-destruction. Just something to think about. I mean we take it for granted, that well—we must the "prime directive" you know in five billion years. Jesus Christ if we live for another two hundred I'll be very surprised of course I won't be around to see it. That's our real task you know? I think it is premature to worry about the sun burning out.

Q: What do you think would be needed to build a functional moonbase?

Sanbonmatsu: From a lay-person's view, I don't know. Obviously you would have to build machines that can mine and you have to have machines that can process the material and you need people to take care of the machines because they always break down, that is where this notion of autonomous robots seems kind of laughable. You can't even get Windows XP to work let alone something more complicated.

Q: Should the moon remain non-territorial? Do you see this as a problem?

Sanbonmatsu: Sure, I mean basically this comes back to what we've been talking about. As long as human beings remain militaristic, nationalistic, and etc. As long as this tiny elite of people control everything and the rest of us kind of get by, whatever happens in space is going to produce that same dynamic. So yeah you have this national competition over the Arctic and if the moon becomes seen as a viable place then it is going to be a conflict in space. Which is precisely why the United States as you know probably is militarizing space as quickly as it can. And I must that concerns me I wonder whether—how much the interest in moon colonization is fueled by legitimate scientific interest and how much of it is fueled by the desire to simply keep the US in its position of supremacy for eternity. So I think that it is a bad thing, the moon should remain untouched or at least it should remain in the public domain. We often speak of well should "Man" do this or that should we as a species mine the moon and so forth, but it isn't going to be you or me as a species it is going to be the Exxon Mobile corporation that is going to mine the moon or it is going to be the Russians who mine the moon. But that is the problem. So long as the decisions about technologies and resources are not democratized it is hard to see there being an ethical outcome. If it was the case that we the American people had a say over this then that is one thing. No one asked me if we should send a rocket and smash the moon and look for some water. Setting up camp on the moon should be open to a plebiscite or some democratic form of input.

Q: Do you find a problem with the American government not putting enough emphasis on the space program as opposed to all the other nations in the world?

Sanbonmatsu: No, it's a question of what space is there for, what we want out of space. If it's supposed to be to satisfy human curiosity or to be there in service to human needs, I don't see why other countries shouldn't have the right to do that. On the other hand, I think that all of these space missions are pouring tremendous amounts of carbon into the atmosphere. A space shuttle alone contributes I don't even know how many millions of tons of this stuff, so probably they should be curtailing their space exploration right now til and unless we can find safer ways to do it. The climate issues are a big problem and these launches are devastating that way.

Q: The moon would lend itself better than Earth when launching probes or shuttles without much detrimental side effects. What are your thoughts on this?

Sanbonmatsu: Well, that's true as I've kind of hinted that I grew up with Star Trek and there's a part of me that is kind of romantic like you guys to see what's out there you know but at the same time realistically speaking I don't think it's feasible, and I am just not convinced that it is going to be used for good. That's the problem. Maybe we should moratorium on space exploration until, as I started out by saying, we have worked out the problems here and shown that we can be a responsible species. I can't remember which science fiction series but I'm sure there are probably several where there are species that are not allowed to join the Federation of Planets until they have arrived at a certain level of evolution and I don't think we are there yet. And if there if “life”, intelligent life in outer space then that assumes of course too they would have technologies like ours and why should they... dolphins may be as smart as we are for all we know, and they just don't bother with technologies. But in any event I think if there were other creatures out there who were smart they wouldn't want us within their neighborhood, they would be like, “We gotta stop these folks. Look at the mess they're making of their own planet.”

Q: With recent environment concerns such as global warming and land preservation to what extent is it reasonable to mine the Earth?

Sanbonmatsu: It should be minimal I think. It should be subject to democratic control, popular control. These decisions about mining shouldn't be made by these anonymous amoral bureaucracies that care only for profit and don't give a damn about the animals or the people that they are destroying. I think it would be crazy to say that we shouldn't do any mining. On the other hand, there's a lot of stuff that's mined that's now out there that we can reuse, we can reduce the population of the Earth which as you know is exploding, and reduce our needs and then we would have to mine a hell of a lot less. We could do so in much more sustainable ways. On the question of robotics as I've said I do think that it's such a dangerous horrible business, mining, that mining here on Earth with robots I could see being justifiable.

Q: What about the moon?

Sanbonmatsu: Well, it depends on what it is for and who it is for. I would say mining on the moon so that a small number of folks can get rich is not acceptable, nor is it acceptable if it is to increase our military supremacy over the rest of the planet and the other peoples of the world. It is hard to see any scenario where mining on the moon is both desirable and ethical unless it is going conduce to the greater good for the greater number of people and animals. So you would really have to know what the purposes are before you could so.

Q: Do you think that we are heading in the right direction with advances in robotic technology?

Sanbonmatsu: No, I don't think we should be developing robotic technology. It is at a very scary level already. We're basically blurring the distinction between life and machinery. We're treating human beings as machines—if you call up technical support in India or Bangladesh you know what I am talking about, where someone just reads a script in a monotone voice and just goes through the thing. What if you work for a company you'll be treated like a cog, you won't have rights really. Our state, our government treats us like things and so forth. At the same time now we have technoscience in the military investing in robotics in order to create machines that are like us and I don't see the need for it and I think that even though there can be a need... you can make a good argument for medical robots say, or mining robots even but the problem is you can't disentangle that from robots that are going to be used for lethal actions. Suppressing citizens for example. In China right now there are US companies that are going over there providing the Chinese government with surveillance technologies so that for example, face recognition software so that if more than three people congregate on a street corner, instantly a message will go out to the secret police and they will go and break them up. So that every possibility of dissent, of democracy is kind of being thwarted from the outset and I really fear looking at some of these, from watching YouTube videos of some of the new robotics stuff, I'm sure you've seen them too. Boston Dynamics what they've been doing and ASIMOV or ASIMO the robot, the Japanese robot. These systems are going to be so lethal and so far above what humans are capable of biologically, that they're a danger, not that they are going to take over, right? But that they will be used by other unscrupulous human beings against the people. That's what I think is going to happen.

Q: Final thoughts?

Sanbonmatsu: As future scientists, I will say this to the two of you. It's easy to create or bring something new to the world, but it is much harder to control it once it is in there. It's hard to know who's going to use it and for what purposes. Who is going to use your technology and how? You look at the automobile. We take that technology for granted as a good technology. Well, kills and injures like millions of people a year, something like half a million people are killed outright, kills hundreds of millions—hundreds of billions probably of animals, it has destroyed the natural landscape... you know what I am saying, and now it's created a climate change problem. So don't assume all technological advances are a social advance. You have to consider the possibility that some forms of technology ought not to be developed. I think robotics is one. I don't think robotics is going to end up doing us any good. You know ironically computerization was supposed to lead to a paperless office, and supposed to free up our time for more leisure, but guess what Americans are working longer hours now than they were working twenty years ago. In spite of the fact that computers made us ten times more productive. And it's true that your generation has grown up with iPods and DVDs and Internet and all that stuff, but I doubt that you are happier than my generation was. It's just my observation, you have more stuff—I do too now, but in terms of quality of life, connection with community, family, friends just kind of being in the world I don't think you can probably say you're happier. So same with robotics we can see ways in which robotics could be helpful—in emergencies, digging through rubble, and all of that stuff is great but if you look at the whole picture it's freaking frightening. Yeah, we think about sending robots over to Iran killing babies in the streets—it's a different thing.

B. Professor Looft

Professor Looft declined to have the full transcript of his interview printed.

C. Professor Wilkes

Q: What is your area of expertise?

Wilkes: Well, my general expertise is that I'm a sociologist interested in the relationship between science, technology and society. I am considered a sociologist of science. I'm also considered one of the few members of the new field of astrosociology, which is the group that basically feels that the communities that will be emerging in space will be sufficiently different and interesting to be worthy of sociological investigation. in fact, these communities are already taking shape and probably should be studied the same way that those people who were setting the stage for seafaring technology and just before the Age of Discovery in Europe were. In particular, Henry the Navigator of Portugal was setting up research institutes and setting the stage for what would be a period of colonization. That period is already the seeds of a new era and by analogy sociologists today should be very interested in what's going on as the first space faring societies take shape. So five hundred years from now people will be very interested in what was the state of society on the eve of what will be probably as significant a period of scientific and technological advance as the Renaissance.

Q: How extensive is your knowledge of robotics?

Wilkes: On the technical side of robotics I know very little. On the other hand I was the one who was at an AIAA conference a few years ago in California and discovered that there was indeed going to be a regolith excavation contest in California. I brought that information back to WPI, setting in motion the events which ultimately led to Paul and his team winning the darn thing. At that point I was also very aware of the significance of regolith processing in terms of the future developments of what I suspect will be the next continent in the Earth system. The moon is about the size of North and South America; it's made of approximately the same material that Earth is, with the exception of Helium-3. Helium-3 comes from the solar wind which, of course, bathes the moon in a way that it cannot reach Earth due to our atmosphere. So, I suspect the presence of Helium-3 and a couple other exotic things on the moon will have historic and economic consequences for the Earth.

Q: What do you think about the role of robotics in space exploration?

Wilkes: If you mean by that autonomous systems that can go places humans can't at the moment, I would say it's been scientifically liberating. If you mean by that the very ambivalent view that NASA has towards robots because it is so committed to man in space, I think NASA is mistaken and underestimating the implications of robots. However, I am suspicious of autonomous systems because of our history of technology getting out of control.

But, I like the idea of semi-autonomous systems since I envision in the space environment as the place that development of a new relationship between man and machine will occur. It will be some sort of symbiotic relationship because flesh and blood just doesn't adapt into space. That is a place for well, metals and silicon intelligent systems effectively operated under carbon based system monitoring and control.

The deep commitment of NASA to have the humans inhabit space, particularly where the moon is concerned, seems to me to be little biased. The moon is so close that we should be thinking of systems that we exploit the moon using robotics that are semi-autonomous—human controlled from the Earth. The time delay in communications of the speed of light between the Earth and the moon are so trivial, basically three seconds round trip. The basic limitation is how quickly we can gather information to signal back to the Earth. Once you start to get to Mars and beyond fifteen minute and more delays, autonomy becomes more of a virtue. My attitude is that we would waste way too much time and energy and would not be developing the right precedent to go too autonomous for lunar operations. However, robotic systems that are semi-autonomous seem to me very promising to make a lunar base pay for itself, and I don't think we're going there if it’s not going to pay for itself. A twenty year payback on infrastructure investment would be acceptable, but in the long run it has to pay for itself.

Q: Do you think that higher degrees of autonomy in robots than we have now would be a good development?

Wilkes: One of the most longstanding debates in the society and technology field has to do with the capacity and tendency for technology to get out of control, or to have unanticipated consequences. So when you get into the area of robots and artificial intelligence you are on very controversial ground. The endeavor in the AI community to create an ultra intelligent machine more intelligent than a human being is even more controversial. But, when we get into autonomous systems, these have far reaching cultural consequences and they change the relationship between man and machine. An example is the clock. This idea that time wasn't cyclical-that it was uni-dimensional, a vector—one time through, that it could be lost forever was revolutionary. A machine created to represent time in those terms meant that the whole rest of society became synchronized and people became subject to the time scale and the demands of a machine. It's a pervasive impact on culture and society. It took decades of scholarship to fully comprehend. Now we have a second truly autonomous system. Computers operate by their own rules and we adjust to them. So with that kind of a background, although I remain cautiously optimistic this is a development that bears watching because it could change the man-machine relationship. Doing that in space you know I am okay with in space as that is a hostile environment where we're probably looking for some new way of operating. But the autonomous systems we're talking about on Earth, particularly autonomous systems at the nano level, we may see something that is destructive on the scale of the plagues before we're through just because we don't know what we're doing and aren’t looking far enough ahead. I am skeptical that we would want to go where we are likely to end up if we are not careful in the field of AI.

Q: Do you think that robots will ever be truly autonomous?

Wilkes: Well ever is a long long time. One of the things we are fantasizing about in science fiction is robots that are humanoid—partners. There has been fifty years of speculation about what the rules governing robot vs. human behavior might be. With all of that going on and a cultural quest in that direction I would be surprised if it didn't happen. The only thing I think that could stop it would be a religious movement or a political ideology that made that an unethical and evil behavior. Other than that we basically have a social momentum in that direction and without a counter-force the only question is how quickly it will happen and will we be ready to handle it. Personally, I hope it doesn't go too quickly so that we can learn enough to design the man-machine relationship as we go along, since it could be quite problematic.

Q: What do you think about sending robots rather than humans into space?

Wilkes: I tend to like the idea, but my image of the proper way to do this using the moon as an example (different if we're talking about further away) is to keep the systems simple and cheap and on a short leash. I'd like to keep 90% of the workforce here but I really think we need a presence maybe 10% of the workforce on site at a lunar base working with, monitoring, maintaining, repairing a robotic work force controlled most of the time from Earth. You see I think we're going to get into a situation where we're essentially going to have robots building other robots on the moon and that gets you into an autonomous situation that we have reason to be a little cautious about. I mean this is kind of the definition of life where you can reproduce yourself, right? If you reproduce yourself with a bit of improvement each round that is where you start talking about ultra systems which get beyond the ability of their initial creators to figure out where they are going or control that kind of directional destiny. So there are some big issues here. So basically yeah I see a community on the moon which is heavily mechanical, semi-autonomous, but with most of the carbon based organisms on Earth theoretically in control of what is going on.

Q: Now when you say 10% of the workforce you mean the workforce relevant to space mining or do you mean the entire human workforce?

Wilkes: Oh I meant if indeed we were going to view the moon as having an economy. See I want to be a little careful. Initially it is probably going to be a mining colony, but once you have the capacity to get people back and forth regularly and you have habitats there and you produce food there. The moon is going to be the base of human activity throughout the near space. It would even be cheaper to supply things to a space station in low-Earth orbit from the moon than to get things out of the Earth's gravity well. So you're talking about a major Lunar productive facility that supplies even food. I anticipate that we're going to have to have an agricultural revolution on the moon. It will supply scattered facilities in space, such as hotels and labs and depots throughout the near Earth-Moon system. After we reach Mars agriculture and oxygen production and water creation will move to there.

At any rate my vision is that now 10% of humanity will not get into space for at least a thousand years, but that I think it is quite likely that people who are controlling productive activity on the moon, 10% of them will be present and 90% will stay on Earth but work there remotely. Then the tourists will start and the service industry will have to involve lots of other humans with jobs in space. So between the scientific community, the tourists and people who are doing exploration of various kinds trying to understand the full potential of the moon, one will end up with a few colonies on the moon. This will be a technically advanced community too. Let's take, for example, on Earth nuclear power is quite problematic. We're trying to protect the biosphere from radiation. We're talking about very very long times if something gets irradiated in terms of half-lives before it gets decontaminated. It's very hard to sustain a fusion magnetic field in a vacuum on Earth. However, in the lunar environment some things that are nasty and dangerous here or difficult here would be a cinch there. In an environment where you really don't have an alternative of coal or gas or anything that involves carbon, the push for nuclear power is going to be very very strong and with Helium-3 there and breakthroughs with fusion reactors probably 2030 somewhere around there nuclear power will advance there before it does on Earth.

You are talking about a whole new civilization that operates in an alien environment that is interesting in that it is complementary to conditions on Earth. So certain kinds of technological things will get going there first, and one will be robotics. The community that lives there will develop certain types of expertise and knowledge and ultimately once you have a sufficiently energy rich society to exploit what's available on the moon, we could see a second very interesting civilization emerge. People who are born on the moon and live on the moon for more than five years probably can't ever go to Earth, as the greater gravity here would crush them. So there will be a new branch to human race with a different technology base.

They will probably have the seeds to the future in their hands because once fusion energy is mastered to drive the lunar economy it is modest innovations that will turn that into a space drive. Then fusion reactor space drives powered by Helium-3 (which doesn't exist on Earth) will the basis for a solar system wide civilization and a new era. This will probably be the salvation of the human race because if we don't get off the Earth we die with the Sun. The Sun will go supernova at some point. So if we are to have any future, if our development on this planet is to have any larger significance or universal meaning, then we have to leave Earth or die with it.

Q: Do have any knowledge of the current funding NASA is receiving for its space robotics department?

Wilkes: Not specifically towards space robotics, but I know their attitude towards computers. I had the opportunity in 1982 to go to a conference funded by ASEE and NASA over that summer. NASA was struggling with the question of whether to divert resources from aerospace technology into computers. The scientific community within NASA was in favor of it and the NASA regulars were having a very hard time with this. On the one hand they wanted credit for having needed computers when nobody else did and having kicked off computer revolution in American society. I think the factual basis for that claim was a little sketchy because the military also needed computers, but it was a taken for grated part of the NASA lore. I mean it might have happened a little later without Apollo but you know the investment in computers was coming for other reasons.

At the time I was there they certainly wanted to foster the development of a new supercomputer and they wanted to get their hands in on that because they needed the advanced computing capability. On the other hand they were extremely skeptical of artificial intelligence and other computer applications in part because they saw that as diverting money from their mission which was to build step stones to the stars. Getting humans off of planet Earth was their mission, whatever they told the public. So they wanted the computer technology to exist there, be on the shelves, something they could just pull, not have to spend to develop themselves.

Now, why would the scientific community be at odds with NASA? It's because their image of the purpose of going into space and the image of NASA as to why go into space is different. The scientists felt that NASA at its heart was an information processing organization with access to specialized kinds of information. In their view, NASA should actually be viewed as the eyes and ears of spaceship Earth. Notice they had no commitment to the idea that people had to go to space to gather the information. Therefore they tended to support the development of unmanned technologies and felt that you could therefore send missions that were 90% reliable rather than 99.5% reliable, which is what you want when sending humans. This meant you could reduce the redundancy, remove the life support and so an unmanned mission to the space scientist was $1/20^{th}$ as costly, didn't carry the risk of losing a human life, increased the payload, no need for a return trip … To a scientist, there was just no case for putting humans in space if you could get the information in another way. So the space technology was a means to an end and the end was information.

Whereas for the NASA regulars the manned space technology was an end in itself and the goal was to get people into space and develop the next generation of evolution. When they saw somebody doing a spacewalk they would say, "That moment, that moment is like the first lungfish crawling out of the oceans and beginning the inhabitation of land, it's an evolutionary moment." Since evolution certainly hasn't stopped they envisioned some sort of new intelligent cyborg, half man half machine, adapted to space. Some were pretty excited about that, some were kind of upset by it, but they were like that, far apart on what the space program is all about. You notice how the implications of computing, artificial intelligence, and manned systems all hung in the balance of that question of what was the raison d'être for going into space. So NASA is going to continue to underfund that which it finds threatening, robotic systems that undermine the case for a manned space program.

Q: What do you think are the advantages and disadvantages of mining in space?

Wilkes: You remember my bias that it all has to make economic sense. So if you look at what is available on the moon, which is the closest source of resources, it is very rare that you could make a case for bringing anything to Earth from the moon. You might choose to do things on the moon so as to protect the Earth's biosphere, you might choose to not to despoil the Earth and therefore create things on the moon and bring back just the finished products. So what's the case for mining the moon?

The case for mining the moon is that it is the base from which you develop an infrastructure in space. So let's say you wanted to have solar power or electricity beamed down from low-Earth orbit, it would be prohibitively expensive to lift facilities, platforms of the size required from the Earth. But the moon, which has the same metallic resources and the gravity is $1/6^{th}$ as much, it would be nearly trivial once you are set up to fabricate large things from iron, steel and aluminum on the moon. You would be able to lift with the same rockets things that were six times as large, and what is even more interesting is that from the moon you don't even have to blast things off.

The reason why we cannot build a space elevator is because we do not have a material that is seven times stronger than steel that can handle those requirements in Earth gravity.. Carbon nanotubes might do it one day, but we're talking about very very long, tens of thousands of miles of very resilient material to do this. But on the moon, hell we only need something that's more flexible than steel but about the strength of steel; we have that now: Kevlar. And we could come up with others. So if we really wanted to get heavy stuff off the moon, we have no atmosphere in the way and $1/6^{th}$ the gravity and every device and human on the moon is six times as strong as they would be on Earth.

With a relatively small labor force you could start talking about lifting massive facilities into orbit; access to space is much easier. As long as you are not moving too fast, relatively cheap delivery to low-Earth orbit is also possible. Refueling depots that are dependent on oxygen taken from the rocks in the moon will be common That's 85% of the weight of your fuel so you'll only have to bring up the hydrogen from Earth. There is evidence that you can turn regolith into a growing medium. Basically it is to occupy and develop space that you develop the moon. You can't justify bringing the materials other than maybe the Helium-3 to the Earth but you certainly can bring it to low-Earth orbit. Once you have oxygen supplies and water sitting there waiting in low-Earth orbit it transforms the economics of space—now you can refuel. The cost of getting somewhere anywhere in the solar system is the cost of getting it to low-Earth orbit. You don't have to carry any fuel. So the moon is highly significant and there is nothing really on the moon that we can't find elsewhere, with greater difficulty.

It seems that there is enough Helium-3 on the moon that at our current rates of energy consumption it would take something like a thousand years. Since the Deuterium reactors in principle can't be more than 30% efficient but the mixture of the two can be 60-65% efficient once really wants a source of Helium-3. So you bring Helium-3 from the moon and mix it with the Deuterium and you double the energy yield of your local Deuterium sources. You are also at that kind of elegance where things go directly with no moving parts into electron streams, you don't have to heat water and turn gears and all the rest to get electricity. So you're kind of at a new level of technology, and then added to that the United States could operate for a year on what is the equivalent of about...one transport.

Let's say we could get a shuttle sized space craft that is a “truck” to the moon. Let's say the payload is twenty-six tons. That one delivery could cover the electricity demand of the US for a year. One ship, one payload. So if you're talking about compared to the oil age, something that lasts for a thousand years as opposed to... are we even going to make it to a hundred? No... maybe... Remember that this is mining operation to get that 26 tones of Helium-3 that is not disturbing the biosphere of the Earth. So you're getting your energy source, you're bringing it in from outside any biosphere disruption, it has been on the moon where there is no biosphere. It's a very interesting scenario and once you run out of Helium-3 on the moon, well by then you'll probably have the technology, a thousand years out of here, you'll be able to go to the next big source of Helium-3 which is Saturn. The gas giants are basically made of it but we're not prepared to deal with the gravity of Jupiter yet.

Mars on the other hand doesn't seem to have anything we need economically; it would be easier to live there though. So if we were exploiting asteroids, then maybe going as far as Saturn for Helium-3, we probably would have major trading bases on Mars. Mars also has the advantage of having an atmosphere, heavily CO_2, which means carbon is available, which isn't available on the moon. But nonetheless you can turn that atmosphere into rocket fuel because there would be both hydrogen and oxygen available. We're going to see something very interesting; we're going to see Helium-3 going from the moon to Earth, and what the moon will want in return is very plentiful on Earth—hydrogen. It will be a gas trade economic system.

Wilkes: I should mention one thing that is part of my credentials. For reasons I will not go into I am the current chairman of the AIAA(American Institute of Aeronautics and Astronautics) chapter of New England. So that means that I'm kind of joining the aerospace community.

Q: What is your take on the recent discovery of water on the moon?

Wilkes: The way I heard, they were expecting that if there was ice on the moon it would be at the South Pole, more than 80% of it would be at the South Pole. It is interesting that that's been confirmed because that will determine where the first base is, but I never thought it was a big deal because I figured if there wasn't water we would make some. The oxygen is already there, we just have to deliver hydrogen.

Q: What is your take on the development of robotic technology in relation with autonomy?

Wilkes: I come from a field that has a job of raising cautionary notes about how quickly and what kind of autonomy is developed. Let me say that I see a little more zeal in the technical community to create truly autonomous systems than I think makes sense in terms of our immediate needs. Although that it is a worthy technological goal in terms of deploying completely autonomous systems, I lean towards the, shall we say, careful consideration of the man-machine relationship and various kinds of semi-autonomous systems as our proper priority for the moment. To the extent that we are operating farther and farther from Earth and in more and more hazardous environments I see the case for more and more capable systems, but as we are just starting out and particularly where we are only going to the moon, I wouldn't invest in the extra autonomy. It doesn't mean that the system shouldn't be able to take care of itself for a few hours before somebody checks it.

Q: Do you have any final thoughts?

Wilkes: Let me say that I would really like to see this field fostered by WPI. I think we are kind of at an interesting moment right now because of the high visibility that the regolith competition gave us to do what NASA is loathe to do—really really think about what a new kind of man-machine relationship appropriate for lunar exploration and development would look like. At NASA they have a bias toward keeping humans present and in control. I don't think that's going to pay for itself. I don't think that is where the future lies. So somebody outside of NASA is going to have to be the bank and brains for us and I don't see why it shouldn't be us. I mean Robert Goddard came out of WPI.

Wilkes: What's lacking at the moment is that the public has never really heard: a case for a coherent space program that focuses on the moon for at least the next two decades and uses that as a launching pad to do other things.

D. Professor Rich

Q: What do you think about the current state of robotics?

Rich: I think it's on the cusp of huge breakthroughs… Sound bite?

Q: What about their role in space exploration or space mining?

Rich: I don't know a lot about space exploration… it's not something that I've really looked at. So, it seems that the ability to run really by itself remotely, a million, literally a million miles away… is kind of scary, and it means you have to be very, very conservative about the engineering. So that's not the place you're going to try out new ideas.

Q: Do you think that robotic autonomy is a good thing or a bad thing?

Rich: There's an engineering and there's an ethical answer to that. I mean, I think from a practical engineering point of view it's a good thing, in the sense that it'll allow robots to do more things, you know, provide more applications. It does bring up some real ethical issues. In fact, I think as we were discussing in the IQP that I'm co-advising with professor Schachterle... there is an ethics code of robotics engineers, which you know about, right? It obviously, to the extent that engineers' creations really have autonomy, it's a much more complicated question of responsibility. It's harder to predict what a… [for example] if you build a bridge, it will fall down, or something, but, you know, it's not going to go off and decide to go rogue and kill people.

Q: How does this relate to the field of artificial intelligence?

Rich: Its core. Artificial intelligence is at the core of autonomy. Artificial intelligence is all about autonomy. It's all about how to build computational mechanisms… what's the definition of robot? That they sense, compute and react, right?

Q: Do you think robots will ever come close to being fully autonomous?

Rich: Well… ever? Yes. The question I ask is: in my lifetime? And, I'm not sure I hope so. I'm trying to eat well, so I'll have a longer lifetime. Yeah, I think it's inevitable, and I'm just not sure whether I'm going to see it.

Q: So far humans have always been at the forefront of new discoveries and breakthroughs. Do you think that would change if robots were the ones on the frontlines?

Rich: You mean autonomous robots? Or exploratory robots? A:(Autonomous robots) You know, we're going to get into "should robots have rights?" I guess the answer is: I don't know. I mean, I think that it's just too far in the future. I think it's a good thing to discuss things very far in advance, and it's good discussion, but I think it's a little too far in the future for me to have an opinion about that.

Q: Do you think that sending robots into space in place of humans is an acceptable practice?

Rich: Yeah, absolutely. Sure it's acceptable. I mean, there are tradeoffs, obviously, in terms of unexpected circumstances and in terms of how we feel about exploration, as you said in your previous question. But, it's not all or nothing. Who said you have to send all humans or all robots? I mean, why can't you send 80% robots and 20% humans? Split your budget, you know? I think it's a false sort of either-or dichotomy. It's certainly acceptable to send some. I mean someone who thinks that it's not acceptable to send any robots, I don't agree with that. I think there's probably room to send people too, and also, in the short term, it's just so much more practical not to send people, you wouldn't need life support and so on. So yeah, I do think it's totally acceptable. Of course it's acceptable.

Q: What would be the implications of using humans for space mining?

Rich: You mean digging up stuff and sending it to Earth?

A:(Yes)

Rich: Your question is what are the implications of humans doing it?

A:(Yes, for example would it be too dangerous, unethical to use humans…)

Rich: No. I mean, it's no more dangerous than mining in South Africa for goodness sake. I mean no, in quality, there are always people who are willing to take risks… and, society allows that. I think it's totally acceptable. It may not be cost effective… that's a different question… but for me there's no ethical issue. Let me clarify: I don't think there's anything uniquely, qualitatively more dangerous about outer space than about any other frontier. I mean when people went to the Wild West, the attrition rate wasn't so great. People got killed by disease, or by unfriendly natives. That's not a new phenomenon, right? I don't think there's anything wrong with it at all.

Q: What would be the implications of using robots instead of humans?

Rich: I think … for space mining? For space exploration it's a little different. For space mining, I think it's strictly economic. If the purpose of space mining is just to get the minerals, then it doesn't much matter. Just the same as the purpose of… I mean it seems the same as … between using machinery in a coal mine in Appalachia, versus using people, to my mind at least. I don't see a fundamental difference other than you know, it's a lot harder. A lot further.

Q: Do you think the funding we're allocating to the robotics section of NASA is sufficient?

Rich: I don't know what it is. How would I know?

Q: Do you think we're putting more emphasis on robotics or on manned space missions?

Rich: What would be my guess? I don't know. I don't follow NASA that closely.

Q: Do you have an opinion as to whether they should spend more on one or the other?

Rich: Now that's a different question. Whether they should… I think, I guess maybe an indirect answer, but I think the answer is they should spend more on robotics. But the reason I think that is, I think it's more important that we keep up the momentum on space exploration that we originally stated, the human only thing. I'm afraid that if we say human only, that will be equivalent to doing almost none. And so, if robotics will sort of help us sort of keep the momentum going, you know, visit more places, keep it going, then I think that that's sort of more important than some principal argument about how humans are more important, that they do it. That would be my concern.

Q: What would be the advantages and disadvantages of mining on the moon, or elsewhere from Earth?

Rich: Hmm… It's not a topic I've looked into in much detail. To be honest, I don't understand how it's economically feasible to do it at all. I just don't know what it is, or maybe I'm just ignorant, I mean, I apologize… but you know, what it is you would mine on the moon even, which is pretty much as close as you can get, right? That would be so valuable that it would be worth mining it there and getting it here. What are people talking about mining on the moon? I know being on the moon, you can do stuff in microgravity, and you can do stuff in high vacuum, you know, it's a special environment, I know, and the space station is too. But what are you actually going to dig up on the moon that's so valuable that it's worth sending back to Earth? I'm curious.

A:(Explanation of regolith and byproducts)

Rich: But is it valuable enough to send it back to Earth? Or would you just mine it on the moon for moon use?

A:(Explanation of potential uses of helium – 3; explanation of helium-3's scarcity on Earth and abundance on the moon)

Rich: Oh, I didn't know that.

A: So the original question was : What would be the advantages and disadvantages of mining on the moon, or elsewhere from Earth?

Rich: Oh, well, if it's a place to get something you can't get on Earth, that would be the advantage. To me it's just economic. I mean I just sort of… if there's something that actually is valuable enough, then that's the advantage of doing it.

Q: Do you think space mining would lay the groundwork for future operations? By NASA or others?

Rich: Absolutely. There's a huge kind of general, generalized engineering experience curve, that you get just be being there and doing things. You can't even predict it. You just get schooled in all the different various ways… let me put it this way: if you're not there, you're not going to learn anything. I think there's a huge experience effect.

Q: What do you think NASA's plans are, given the recent completion of the Regolith Excavation Challenge?

Rich: I have no idea.

Q: What would the impact of mastering nuclear fusion be, on society and on economy?

Rich: A fusion reaction?

A:(Yes)

Rich: Well it would depend on how cheap it was. The obvious answer to that is it would change the political balance tremendously… countries with oil under the sand would be going back to having sand. It would also help with greenhouse gases, emissions… it would be tremendously important. It's a big if. If there really was a causal link between getting more helium-3 and actually getting cost-effective fusion, then that would be a tremendous justification for spending more money for getting more regolith mined on the moon and sending back the helium-3. I mean it's a big if… plenty of people wouldn't agree with the implication there, that fusion really was that promising, but if it was, which I don't know the answer to, I'm not that kind of scientist, but if it was, then I think that it would be of monumental importance.

Q: Do you think that the moon should remain non-territorial?

Rich: That's a great question. That's a great question... you see the idealistic part of me says, "Oh yeah that sounds great, you know," and the realistic part says, "Humans have never done anything like that, why?". It even could be an impediment to development and efficient exploitation. Do you think we would exploit it? I mean we aren't kicking out any natives, not that I know of... I guess I don't feel strongly... I can't say that I feel strongly that the most important thing, being non-territorial, I can't honestly say I do. It seems sort of like the nice idealistic thing that everybody talks about like the Antarctic and so on... the Antarctic is a little different also, the Antarctic is sort of smaller and... I don't know... yeah I haven't thought about this... good question I don't know the answer. But I definitely wouldn't say absolutely yeah, I'm not so sure about that.

Q: What are your thoughts on the recent discovery of water on the moon?

Rich: I'm not sure what that really means, I have heard about it but I haven't really followed it closely. It's very interesting.

Q: Will there be any windfall given that discovery?

Rich: It's too early to tell. I'm not a lunar scientist but I could imagine... one dirty iceball hit there and just sort of stayed there and it could really indicate anything or it could be that there are thousands of them in which case it may be something, but it's still too early.

Q: Would you anticipate any future plans of NASA given that they have found water there?

Rich: Yeah, if I'm not mistaken that is a very big deal in terms of getting oxygen so yeah if it pans out I think it could make it a lot easier to put people up there, I believe so... I mean I'm not a lunar scientist but based on everyday knowledge that seems to make sense. Not to mention that we need both water and oxygen.

Q: What do you think is needed to build a working functional lunar base?

Rich: The main thing you need is lots of energy, secure and plentiful supply of energy because with energy you could cycle all kinds of things around. You could take oxygen to make carbon dioxide, and get the oxygen back. I mean you could do all kinds of cycles with a lot of energy, with some lossage. So I think that, with some solar cells or fusion—a lot of power. Enough power so that basically you are not limited by power. The second big thing I think is a way to make a stable biological ecosystem. I don't think you can live off of cans the whole time and rations. You actually have to have a stable plant system, even if you can make everything artificially you are going to have to figure out some way to have an environment that has more than just humans and tin cans in it. And they have done experiments with biospheres and so on, but I don't think we really figured it out yet.

Q: What about the ratio of robots vs. humans?

Rich: Psychologists will tell you that you need a certain size of population for it to be stable, but I don't think it is all that large. My research is about how to make robots companions to people—social robots.

Q: Do you think that successfully building a lunar base could be the starting point for more distant exploration?

Rich: So again, I'm a science-fiction reader, not a space scientist. There is this issue about having experience in the space environment which you get by being on the moon. So far as the logistics of low-Earth orbit vs moon, gravity wells and the economics of that which I know people who know stuff think about this. I just don't... I believe there is a huge sort of potential energy advantage to just basically basing everything off of the moon as opposed to even going in and out of low-Earth orbit but I'm not sure. So I suppose the short term answer I suspect is yes.

Q: With recent environmental concerns do you think it is reasonable to mine on the moon given the state of current conditions on Earth?

Rich: Yes.

Q: Should we spend the money to clean up the Earth before doing so?

Rich: No, I think that there is nothing wrong with mining on the moon. I don't think the problems that we have on Earth are an excuse to not look beyond. Simply put. There will always be problems, there will always be an excuse, then we'll never do it , wait til we have no problems it's like, "Yeah I'm going to get this done when I have time, well I never have time so it never gets done."

Q: Do you think we will need to exercise a certain amount of restraint when it comes to mining the moon?

Rich: Obviously there is some limit... well you know it is a good question I never thought of it that way. I am of two minds... one mind is: It's there, nobody lives there, no animals live there. Do we want to sort of chew it all up into little pieces and use it for something... that would be fine. Other than that you would literally change the tides as you literally wouldn't want to do that, but literally it's sort of just there to be used. That's what one part of me is saying. The other part is sort of saying: Well this whole stewardship issue... the answer is I don't know how to think about the rest of creation so to speak. Is it just there for our use or not? It's pretty clear with our Earth that we have a real stewardship to future generations, to the Gaia if you want to call it that. It is clear that you can't be rapacious with respect to the Earth, it's just a really bad idea that will come back and bite us ten times over. And maybe it is obvious to some people that we should think of the moon in the same way, because people used to think about the Earth—it's so big, the oceans you can just dump stuff in it and it wouldn't matter, well it does matter... we can actually screw up the Earth. I am conflicted on that question.

Q: Do you think we’re currently heading in the right direction with robotic technological advances?

Rich: Yeah. Yeah, I do. I mean, as I said I think we’re on the cusp of a lot of breakthroughs, I think there’s terrific research going on… absolutely. At all levels… mechanical, AI… all of the above.

Q: Will there come a point when that research will become unethical?

Rich: Well… when is research unethical? Well is there no limit? It’s not a simple question. Yes, there is a limit. the right answer is yes, of course there’s a limit. You know, making autonomous soldier robots that you couldn’t recall, and making them by the millions, really would be unethical. I mean, really stupid. So yes, of course there are limits. It’s a pretty wide question. Yes, there are limits.

Q: What exactly is your expertise with robotics?

Rich: Artificial intelligence, primarily. And human-robot interaction. That would cover it.

Q: What are you currently researching?

Rich: I’m currently researching human-robot interaction, generally. More specifically looking at non-verbal behaviors like nodding and shaking and eye-contact, that go on between a human and a robot that make the conversation and the collaboration be more natural.

Q: Do you have any final thoughts that you would like to add?

Rich: Nope. Good job with your questions.

Q: Any future predictions?

Rich: Not really. I sort of gave mine at the beginning, right?   Good luck on your project.

Thank you, and thanks for your time.

E. Professor Ciaraldi

Professor Ciaraldi declined to have the full transcript of his interview printed.

F. Professor Schachterle

Q. What do you think about the current state of robotics?

Schachterle: The only knowledge I have of the current state of robotics, which I am not at all involved in the profession, is the participation and creation of Robotics engineering program at WPI. And I have no opinions at all as to whether it is proceeding fast enough or slow enough. What I am curious about is what is going on, but I have no professional stake and certainly no... It would not be worth it to you for me to express an opinion on the question you ask because it would be worthless.

Q. How excessive is your knowledge of Robotic space mining? Do you know of any of the developments that have been occurring recently?

Schachterle: Not at all.

Q. Do you know of the Regolith space Challenge?

Schachterle: I am aware of the NASA regolith space challenge.

Q. Recently there has been discovery of water on the moon. Did you know of this?

Schachterle: Yes, I am aware of the discovery of water on the moon.

Q. What knowledge do you have of robotics as it is today?

Schachterle: I have a lay-person's idea of what goes on because I participated for 3 or 4 years in the development of the robotics engineering program. So I've heard mechanical engineers, electrical engineers, computer scientists all talk about how their three disciplines coming together enables us to create robots.

Q. But as far as the capabilities of machines today?

Schachterle: I have no real extensive knowledge of robotics.

Q. What do you think about robotic autonomy?

Schachterle: That is a good question. I am actually advising with Professor Rich, Chuck Rich, an IQP on ethics for the robotics profession and that certainly is one of the topics we are concerned about. I suspect it is inevitable because that is the way technology has always worked. That the autonomy of robots will automatically increase. I am less optimistic that those engineers designing increasingly more sophisticated autonomous robots will think through the ethical and safety situations associated with increasingly autonomous machines.

Q. So you are concerned that engineers are not taking a wide enough perspective on the implications that may arise?

Schachterle: I am concerned with the future. That the history of engineering has shown either that engineers have not put enough thought into the social and moral questions or, more tragically, if they have they have been overruled by the people who run the country. To my knowledge there are very few large scale high-tech companies that are run by engineers. There was a rare one that was started by an engineer but that person is no longer functioning as an engineer, rather a CEO. The people who are running the companies are concerned with creating new technologies to make more money. So there are too many examples that I am aware of in the history of science and technology of engineers trying to prevent what they would consider and many others would consider, often in debatable context, trying to prevent what they would consider to be the misuse of technology but being overruled by political or economical forces who, in our society, make the decisions. Engineers rarely make the highest level decisions, based on engineering choices.

A classic example was the decision to drop the atomic bomb on Japan. Most of the high level scientists and engineers did not want the bomb to used against an inhabited city. They wanted to convene a group of Japanese scientists, take them somewhere in the wastes of the Pacific, and explode a bomb and let them know how incredibly strong it was and let them realize how strong it was. They hoped that those experiments would make those scientists persuade their government to surrender. But President Truman had to make the choice in a shorter time frame than would have been possible for that demonstration bomb. So he had to make the decision and he decided to release the bombs on the cities, against the will of the scientists and engineers—the majority of them, though not all. Similar things can happen with robotics.

Q. So you are concerned that it may follow a similar, if not identical pattern?

Schachterle: The bottom line I am saying is that no matter how ethical engineers may be, we've got to realize that the chance that they will be able to make the final decision about the implementation of any very substantial technology is slight… because they are just cogs in a wheel. People turning the wheel are the politicians, generals, and the financiers. Who may or may not have taken an engineering course in their life.

Q. Do you think that sending robots into space instead of humans is reasonable, and/or ethical?

Schachterle: Absolutely. Let me reverse the question. I think sending humans into space to do things robots can do is incredibly stupid. Make the ten worst adjectives you could possibly think of and put them all down. It just turns my stomach to think that people would waste the time and money and the risk of sending human beings into space to do things robots could do. I think ultimately robots can do most if not all… I would certainly think robots would be as good miners as human beings.

Q. What about the adaptability of humans?

Schachterle: Well I mean something we always crow about-- with some reason about the value of having human beings, was Apollo 13, when they managed to get off the moon after the things failed. And people pointed out that robots probably could not have figured out how to duct tape everything together and save the mission.

Q. But robots would probably just have been sacrificed. We would not have even been concerned.

Schachterle: Precisely my point. Exactly. How much cheaper would the mission have been if your cone of protection was robots and not humans? I think that it would be an outrage to the people of the United States. I hope they would rise up in arms and arm themselves with every teabag in sight and storm every state capital and town hall if some idiot in the federal government decided to send human beings back to the moon or Mars instead of robots. Steve Weinburg in the *New York Review* said two weeks ago, that there would be no science to be learned from that—scientifically absolutely useless. What it would do is create favorable buzz and PR for NASA. But if that is the best NASA can do to get its favorable PR, then I am just as happy to get rid of NASA and turn everything over to some other organization that spends money far more efficiently and gets human beings out of space, where I think we presently do not belong and we never belong.

Q. If space mining were to become a more common practice do you think that it should be done by robots if they are capable?

Schachterle: Definitely. Even more strongly than robots not humans, *always robots, never humans*.

Q. So we should use robots to the greatest extent possible?

Schachterle: Yes.

Q. What knowledge do you have of the current funding space robotics is receiving?

Schachterle: I do not know.

Q. What do you think are the advantages and disadvantages of mining other possible moons or planets?

Schachterle: I have no idea what the economics are of getting the machines there and getting the products back. I mean the big unanswered question here is how much do we know about the value of minerals off planet vs. what we still have on Earth? Obviously we are not going to send a robot to Mars looking for oil. Obviously if there are rare minerals that are unavailable on Earth and are available on say the moon it might well be cost effective at some point in time to mine it there and ship it back. But that is extremely expensive—I mean the cost barrier of getting robots on site, and more expensive getting the products back to Earth, obviously has to be figured against the value of those materials with respect to their availability on Earth. What minerals are we talking about? What are we mining up there? What do we need to mine? What are the minerals we are running out of?

Q. What do you think of the lunar base?

Schachterle: I am against putting human beings on the moon.

Q. What do you think about the possibility of further planetary expansion stemming from the lunar base?

Schachterle: Yeah, it is a possibility, it is just stupid.

Q. Suppose the lunar base were only used as a refueling station for robotic probes and the like. Would you think it might then be worthwhile?

Schachterle: ONLY if the scientific or economic objectives of such an operation were carefully thought through and were beneficial. Just to do it for its own sake would be pointless. I have absolutely no interest as a human being and a taxpayer seeing someone else's science fiction ideas come true. None at all. I want payback. I want a health bill on this planet and I'm damned if some idiot who puts robots or human beings on the moon are going to run up our deficit so that we can't have universal health and China takes over our economy. What could be more obvious? The Chinese have all of our money, let them go to the moon. It'd be great for the Chinese to go to the moon. Not the robots but real Chinese, as many as possible, they have all our money let them use it on that. Then they would actually have to buy something for us for a change.

Q. What do you think of NASA's future plans for our moon, other moons and other planets? What are your thoughts on the amount of money we are spending there?

Schachterle: I have no idea what the money is but I would be opposed to spending one penny on anything that involved a human being going into space. I think we should terminate the space station, which is a toy. I am not aware of any scientific advancement that has come from the International Space Station. The best thing that can be said is that astronauts have kept the Hubble Spacecraft working.

Q. Are you against the Mars Rovers?

Schachterle: I am all for them. However there must be a scientific goal involved with it.

Q. What do you think would be the effects of mastering nuclear fusion?

Schachterle: Well, it could be very positive. I remember back when two frauds in Iowa said that they had achieved tabletop room temperature fusion. You know, for about six hours the world was in euphoria. So yeah if we could get a safe fusion system… my impression is that nobody anticipated the extent of highly toxic byproducts that exist from fission reactors. And essentially in twenty years had not had the political guts to decide where all the tons and tons and tons and tons of radioactive wastes are going to go. Now my impression is that fusion reactors do not cause as much collateral damage in terms of creating nasty radioactive byproducts with tens and thousands of years of half-life. That certainly would be a good thing for the world.

Q. Would you support the use of Helium-3, which is a byproduct of processing lunar regolith?

Schachterle: Yes.

Q. What is your knowledge of mining techniques such as strip mining? What do you think is an acceptable level of mining on the moon?

Schachterle: Yeah, that's a good question. We have no human beings on the moon. So there is going to be no environmental contamination to affect them. I mean the moon as far we know is organically dead—as far as we know. I mean the recent discovery of water may alter that so I would hate to see any mining operation interfere with the discovery and then contamination of any organic molecules—even if they are just fragments of what could be life or alive themselves. I have no problems at all with any kind of manipulation of the lunar surface for the sake of either scientific discovery or to bring back to Earth minerals or ions like Helium that we could use so long as we don't upset whatever ecology exists on the moon. There may be none whatsoever, it may be totally dead if that is not known. So one would need to know, be absolutely certain that there are no life forms on the moon before you start messing with the ecology that could destroy it.

Q. Do you think if we were to find the same minerals/materials on another planet/moon that could also be found on Earth would it be better to dig there instead of Earth?

Schachterle: If it is cost effective, sure.

Q. If the mining of the moon were to change its orbit and therefore affect our ecosystem would it be a cause for concern?

Schachterle: Well only if being dead is a cause for concern. If we are not worried about that then go to it.

Q. What is your opinion of robotic advancement with respect to efficiency vs. safety?

Schachterle: Safety comes first. Safety would always trump efficiency. I don't believe in failsafe technologies but it is the responsibility of the engineers and their corporate managers and legal offices and their PR people and their stockholders to make any products as safe as they possibly can.

Q. What are the implications that come along with the advancement of robotic technology?

Schachterle: Any kind of technology needs to be thought through in terms of social consequences. It has been a dream for a hundred years that we would discover some source of energy so abundant that nobody would bother to meter it because it would be so cheap. It would be free. But it hasn't happened. If an energy source came in that became an extremely effective competitor to existing energy sources, obviously a heck of a lot of people, most of them being in areas where liberal academics like me don't like them, like the coal companies etc. are going to go out of business. I think it is going to be a wrenching social experience not only for the workers dependent on those jobs but for all the people down the supply chain and for the shareholders of those companies as well.

Q. Do you think a discovery like free power would be constructive or destructive?

Schachterle: I think it would be constructive more than destructive because it would reduce or eliminate the competition over increasingly scarce natural resources. The geniuses who decided that we should conquer Iraq and secure their oil for our own uses would not have found the Iraqi oil fields so attractive had a much cheaper source of energy been available which would have rendered oil worthless... oil is too valuable to burn for energy, there are other uses of oil like making plastics where it still has a significant part. So if we were to have a much cheaper source of energy then we would reduce the competition for scarcer sources, enabling us to use those sources in more efficient ways.