Table 2.6. Summary of Technological Rationale

Rationale for Going	Arguments Against Going	Responses
Direct Technology Transfer • Enable Deep Space missions • Lunar Enabled Technologies	Technological Opportunity Cost • Distracts human capital from other pressing issues	There are other places that have less societal impact than space from which to redistribute funding.
Spin-off Technology • Health and Medicine • Transportation • Public Safety • Consumer Goods • Energy and Environment • Information Technology • Industrial Productivity	Use of space technology for potentially violent/destructive purposes	Any development can be misused, so the answer is not to refuse to innovate but to properly regulate.

2.3 Scientific Rationale

This section will build on Section 2.2 by discussing the scientific gains to be made through lunar missions and the development of a lunar settlement. While there is vast amounts of crossover between technology and science, there is a greater focus on the acquisition of knowledge in this section. The reasons that a lunar settlement may be undesirable are focused on the scientific barriers to building habitats on the Moon, and the responses to the critiques highlight the opportunities that scientific missions on the Moon provide, despite the difficulties of the lunar environment.

2.3.1 Scientific Rationale for Going

2.3.1.1 Scientific discoveries

Lunar Geology

Little is known about the inner structure of the Moon, the remnants of its magma oceans, or its craters. A lunar base would allow for an in depth study of lunar features, which remain untarnished by external factors that could prevent scientists from discerning the formation history on Earth, such as the wind, rain, tides, and tectonic movement. Examining lunar features could be the key to understanding how our solar system and planet Earth formed. For example, understanding the craters on the Moon helps to accurately determine the Moon's age, as well as the cosmological events that were happening at each stage of its life, in terms of prevalence of impact events (Jaumann, et al., 2012).

Development of lunar-based astronomy

The lunar environment has many specific attributes that make it attractive for astronomy: the near-vacuum, thin atmosphere, orbital stability, two-week long nights, and abundant surface area create an ideal environment for conducting astronomical studies (Burns, 1995). It is possible to use unique thermal conditions of the lunar south pole and the radio silent lunar far side to conduct astronomy research that would otherwise be difficult with Earth's radio interference, specifically infrared and radio astronomy.

Constructing telescopes on the Moon would allow for astronomers to peer deeper into the past to study the earliest stars and galaxies in order to gain a greater understanding of the universe as a whole.

Development of lunar medicine and biology

Changes in gravity environments, from Earth, to space, to the Moon, have effects on human physiology, which includes impacts on the neuro-vestibular, cardiovascular, musculoskeletal, and vision systems (Benaroya, 2018). In addition, to this hypogravity environment, space radiation negatively affects the shielding mechanisms of spacesuits and spacecrafts, which exposes the astronauts to even greater risk of overexposure to radiation (Aimone, et al., 2014). Therefore, the establishment of a long-standing lunar base with constant human presence may have an impact on the development of advanced medical care and life support systems to protect astronauts from the harsh lunar environment. Prolonging space flight time on the lunar base may increase the risk of pathological, traumatic, or other health related events, which will require applying and furthering the existing knowledge gained from ISS missions. The lunar medical and biological knowledge required for deep space exploration could lead to breakthroughs for medicine on Earth, especially medical care in extreme or remote environments.

Additionally, biological knowledge about how to grow plants, microbes, etc., is likely to develop in tandem with a lunar settlement. The lunar surface micro-ecosphere carried out by Chinese Chang'e 4 mission, shown below in Figure 2.2, is a good example of the advancements already taking place. If the experiment is successful, it will lay the foundation for human beings to generate their own food on other celestial bodies (Shen, 2018).

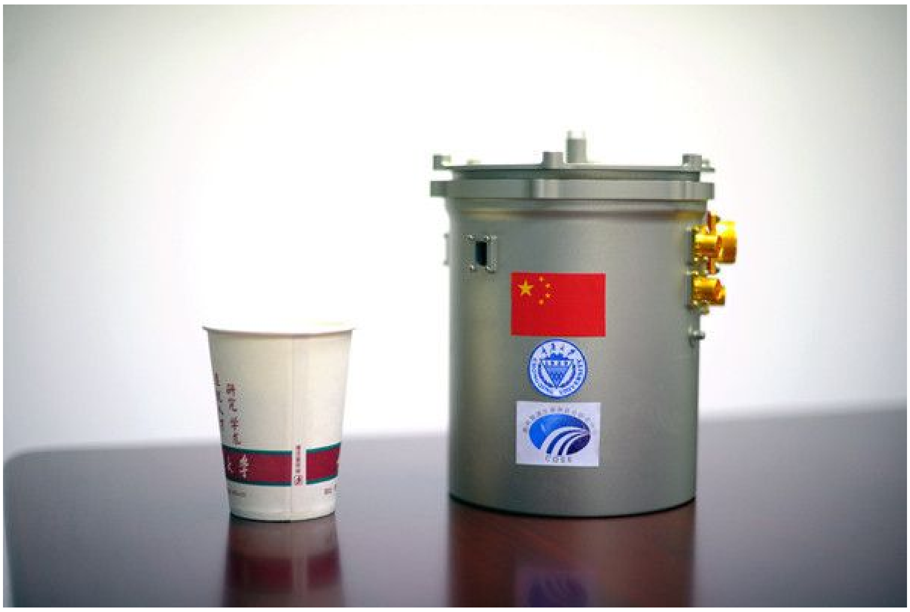

Figure 2.2. Chang'e mission lunar surface micro ecosphere (Shen, 2018)

2.3.1.2 Benefits of Further and Future Space Exploration

The Moon as a training ground for future missions

Missions to Mars, or other places in our solar system are difficult and dangerous. Therefore, it is important to give the astronauts the best training possible before sending them into deep space (Whatculture, 2016). Currently, astronaut training on Earth is undertaken using the best approximations of deep space conditions, but it is still hard to duplicate the exact off-earth environment (Whatculture, 2016). Compared with such places as the Mojave Desert, the Moon would be a more suitable analog for a Martian environment because of the similarity of the hypogravity environment and necessity of protection from the external environment. Training the astronauts in the lunar environment before going further into space would increase the probability of success (Whatculture, 2016).

The Moon as a stopping point

A lunar base would make the Moon a useful intermediate stop on the way to anywhere else in space. The Moon's smaller size, lower mass and resulting lower gravity, bring the escape velocity down to 2.38 km/s meaning less fuel is needed for launch (Whatculture, 2016; NASA, 2017b). Space agencies or commercial companies can store fuel on a Moon base in advance or derive the material from the lunar surface, which facilitates easier access to deep space. In addition, supplies could also be stored on the Moon in advance for longer missions.

2.3.2 Scientific Arguments Against Going and Responses

2.3.2.1 Lunar environment is not suitable for human survival

The Moon lacks an atmosphere that can support human survival, there is no evidence of liquid water being present, and the excess radiation exposure due to the lack of a lunar magnetosphere is harmful to human health. Last but not least, the broad lunar temperature difference can be hundreds of degrees Celsius, which is a great challenge to both humans and spacecrafts (Seybold, 1995).

However, considering the lack of nearby options in the solar system, the Moon actually represents a fairly benign place to settle compared to the extreme heat of Venus or the distance of Mars. Establishing a lunar base would allow humanity to devise ways to survive in less than ideal places on Earth, elsewhere in the solar system. Closed-Loop Life Support System (CLLSS) techniques are becoming more and more de there is evidence that abundant polar ice exists on the Moon, which may be a solution to water supply, and techniques such as 3D printing, in-orbit manufacturing, and in situ resource utilization (ISRU) will enable means to build a settlement on the Moon that will protect humans from the lunar environment (Noreen, 2007).

2.3.2.2 Lunar dust is dangerous for exploration

Apollo 11 astronauts were surprised at the very strong electrostatic adhesive forces of lunar dust (Sharp, 2017). This resulted in diverse problems, such as scientific instruments destroyed by overheating, opaque dust clouds which made lunar capsule descent maneuvers dangerous, threadbare spacesuits, and dust-related health hazards. However, this is not an insurmountable challenge.

When the Apollo astronauts went to the Moon, they had no idea what to expect regarding the dust on the surface.

Now that the properties of lunar dust are better understood, new technologies can be designed to equip the next generation of settlers, spacesuits, and lunar equipment for the dusty environment (Sharp, 2017). Additionally, scientific exploration using robotics is a good alternative to human Moon landing for the first stages of lunar settlement, especially considering the harshness of the lunar environment mentioned here and in Section 2.3.2.1 above. In the past robots were mainly used for scientific research, but in future missions they will perform a broad spectrum of tasks, varying from assembly, maintenance and construction, to surface mining of celestial bodies.

As an alternative, interfaces between robots and human could be a middle ground. Distributed robotic collaboration and coordination interaction technologies should limit the demand for crew time during missions, and improve safety and efficiency, which directly corresponds to Goal 8: Health and Safety in the Lunar Sustainability Goals. More discussed of the transition between robotic missions and human settlement can be found below in the Roadmap Section.

2.3.2.3 Scientific opportunity cost

There are two major arguments surrounding the scientific opportunity cost of a lunar mission. First, searching for life is one of the main areas of current scientific research, however, the Moon is not a compelling place to search for life, which undermines the focus on using the Moon for exploration that could be done where life may exist (e.g., Mars). Second, it is incredibly difficult to derive conclusive results from lunar surface studies due to the difficulty of testing in the environment. There is plenty to discover on Earth, so the focus should be on studying Earth's understudied regions, like the oceans.

To address the scientific opportunity cost, which asks, "why not go to Mars instead of the Moon," there are significant discoveries to be made on the Moon, including the formation history of the Moon and the cosmological events that occurred during the early years of the solar system. Additionally, going to the Moon is a necessary step for humans to take in order to reach Mars more efficiently, and to make the most of scientific studies on the Martian surface upon arrival. For example, the studies done on the Moon will help to better understand the Martian environment, especially with regard to the sample collection and return protocols. Moreover, the lunar scientific experiments may help attract interest from the public and decision makers, which will be necessary for obtaining funding for future missions to Mars. The proximity of the Moon allows for its use as a proof of concept for deep space human habitation, and settling the Moon is the first step in developing the technology required to expand the influence of humanity outside of the Earth-Moon neighborhood of the solar system (Whatculture, 2016).

To address the scientific opportunity cost, which asks, "why explore the oceans here on Earth instead of going to the Moon", in principle, Moon exploration neither contradicts with ocean exploration, nor any other kind of exploration on Earth's surface. However, there are difficulties and risks inherent in exploration. Due to the unknowns associated with exploration, it is impossible to exactly predict the potential value of the yielded science. Therefore, both sides should be taken into account, if possible, rather than subjectively assuming which is more valuable and more worth exploring. Additionally, the technologies developed for exploration in harsh environments like the lunar surface may aid future exploration in hard to reach places on Earth, as described in Section 2.2.1.3 above.

2.3.3 Scientific Rationale Summary

The Moon is a compelling science case, as discovering more about lunar geology and geophysics will allow us to understand the events that shaped the formation of our solar system. The Moon also constitutes a prime location from which to conduct scientific research in astronomy, hypogravity medicine, biology, and other fields. While the lunar environment itself poses exploration challenges, the development of new technologies and techniques to combat the harsh lunar environment will prepare space actors for the next steps of deep space exploration. The rationales discussed above are summarized below in Table 2.7.

Table 2.7. Summary of Scientific Rationale

Rationale for Going	Arguments Against Going	Responses
Scientific Discoveries ● Geology ● Astronomy ● Medicine/Biology	Lunar environment is hostile to humans	Establishment of a lunar base will significantly reduce risk to human visitors.
	Lunar dust poses huge exploration challenges	Use hardened robots to complete the majority of exploratory missions, and develop technology that can withstand the challenges of lunar dust.
Using the Moon as a stepping stone for deep space exploration	Scientific opportunity cost: ● Lunar experiments have low conclusivity. ● Multitudes of other relevant missions on Earth.	Scientific opportunity: ● In order to graduate to deep space missions, an intermediate step is needed. ● In principle there is no reason that scientific exploration should be restricted to one major mission.

2.4 Cultural Rationale

Cultural rationales for going to the Moon are often weaved into the speeches of leaders like President Kennedy or Jan Woerner, but are very rarely addressed directly. Appeals to the sense of "exploration," "international cooperation," or "achieving the impossible" are all inherently cultural. Yet, they are often the most motivating factors for the general public in regard to space exploration, as opposed to the more concrete economic, technological, or scientific rationales. This section will assess the cultural reasons for returning to the Moon, and, as with previous sections, also discuss the cultural reasons to stay on Earth.

2.4.1 Cultural Rationale for Going

2.4.1.1 Promotion of a culture of exploration

When humans first stepped foot on the Moon, a generation of aspiring scientists were inspired to take humanity further into the depths of the unknown than ever before. There was a significant boom in technology education, and people who were greatly motivated by accomplishments of the Space Race (Chaikin, 2007). The subsequent generation was left bereft by the cancellation of Apollo and are thus referred to as the "Orphans of Apollo." However, returning to the Moon and establishing a continuing lunar program could inspire current and future generations to develop new technologies and promote science as a meaningful and impactful field in which to study and work.