LUNAR ROBOTICS 7th GRADE CURRICULUM

Interactive Qualifying Project Report submitted in partial fulfillment of the degree of Bachelor of Science

Worcester Polytechnic Institute

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Abstract

This Interdisciplinary Qualifying Project designed a curriculum to expose students to an engineering process, in 7th grade classrooms of Worcester Public Schools. It is set up to mimic the basic curriculum structure at Worcester Polytechnic Institute, culminating in a hands-on project to apply what the students have learned. The engineering challenge is framed in the context of a proposed lunar colony. The curriculum focuses on teaching students about lunar exploration and basic concepts of modern robotics.
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**Introduction**

Science and technology are integral parts of a young student’s education. Without early exposure to these disciplines, students may not develop basic understandings of scientific concepts, which can help develop problem-solving skills. There are a few problems when trying to get students to truly understand a scientific or engineering process. Many science classes simply teach facts, their curriculums mainly based upon memorization of these facts. With such repetition it can be hard to keep students interested and have them truly understand the core concepts and methods that they need to comprehend in order to be successful in their academic careers.

In recent years, Worcester Polytechnic Institute has worked with Worcester Public Schools to create curriculums to diversify and enhance some of the elementary and middle school programs. Projects have been completed working to incorporate ideas and concepts from the existing curricula in elementary and middle schools. As a kind of hook for interest in both newly advancing technology and a new way to incorporate aspects of the existing curriculum, the overall theme of the projects has been application of science and technology to a potential lunar colony. Projects have focused on areas such as biology, energy, and astronomy in various grade levels. This project is a focused curriculum to teach an engineering process, specifically about engineering compromises, to a 7th grade class. Applying this concept to a lunar colony, the curriculum incorporates a brief history of lunar exploration, and focused sections on the lunar environment, modern robotic technology, and powering a robotic workforce throughout the colony. Taking inspiration from the structure of many courses at WPI, the sections of the curriculum will culminate in a capstone project. This project, a hands-on exercise using a
LEGO® Mindstorms® kit, is briefly described in the LEGO® Mindstorms® Design Challenge section later in this report.

As a guideline for the design of the curriculum we had an unofficial Pre-Qualifying Project reading assignment from the book *Understanding By Design* by Grant Wiggins and Jay McTighe. With the help of this book we were able to figure out how to begin our starting point for the curriculum. The summarized reading assignment notes taken by each group member can be found in the appendix under the section of PQP. In addition the curriculum was designed with guidance from Mr. Donald Brown who is a science teacher with the Forest Grove Middle School in Worcester.
Moon Environment

Building a curriculum was very challenging for Assaad, but the project idea “Robots on the Moon” was very interesting also, especially since Assaad loves space and always wanted to learn about it. The project went very smoothly, the teacher was very helpful, and, most importantly, partners were always respectful and got work done on time. Since we were designing a curriculum for a seventh grade class, we decided to go and meet with a teacher at the Worcester Public Schools by the name of Donald Brown (Mr. Brown). We asked him to describe the students’ knowledge level especially in Math and Science, then we talked with him about what he would like to see in this curriculum and what he expects. Also, Mr. Brown gave us the opportunity to meet with some of the students who are interested in robots and space. The students told us what they already know about it, and then we had the opportunity to ask them some questions that helped us to find their interests.

Thus, based on the information we got from both the students and the teacher, we decided to build our curriculum for four weeks long. From that we split the project for four parts. Assaad was in charge of the Moon Environment, Nick was in charge of the introduction and the benefits of a Lunar Base, Ben was in charge of the robots’ design, and Mitchell was in charge of power plants.

The Moon environment part was very interesting for Assaad. The Moon environment was compared to the Earth environment, which helps students have a better understanding of the difference. For example in one slide the size and motion of the Moon is compared to the Earth (Moon is about 1/4 the diameter of the Earth), and as result gravity changes, mass, temperature, and many other things are presented. In addition there is a section that talks about the radiation
and its risks. For example, what effects can the radiation cause on the human being, and what are the procedures to avoid it and save the astronauts.
Robots

Mechanical Aspect

This was a very challenging part of the curriculum to develop. This is because it has to cover many of the parts of the curriculum’s design goals. It has to get the students to think like engineers and discuss real-world tradeoffs. It has to introduce the robots and explain what they do. And finally, it must explain how robots on a lunar base could function.

In order to accomplish these goals, we split this section of the curriculum into three distinct, discussion-based lesson plans. The decision not to make heavy, fact-based lectures was based on a number of reasons. The primary reason was that students would be getting many facts and figures from other sections of the course; also the goal of getting students to think fluidly and consider varying ideas is better suited to discussion than lecture.

Facts for this section were also especially hard. This is because unlike other sections (the lunar exploration, the Moon, and power generation) it is the only section that largely hinges on experimental or theoretical technologies. As such, a lecture would be hard to deliver, since the teacher would constantly have to preface every line with, “as far as we can predict…” or a similar caveat.

The robots curriculum section was split into three days of teaching, each with its own goals. The goal of the first day was to introduce the concept of robots and explain how robots could be used on a lunar base. The second day was there to present a sample engineering
problem and discuss tradeoffs in design. The third day presented a number of challenges related to robotics on the Moon, and showed why existing lunar rovers were built as they were.

**Energy Sources**

If there is anything that has the utmost importance in designing a robot, it is having the robot powered at all times. The purpose of this section is to focus getting students to start thinking about methods to keeping the lunar robot alive, and for this reason it is important to get students to think about what resources are available to the robot on the lunar surface. Two specific ways of powering the robot are by either a physical or wireless connection, which can be further specified as either direct power from lunar base or wireless power using solar panels. These two energy sources will be the main sources for the robots, since the robots will either work within the base, around the base, or outside the base (where solar power would become the main source of power).

The next concept that students should be aware of is methods for delivering power to the robots, and for this we have the concept of robots that are directly powered by the base, which can be achieved using wires for robots that are fixed in one spot inside the base, and battery-powered robots that use recharging stations for free movement. Another idea that might be feasible is having tracks running across the ceilings of the lunar base where robots that have specific tasks can run across and also receive direct power from the base. This idea works better on the Moon than on Earth if you consider the difference in gravity discussed in the Moon Environment section. For robots working around the base there is the idea of delivering power using direct power lines for robots around the base, or additional recharging stations for battery-powered robots. There will also be the situation where robots assigned to excavation and resource delivery/development might not be able to access power directly from the base or have
the opportunity to recharge, which is where the idea of wireless power comes in. Robots assigned to time-consuming tasks on the Moon surface can have solar panels installed on top of them as a means of recharging their batteries, and thus become independent of the lunar base and have a higher level of freedom.

Continuing with the situation of robots that cannot be directly powered or recharged by the lunar base, we developed two other ideas as a fallback for the extreme situation that not even solar power was accessible as a means of keeping the robot recharged. The first idea came as a means of wireless power in which microwaves can be transmitted from the base to the robots using a microwave receiver and transmitter to recharge the batteries of the robots [Ishiba]. Because of the frequency microwaves operate in (lower than infrared and visible light), microwave power can be delivered across good distances, and considering that there is no atmosphere in the Moon, there are very few obstacles that can affect the microwaves (one of those exceptions being the lunar surface itself of course). The second idea was specifically aimed at assisting robots that focus on excavation or other tasks that require a large robot to work in one area for many hours without sunlight or direct power. The idea was having smaller robots around the base docked at recharging stations. These smaller robots would replace the batteries of the larger robots with charged batteries, while taking the nearly discharged battery back to the recharge station to prepare for the next swap. The large robot would have to have at least two battery packs with hot-swappable features (can be removed without causing system errors) in order to not be disturbed from its task. This idea is introduced in the slides found in the Appendix and further discussed in the PowerPoint follow-ups (also Appendix).

The next important subject relating to powering the robots is how to distribute power to robots that are assigned to exploration and off-site projects. Robots assigned to these tasks must
run independently from the base either using solar power, access points that might be using microwave power, or any other feasible means of powering robots using an access point. We have also developed sample homework questions, in which one of the questions addresses the issue of a scenario where a robot is running out of batteries yet the Moon base is too far to connect to a recharging station.

The final subject we addressed was the idea of protecting the internal systems of the robot. Due to the fact that detailed discussion about the circuitry of the robot and any other electrical concerns would be outside the scope of this course very little is discussed about this in the slides. Basically this part of the section just wants students to be aware of the fact that radiation can affect the electrical system within the robot, and for this it is important to keep in mind that special shielding must be used to protect the robot from this hazard. Some examples of radiation that can affect the robot are the radiation accumulated on the lunar surface, and also proton storms that come as a result of solar flares. Another issue that is not mentioned in the slides for this section, but is mentioned slightly in the robot section of this curriculum is that regolith (“Moon dust”) can enter inside the robot if it is not properly sealed, and disturb the electrical and mechanical components. This is similar to how dust on Earth disrupts electrical devices by blocking vents, creating short circuits and other such hazards.
Class PowerPoint Slides Follow-ups

Introduction

The introduction section of the curriculum is a fairly short, relevant introduction to the history of lunar exploration and travel. It briefly describes the initial programs undertaken by the Soviet and American space programs, up to current and some future technology relevant to a proposed lunar base. The introduction’s contents are focused more on a brief history of technology relative to a lunar base, specifically technologies applicable to robotics.

History of lunar exploration does not have any immediately visible relevance to an engineering challenge dealing with robotics on a distant future lunar base. The section of the introduction dealing with the Soviet and American missions put increased focus on the transportation of equipment or astronauts across the lunar surface. To help broaden the intellectual spectrum, equal emphasis is put on both the Soviet and American space programs.

The Soviet Zond and Luna missions sent the first unmanned probes to the Moon; Luna-17 put the first remote controlled robot on an alien surface. Called the Lunokhod, this unmanned robot was the very first machine with any applicable robotic technology, the predecessor of any robots that would find their way to the Moon or any other celestial body. Since it was completely autonomous, all of its major technological features were described in the PowerPoint and lesson outline. The Lunokhod had a number of relevant technological advancements and was powered by on-board batteries charged by solar cells. It used a radioisotope heater to keep its components at operating temperature, and a fluoride based lubricant to help it operate within a vacuum. Of specific note is the way the probe moved across the lunar surface, as it would be relevant to the capstone design challenge at the end of the curriculum. It used eight independently powered wheels on wire frames to navigate over the lunar regolith.
In keeping with the nature of different approaches to similar engineering problems, the next section of the introduction describes the famous Lunar Roving Vehicle (LRV) used by the Apollo missions. While not directly comparing the LRV to the Lunokhod, considering their different applications, similar traits of the two machines are described. Students should be guided to notice the similarities and differences between the two. The LRV, like the Lunokhod, had independently powered wheels driven by electric motors. Its tires were made from woven zinc coated steel strands, with titanium chevron treads with an inner bump stop frame to protect the hubs. It was steered by two additional motors, and powered by two 36-volt non-rechargeable batteries. For navigation, the LRV used directional gyros and an odometer, combined with a primitive computer, to keep track of the LRV’s direction and distance from the Landing Module.

The final roving vehicle described is the current technology available, and is a great advancement over the rovers of the 1960s and ‘70s. The Space Exploration Vehicle (SEV) has more in common with a self-enclosed space capsule than a rover. The main advantage of its inclusion in the segment is to show how far technology has come, and show what can be accomplished with different engineering and combinations of ideas. The SEV combines many of the aspects of both space capsules and rovers. Having the same style of independently powered wheels that can each pivot 360 degrees, the SEV can support multiple astronauts for up to two weeks and allows for multiple external attachments for optimum versatility. Both a traditional airlock and a spacesuit port accomplish entering and exiting. To get the students into the mindset of an engineering challenge, one of the sample homework questions provided asks the students to draw their own version of a lunar rover based on the designs of the rovers they have previously seen in the curriculum.
An effective way for students to understand what they are learning is to put it into a specific context that can be easily visualized, and therefore more easily remembered. The students then associate the information with a problem instead of simply trying to remember the information in its own right, which can be much more difficult. The current state of the United States’ space program is relatively unstable, with little research currently being done to advance any kind of manned extraterrestrial exploration. There seems to be a lack of interest from both the government and the general public. To address the “why would this matter?” question, the final slides of the introductory section of the curriculum highlight the advantages of establishing a permanent base on the Moon. They put the introduction in context of modern technology and aspirations, and establish the idea of a permanent lunar base as a starting point for the rest of the curriculum. Three main types of applications are discussed: research, economics, and further exploration. The research and economic benefits directly address and establish a few challenges and benefits of the environment on the Moon itself. Research can be done over long periods of time in low gravity, there is no atmosphere to skew electromagnetic and optic telescopes, which would also have a much more stable platform than an orbiting telescope, and there are minerals found in the regolith that could be important to advancing technology but are not found in sizable quantities on Earth. As a final practical advantage of a lunar base, it is described as a jumping-off point for future missions and technology. Touching upon housing and life support for the lunar colonists, the Moon is proposed as a staging area for technology to be used on other deep space missions, such as a future colony on Mars.

The introduction section of the curriculum does not go into an extravagant amount of detail, doing well to remember its audience. It does, however, attempt to keep the students interested, and pique their interest level. It does as every good introduction should, give the
audience an idea of what is to come, and draw them in to initial understanding of what they will see in later parts of the curriculum.

**Moon Environment**

On the Moon, many of the things that can kill you are invisible: void vacuum, extreme temperatures and space radiation are a few those things.

**Physical characteristics**

Characteristics of the Moon include its distance from the Earth, size, mass, density, and temperature.

**Distance:**

The Moon is approximately 384,400 km (239,000 miles) from the Earth. A radio signal from the Earth, bounced off the Moon's surface and back to Earth would take approximately 2 seconds. Communications with an astronaut on the Moon would take a several second pause between a question and an answer.

**Size:**

The diameter of the Moon is 3479 kilometers (2162 miles). This is about 1/4 the diameter of the Earth (12,756 kilometers or 7,926 miles).

**Mass:**

The mass of the Moon is 7.35*10^22 kilograms, which is about 1/80 of the mass of the Earth.

**Density:**

The density of the Moon is 3340 kg/m^3.

**Density problem:**

Can you calculate the density of the Moon?
Density \( (d) = \text{Mass} \ (m) \ \text{divided by Volume} \ (V), \ d = \frac{m}{V}. \)

The volume of a sphere = \( \frac{4}{3} \) times \( \pi \) times its radius cubed, \( V = \left( \frac{4}{3} \right) \pi r^3. \)

**Temperature:**

The average temperature on the surface of the Moon during the day is 107°C. That is hot enough to boil water on the Earth. During the night, the average temperature drops to −153°C.

**Motion:**

The Moon rotates around the Earth in an elliptical orbit every 27.3 days. The same side of the Moon always faces the Earth. Due to the angle of the Sun on the Moon, we see different portions (sides) of Moon illuminated. These are called the phases of the Moon.

**Gravity:**

Because of its smaller size and mass, the gravity of the Moon is about \( \frac{1}{6} \) the gravity on the Earth \( (g = 9.81 \text{ m/s}^2). \) That means that a person who weighs 180 pounds on Earth would only weigh 30 pounds, if measured on the Moon. That is why when the astronauts were on the Moon, they were able to jump so high, even with the heavy space suit.

**Temperature:**

The temperature of the Moon can go down to -153°C during the night, while in the day the temperature rises to 107°C. Why does the Moon’s temperature vary so widely? It happens because the Moon doesn’t have an atmosphere like the Earth. Here on Earth, the atmosphere acts like a blanket, trapping heat. Sunlight passes through the atmosphere, and warms up the ground. The energy is emitted by the ground as infrared radiation, but it can’t escape through the atmosphere again easily so the planet warms up. Another reason to worry about the temperature on Moon is that the Moon takes 27 days to rotate once on its axis. So any place on the surface of
the Moon experiences about 13 days of sunlight, followed by 13 days of darkness. After the Sun would go down and it gets dark, and the temperature would drop 250 degrees in just a moment.

Obviously, the temperature is a real problem to the astronauts or even robots that are going to live, work, and accomplish missions on the Moon. Scientists have already designed spacesuits that are heavily insulated with layers of fabric and then covered with reflective outer layers. This minimizes the temperature differences between when the astronaut is in the sunlight and when in shade. Space suits also have internal heaters and cooling systems, and liquid heat exchange pumps that remove excess heat. Also, there are craters around the north and south poles of the Moon, which are bathed in complete shadow, and never see sunlight. These places would always be as cool as -153°C. Similarly, there are nearby mountain peaks which are bathed in continuous sunlight, and would always be hot.

**Moon Craters:**

The picture in slide 21 shows you a bad site for landing, robot transportation, or even a Moon base.

In 1978, Chuck Wood and Leif Andersson of the Lunar & Planetary Lab devised a system of categorization of lunar impact craters. They used a sampling of craters that were relatively unmodified by subsequent impacts, and then grouped the results into four broad categories. The lunar impact craters (LPC) types were as displayed in slide 22. The shapes can be described as…

- Small
- Cup-shaped
- Having a diameter of about 10 km or less
- No central floor.
Similar to the picture displayed in slide 22 is the crater pictured in slide 23 where the interior floor is wide and flat with no central peak. The inner walls are not terraced, and the diameter is normally in the range of 15–25 km. Craters similar to the ones in slide 24 are complex craters large enough so that their inner walls have slumped to the floor. They can range in size from 15–50 km in diameter.

Slide 25 shows craters that are larger than 50 km, with terraced inner walls and relatively flat floors. They frequently have large central peak formations as displayed in slide 26. A Moon crater can stay virtually intact (as it is) for millions or even billions of years because the Moon does not have dynamic bodies of water on its surface. Damages or distortions to such craters cannot be caused by erosion. The oldest craters are found to be over 2 billion years old. In addition to that, the Moon also does not have active tectonic activities. Thus, alterations to the Moon’s surface, like those that have formed the Earth’s mountain ranges, trenches, and continents, cannot occur. The relative ages of Moon craters can be roughly determined by comparing the number of craters in them. If a crater is very old, naturally, more recent impacts will form craters inside them.

**Radiation**

Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves, and particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), while other forms like x-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment. Radiation can be either non-ionizing (low energy) or ionizing (high energy). Ionizing radiation consists of particles or photons that have enough energy to ionize an atom or molecule by completely removing an electron from its orbit, thus creating a more positively charged atom. Less energetic non-ionizing radiation does
not have enough energy to remove electrons from the material it traverses. Slide 30 gives a good example of this.

People in low Earth orbit receive protection from the Earth's magnetic field, which shields out some of the heavier subatomic particles that stream in from space. These cosmic rays are energetic and dangerous to life. Go beyond this region of space, and this natural protection disappears. The Moon itself has essentially no magnetic field, and no atmosphere. There is little to stop the barrage of particles and rays that stream in from the Sun and beyond.

The surface of the Moon is badly exposed to cosmic rays and solar flares, and some of that radiation is very hard to stop with shielding. Furthermore, when cosmic rays hit the ground, they produce a dangerous spray of secondary particles right at your feet. All this radiation penetrating human flesh can damage DNA, boosting the risk of cancer and other maladies. The picture in slide 27 shows you the bright spots on the surface of the Moon exposed to space radiation.

For people to live and work on the Moon safely, the radiation problem must be solved. A short mission to the Moon will be survivable for astronauts, mainly because exposure times will be low. Astronauts staying for longer periods will need shielding, to guard against the long-term effects of exposure. The thin walls of spacecraft will not be enough. Bases on the Moon will probably need to be underground or at least covered with a layer of regolith. Radiations that are coming from the Moon’s surface can be solved and stopped by the special space suits or even the thin walls of the spacecraft. Also, astronauts will need radiation sensors placed on the surface, and at different regions, to assess the full nature of the Moon's radiation environment.

Radiation from the lunar soil wasn’t even the actual or the serious problem, the most critical challenge will come when astronauts face the fury of a large solar flare while on the
Moon. Radiation levels can increase enormously, and fatal doses can be absorbed by unprotected astronauts within minutes. At least one part of a lunar base will need to be equipped as a radiation shelter, to protect against the most extreme radiation events. Shielding will be thicker, and provisions will be made for stays of several hours or days.

Being prepared for a radiation storm is just half of the solution. Astronauts will need an early warning system to alert them of an impending event. These warnings come from special satellites that are observing the solar winds that are ejected from the surface of the sun and traveling toward the Moon. Also, the warning should be early in time, so the astronauts will have enough time to retreat to a shelter and take the necessary actions.

Robots Overview

A note on lesson planning: Many sections in this will be marked as non-essential. This means that, while they are informative and interesting in the study of robots, they have low applicability in robots designed to operate on the surface of the Moon. If pressed for time, these are the sections that can be freely omitted. However, context is important, and as such they would be best included, time permitting.

Modern Robotics and Lunar Applications Week Outline

Part 2: Discuss how robots act in detail – Methods of locomotion, forms of behavior.

Part 3: Discuss how Robots can be used on the Moon, given the specific environment and hazards.

Part 1: Defining Robots

The first task of this section of the curriculum is to explain what a robot is. The word robot has many different definitions, making this an infeasible task from the get-go. Explain to
the students that our goal is not to talk about anything called “robot” at some point in history, but rather to refer to a specific subset thereof. Every step of the definition has some amount of common sense wiggle room; otherwise this would become a very long section and accomplish very little. Examples of potential grey areas or unintuitive concepts are included at the end of every property. The properties of what we call robots here include the following:

- **Physically Acting**: A robot can move. This does not mean all robots can move from place to place (although on the Moon this will generally be the case). Rather, it means that robots have some capacity for physical action, to distinguish them from AIs or general computers. 

  *Wiggle Room*: A computer can auto-eject its CD tray. Does this mean that a computer is a robot? For our purposes, it is not a robot, regardless of whether that counts as physical action.

- **Semiautonomous**: A robot can make some decisions on its own, based on what it sees, hears, and perceives. This distinguishes it from, for instance, a remote-controlled car (although RC Cars are very relevant to areas of robotic research). A robot with a set of directions pre-programmed will keep considering different options even while not receiving any directions at the moment. *Wiggle Room*: Many things entirely remote-controlled have some amount of independent decision-making, like a blender that shuts off automatically when jammed. For our purposes, we’re only considering things that can alter their operation more substantially than that.

  *Pitching Robots*
As much as this topic is informed by the topics following, it’s important to include it near the start to keep students engaged. This may be the most important concept of the curriculum, and as such deserves some weight. What tasks can a robot do on a lunar base?

- **Build the base.** Robots can land before the base is constructed and assemble it, performing tasks like digging into the surface of the Moon, assembling, placing and fitting structures.

- **Mine.** It’s been speculated that robots would be able to mine usable amounts of Helium-3 from the regolith on the Moon’s surface.

- **Assist Humans.** A robot could grow food, tend to the sick or provide entertainment, all of which would have varying degrees of autonomy (the balance between doing only what you’re told and doing what you know is best).

- **Assist Robots.** Robots can be designed to help other robots carry out their tasks.

The interesting thing about all of this is that currently we have robots building structures and assisting humans, and in the coming decades their proficiency in these areas will only grow. The only truly novel engineering challenges, then, arise from creating robots that can carry out their tasks on the Moon. We’ll be focusing on what robots can do, what robots will do, and how to make robots functional on the lunar surface.

*What do robots do?*

The first task in this program is to introduce students to robots as a concept. The goal is to discuss what they are and aren’t designed for, and what they can and can’t do. This can proceed as follows:
Open the discussion by asking what robots can and can’t do. The typical responses may include the following:

<table>
<thead>
<tr>
<th>Can</th>
<th>Can’t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move really fast</td>
<td>Think/Feel</td>
</tr>
<tr>
<td>Fight</td>
<td>Get tired</td>
</tr>
<tr>
<td>Keep working forever</td>
<td>Eat</td>
</tr>
</tbody>
</table>

These are all correct (or at least suggest truths), and all will be discussed in the next week.

The subject of the first day’s lesson is what robots can do. Introduce each with an application, then move to a general principle. If the students don’t grasp a principle with the first example, don’t worry, because there are multiple paths to lead to any solution. There is also a good amount of overlap between any two categories, so it’s possible that students will draw similar conclusions but in wildly different orders. Try to roll with what they give you.

1. Robots are used on assembly lines (for instance, to manufacture cars). What does this tell us about robots? The students may figure out any of the following principles off the bat:
   a. Robots can work very quickly and accurately at set tasks. This makes them ideal for assembly line work, where each one’s set task comes after the last and before the next. Together, this enables robots to construct very complex things very quickly. If the students don’t understand this, then another example is that robots can be used as testers (quality control) to make sure newly made products all work correctly.
b. Robots can work all day without rest. This makes them ideal for jobs that don’t require much human interaction, since they can work while the humans sleep. If this is not understood, another example is that robots can be used in drilling operations, and work around the clock.

c. Robots work for cheap. Barring electricity and maintenance, once you have a robot going, it keeps going. Another example of robots saving money is using them to gather data and process forms for others or, depending on how loosely you define robots, vending machines.

2. Robots can dive to the bottom of the sea. What does this tell us about robots?

   a. Safety: Robots can operate in environments hazardous to humans. It’s less of a risk for a robot to malfunction than it is for a human to die. Another example of this is robots designed to handle hazardous materials such as nuclear waste.

   b. Sturdiness: A robot can brave situations that would kill humans in any environment, assuming they are designed for it. And, like the above example, if it fails all you lose is a robot. For one fun example, consider battlebots. For a less fun example, robots for defusing and disposing of bombs. *This could be considered similar enough to “safety” that it could be skipped.*

Bearing all of this in mind, what are robots bad at?

1. Learning. Robots can’t adapt well to new situations, unless told in advance what to adapt to, and how. There are exceptions to this rule, but at our technological level they are still exceptions and not the rule. For instance, an industrial trash compactor like you might find at a dump might not be able to sense living people inside of it.
2. *(Non-essential)* Human interaction, and all that it entails: Speech recognition (understanding what people say), natural language parsing (breaking down what people say into what they mean). For instance: If you say “I would like an apple,” it’s very easy to figure out what that means. If you say “I think I want an apple,” it’s a little more complicated to understand even though it means the same thing. If you say “Man, I’m feeling some apple,” then although the person you’re speaking to understands you, a robot may not.

3. Healing. A robot designed to take a lot of damage will probably be pretty sturdy, but it won’t just heal its cuts and wounds over time. Robots take damage, and to heal it they need regular maintenance, and this can be costly depending on the type. This is due to the fact that while robots on Earth are designed to be repaired by humans, that option may not be available thus demanding that other robots repair them.

4. Synthesis: Putting these limitations together reveals glaring flaws in the operation of a robot. Robots can’t adapt well (1) and they can’t heal (3). So if a robot’s battery case got damaged and one of its batteries started leaking, it wouldn’t know to get a new battery for itself unless it was explicitly coded to check for that. Depending on how it was made, it would see nothing wrong, or go to a charging station to charge its leaky battery (and run out again shortly after), or if all the proper code was in place, it would know to change the battery out.

**Part 2: Robot Design and Behavior**

In this section of the curriculum, discuss the inner working of robots. While day 1 was how they worked in a general form, now start discussing the details, on how individual
mechanisms function, and the pros and cons of each. Students will think about engineering decisions as they weigh different methods of robot design and construction.

Unit 1: Locomotion. How do robots move?

Try to present this as interactive, if possible. Have the class suggest methods of locomotion and throw out considerations on the pros and cons of each. Later, they will be asked to figure out which are the best to use on the Moon.

- Wheels: The most obvious method. Pros of moving with wheels: They’re very easy to design and build, simple to code, don’t use much power, and can be easily replaced. On the other hand, they have a simple weak point and, while they function well, they don’t function very well in varied terrain.

- Treads: Similar to wheels, they are easy to make. They also function better at remaining stable while moving across varied terrain, distribute weight better, and can be harder to jam, but they are also slower and use more power.

- Legs: Legs allow a robot to walk, jump and climb up jumps too steep for wheels or treads, giving the robot impressive freedom of movement. Cutting-edge robots with legs can remain very stable and adapt to changes in terrain. However, they’re also very hard to get to work right, and use more power.

- *(Non-essential)* Gyroscopic balance: Robots can operate on any number of wheels if they can balance themselves using gyroscopes. This allows them to have a small “footprint” and still get around and stay upright. Gyroscopic robots tend to move more with finesse than raw power. Pros: Run well, easy to use. Cons: More moving parts means more ways to mess up; can’t deal as well with varied terrain like getting over obstacles.
(Non-essential) Many types of robots are capable of balancing in the air. One example is quadrotor-style robots, which use 4 propeller blades to stay stable in the air. Pros: Stability, ease of use and speed. Cons: use a lot of power; don’t work as well unless surrounded by stable atmosphere.

Next, discuss which of these are best to use on the Moon. From previous instruction, students should be aware of the four primary issues regarding lunar operation: Lack of atmosphere, regolith (Moon dust), radiation, and lowered gravity. This breaks down approximately as follows:

- Wheels: Very practical, but much care has to be put into hiding the axle from the regolith, lest all of the dust get in and jam it.

- Treads: Also very practical, although power would be a concern.

- Legs: Practical, although power would be a concern. Legs tend to have multiple joints, and thus multiple moving parts, which could be more spots for weakness. In addition, the feet would need wide bases to avoid sinking into the regolith.

- Gyroscopic balance: Fairly impractical on the Moon’s surface. The advantages of gyroscopes (small footprint, can operate on a single wheel, etc.) disappear if you’re trying to climb up sand dunes, and make a robot impractical.

- Quadrotors and other Helicopter-like robots: There is no atmosphere on the Moon. On the subject of other forms of space travel: rockets, jets and other space traveling means are used to get to the Moon, but once there they use more fuel than other forms of travel.

**Part 3: Robots on the Moon**

Designing robots to operate on the Moon poses a few unique challenges. Here are the main ones to consider:
Vacuum: Many technologies cannot be used in vacuum. Heat and ventilation are often difficult.

Regolith: Forces tight seals on a robot, making heat and ventilation an even larger problem.

Radiation: The control board for robots operating on the lunar surface would have to be well-insulated, probably in the bottom or core of the robot, to guard against electrical shorting in the circuitry that might cause the system to crash. Explain this in detail or just gloss over like programming?

Low Gravity: More of an asset than a hindrance. This enables some designs that would be otherwise impractical, and its problems (tipping with a high center of gravity) are easily avoided. However, it complicates designing things since engineers have trouble testing them, except in “vomit comets” and the like.

Temperature: It’s a common issue even on Earth for electronics to work poorly or break due to temperature. Ergo, these issues are similar, but magnified, on the Moon.

Discussion on the lunar rover:

At this point in the presentation, students may remember that wheels have been used on every extraterrestrial surface exploration vehicle since the first ones in 1970. And there’s certainly something to say about the simplicity of wheels. However, they are not the end-all of transport, and the purpose of this section is to get the students to think critically and examine other possibilities. Other technologies are feasible, or could be at the time when autonomous or semiautonomous lunar robots are seriously being considered.
Energy Sources

This section of the presentation is a continuation of the previous section on the lunar robot. While the previous section focused on the mechanical specs and questions surrounding the actual robot, this section will focus on basic power concepts. The goal of this section is to help the students use intuitive thinking to understand how the Moon environment affects the performance of the robot with respect to power. The first two slides are solely meant to be introductory slides with some pictures.

We start this section by talking about the energy sources, which come in two unique forms: Direct power from the base (a constant wired connection) and Battery Power. The idea of directly powered robots from the base is a simple one; most of these robots that are directly powered by the base are performing their tasks inside the base and will not need to worry about any other energy sources. These robots will work on maintenance, tend the greenhouse, and aid people living on and off the base with various tasks. In the case that the lunar base is built within a crater as suggested by many civil engineers there may also be a lunar elevator for mining and crater research in which robots can be directly powered by the base to perform various time-consuming tasks. In addition, some robots near the base may not be able to receive direct power from the base all the time; for this there is the idea of having recharge stations near the lunar elevator and other work areas. The slide following the “Direct Power from Base” section is an example of a Lunar Base proposed by civil engineers in a presentation at WPI and then turned into an IQP under the guidance of Prof. Wilkes. [Warner]

The next section covers battery-powered robots, which are expected to be the robots that are mining at a considerable distance from the base, and robots that are used for anything like exploration, search and rescue (either astronauts or robots), or more. These robots will find many challenges in order to keep their battery charged all the time, and as a result various options
should be considered in order to overcome the obstacles that face them. It is suggested to begin this section by going over what kind of robots would need to use battery power (examples given at the beginning of this paragraph), and then over different ways to recharge a battery powered robot. Next, talk about the challenges surrounding robots that are battery-powered (e.g. being stranded) to then discuss the viable solutions (two of these solutions are displayed in slides). Remember that this project was meant to give students an idea of what a lunar base 50 years from now might look like, so any far out suggestions might become possible in the near future. Once the instructor feels that the students have the general idea of the challenges facing battery-powered robots, move into the covered topics for present day battery power. With this section it is calculated to be about one day of material.

The following sections enter into details of the previous section, actually talking about the power options available for the robots. We first start by talking about Solar Power, and give a few facts. For the first part of the slide most students will ask themselves, “What is TWs (TeraWatts)?” and “just how much is a TW or even 13,000 TWs?” To first answer what a TeraWatt is, first students should know that a Watt is a standard unit of Power, and Tera means trillion. For how much is 13,000 TeraWatts, one way to answer the question in a way which might help them understand 13,000 TWs (TeraWatts) is by comparing it to the “State of the World 2009, Worldwatch Institute” article where the 2008 worldwide consumption of power was 132,000 TWh which means that 132,000 TWhr was the amount of energy (power times time) the entire world used in one year (approximate value). Energy consumption varies throughout the day and from country to country, but dividing the total energy by the number of hours in a year means that, on average, the people and machinery of Earth are consuming about 15 TW at any
one time. This would be equivalent to powering 150,000,000,000 100-Watt light bulbs, 24 hours a day.

The total amount of electromagnetic energy produced by the Sun (called the “solar constant”) is about 1360 Watts per square meter, measured at the average distance of the Earth or Moon from the Sun. So if you had a solar cell with 100% efficiency you could power a lunar rover consuming 1360 W with a one-square-meter solar cell. The solar cells currently used in satellites have about 15% efficiency, but this is expected to improve with advances in technology.

The students should be able to calculate how big a solar cell would have to be, to provide all of Earth’s current energy needs.

Next we have the part where the slide says that 13.6 of light (in units of Earth days) are available every lunar cycle, which directly relates to the lunar cycles in slide 17 and the position that the base finds itself in on the Moon (Moon Environment section of Physical Characteristics and sub-category Motion cover this in details). With this kind of renewable energy always available to robots, it is possible for most robots outside the base to be mostly or entirely independent of the lunar base.

The section on wireless power via microwaves describes a present day technology that is not often heard of for applications outside of heating up food. Microwaves are useful in that they are unaffected by weather and other such challenges that other wireless signals face, which makes them an effective means of delivering power. In our case we do not have to worry about atmospheric phenomena or any other such issues that would obstruct the transfer of wireless power, which just means that microwaves would become even more effective in the vacuum of space. The idea behind wireless power is if there is the case where a robot cannot receive the
sufficient amount of power to last a lunar night (13.6 Earth days) or is simply located in an area where solar power cannot reach it (mining a crater) we can still power up the robot by beaming microwaves to a microwave receiver on the robot. Of course this process does not require just any kind of microwaves since only specific frequencies of microwaves can be programmed on the robot receiver [Ishiba].

The next section covers another idea for delivering power to robots that can’t get what they need from conventional methods, and thus an unconventional method is introduced. As an idea to get students thinking really outside the constraints of just having a limited set of options, the idea of also having smaller robots that would replace the batteries of larger robots is introduced. As a method of drawing the student’s attention towards this concept a picture of Wall-E has been posted on the slide. This comes from the fact that Wall-E is an independent robot which also depends on solar power, and works on various tasks on a future Earth [Wall-E]. In this situation the larger robot in question would have at least two battery packs that are hot-swappable which the little robots would remove and recharge on behalf of the larger robot. The small robot would be docked in an area where it always has access to power (e.g. Access Points or Base) and would respond to any low-battery signals that the larger robot would broadcast (which means transmitting over a large area to a select group of devices or services). This slide is meant to inspire discussion; however it is not required.

The last section talks about protecting the circuit, however the course does not enter deeply into this topic in order to not go beyond the scope of this course. For the purposes of what we want students to understand we focus on just letting students know that radiation can cause interference with an electrical system, and examples of that are proton storms and the radiation accumulated on the lunar surface as already discussed.


**Capstone Project**

**WPS shared robot**

The basic idea behind the WPS shared robot was to have a robot that would serve as a demonstration of what the design challenge the students had to work on using the LEGO® Mindstorms® kit would look like, and to give them ideas for their own robot design. Because our team did not any robotics majors we had a student from the WPI Robotics Engineering Program volunteer to design this robot. The robot was nearly completed. However it was not completed by the time we had to complete this project curriculum, which is why it is only being briefly mentioned. However if this curriculum were to be continued it would be suggested to have a robot separated from the design challenge as a demo for the students.

**LEGO® Mindstorms® Design Challenge**

The decision of whether to use Lego blocks or the VEX kit was not an easy one. There were many reasons to use both, and it took a long time to come to a consensus.

Here are the factors that went into our decision:

<table>
<thead>
<tr>
<th>Lego Pros</th>
<th>Vex Pros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiar to many students</td>
<td>Closer to real robotics construction</td>
</tr>
<tr>
<td>Easier to learn</td>
<td>Robots are sturdier</td>
</tr>
<tr>
<td>Cheaper to buy a functional starting kit</td>
<td>Remotes are standardized</td>
</tr>
<tr>
<td>Starting kit comes with everything needed</td>
<td>Programming language is more powerful</td>
</tr>
</tbody>
</table>
In the end, we decided that unless we had confirmation that Vex was widely rolled out in the school system, we would use Lego for the student class projects, due mainly to cheaper costs. We did not get this confirmation so we stuck with Lego. However, we would still make the demonstration model out of Vex, as fewer of them would be needed, and it may seem more motivating to see something that looks closer to what the students would envision as robotic.

The figure below shows what the LEGO® Mindstorms® vehicle looks like:
The design challenge is to have students work with the LEGO® Mindstorms® kit using the vehicle mode to design a robot that runs across the surface of the Moon. The general idea is that the robot should accomplish one of these three tasks:

1. From a point A to B, pick up something, then go back to point A
2. Obstacle course from point A to B, where it has to move across
3. Robot that moves along track

As part of the challenge students need to work on the robot with a lunar environment in mind, which means that the ultrasonic sensor is out of the picture because there is no atmosphere. While working on the project the teacher will want to explain why the ultrasonic sensor cannot work without atmosphere, which is that sound travels through air, thus making it impossible to travel across a vacuum which has no air. Treads and wheels are acceptable; if the teacher desires to modify the terrain of the robot, the students would also have a learning experience as to how differently the robot moves across a terrain using the two different designs. Examples of suggested designs are in the Appendix, however it is suggested the teacher come up with ways to make this more of a design challenge project rather than a project which builds right off of the project examples.
Appendix

Suggested Homework

Introduction
Question 1: Why did the lunar rovers use wireframe wheels instead of air-filled tires like on your car?

Question 2: What are some unique features of the Space Exploration Vehicle?

Question 3: What are some negative effects of low gravity on humans?

Question 4: Draw your own version of a lunar rover, a lunar base, or a rocket, based on what you’ve learned about earlier Moon missions, and describe why you chose certain parts.

Moon Environment
- Use Quiz as reference for possible homework

Robots Overview
Question 1: Of the following methods, which would you use to move a lunar scout in a very hilly area? How about a mining robot? Explain the advantages of your choice, and how you will get around the disadvantages.

  a) Legs
  b) Treads
  c) Jets
  d) Gyro-assisted wheels

Question 2: How will your choices change if the area is flat? Explain your decisions.

Question 3: Discuss a method of transport not covered in class, and explain its advantages and disadvantages.
Energy Sources

Question 1: Think about what kind of energy sources are there available here on Earth, and how they work. Why would some energy sources that work on Earth not work on the Moon?

Question 2: What do you think would be a simple solution for providing power to the robots that would be working on…
   a) The surface of the Moon?
   b) Inside the base?
   c) Digging inside a crater near the base?

Question 3: Imagine you were controlling with a remote control a robot that was running out of batteries, and the Moon base is too far to make it before the robot runs out of power. Name one energy source that would be able to save your robot from running out of energy and how you would obtain that power.

Suggested Quizzes

Introduction

Lunar Robotics Quiz 1

Question 1: Which mission reached the lunar surface first?
   (a) Soviet Luna missions
   (b) Soviet Zond
   (c) American Voyager
   (d) American Apollo
Question 2: Who was the first man on the Moon and what was the name of the mission?

Question 3: Explain some differences between the Soviet Lunokhod rover and the American Lunar Roving Vehicle.

Question 4: What makes the Space Exploration Vehicle different than the previous rovers?

Question 5: Why would it be important to establish a base on the Moon? What are some advantages that could come from it?

Moon Environment

Question 1: What is the distance between Earth and Moon?

(a) 384,400 (km)

(b) 384,400 (miles)

(c) 987,432 (Km)

(d) 987,432 (miles)

Question 2: The radius of the Moon is …….. the radius of the Earth.

(a) 1/2

(b) 1/3

(c) 1/4

(d) 1/8

Question 3: What is the temperature on the Moon, at night and during the day in Celsius?

Question 4: Why there is a huge temperature difference on the Moon between night and day?

Question 5: What kind of negative effects would radiation cause to human being?

Robots Overview

- Use Homework as reference for possible quizzes.
Energy Sources

- Use Homework as reference for possible quizzes.

Design Challenge Examples

The following figures are examples of models that can be used for the designing of the project with the vehicle mode LEGO® Mindstorms® robot. The first figure shows the basic vehicle mode LEGO® Mindstorms® robot without any sensors installed on it, and will be the basis for all the of the project designs. In this example we have the robot using wheels, however the LEGO® Mindstorms® NXT 2.0 kit has treads that you can easily pop in the same way that you can easily pop out the wheels (information is in the NXT user guide).

Below we have an example of how the sensors can be built and mounted on the robot [Perdue].
This next picture shows the same robot design as above from the bottom view to show where the color sensor would be installed.
In addition to the PowerPoint slides provided outside of this report, the example programs should also be available for the teacher to get familiar with the LEGO® Mindstorms® NTX 2.0 program. These programs are designed in a graphical drag and drop interface so that even 7th graders should quickly get used to the program. Please keep in mind that the example programs are only example programs, and thus it is advised that the teacher revise the program as they find best suited. Any other basic examples are available in the instruction manual for the LEGO® Mindstorms® kit, and for more possible projects for the students can check out Laurens Valk’s book _The LEGO Mindstorms NXT 2.0 Discovery Book: A Beginner's Guide to Building and Programming Robots._

**PQP**

**Notes on *Understanding by Design* by Grant Wiggins and Jay McTighe**

The following notes are as recorded while the team was discussing the book. They are only lightly edited.

*Chapter 1: Backward Design*

- Page 14, Paragraph 1: “Note: Student lvl of learning while developing curriculum. Think of different possibilities for different lvls.”
- Page 15, Paragraph 2: "...too many teachers focus on the teaching and not the learning."
Page 23, Paragraph 2: “… users are prompted to identify the understanding and essential questions to establish a larger context into which a particular unit is nested”
Page 23, Paragraph 3: “Designers need to think in terms of collected evidence, not a single test or performance task.”

Page 23, Paragraph 4: “… the designer should be able to discern what we call the “WHERETO” elements”

**Chapter 2: Understanding**

![Figure 2.1 Knowledge Versus Understanding](image)

- Page 40, Paragraph 2: “Understanding is about transfer, in other words. To be truly able requires the ability to transfer what we have learned to new and sometimes confusing settings. The ability to transfer our knowledge and skill effectively involves the capacity to take what we know and use it creatively, flexibly, fluently, in different settings or problems, on our own.”

- Page 41, last Paragraph: “Knowledge and skill, then, are necessary elements of understanding, but no sufficient in themselves. Understanding requires more: the ability to thoughtfully and actively ‘do’ the work with discernment, as well as the ability to self-assess, justify, and critique such ‘doings.’”
• Something what is obvious to an educator may not be so obvious to a student, which requires the educator to think about what might not be so obvious to a novice that would be to an expert.

• Page 54, Paragraph 2

“Practically speaking, we must begin to design assessments in recognition of the need for conceptual benchmarks, not just performance abilities.”

Chapter 3: Gaining clarity on Our Goals

• Page 56, Paragraph 1: “Backward design is goal directed. We aim for specific results and design backward from them accordingly.”

• Page 66, Paragraph 3: “For any subject taught in primary school, we might ask is it worth an adult’s knowing, and whether having known it as a child makes a person a better adult. A negative or ambiguous answer means the material is cluttering up the curriculum.”

• Page 67, Paragraph 2: “What makes… big ideas? According to Wynn & Wiggins (1997), big ideas are ‘chosen especially for their power to explain phenomena, they provide a comprehensive survey of science” (p. v). Whether you agree with their particular choices, the authors’ approach reflects the need to focus on a smaller set of priority ideas and use them to frame teaching and assessment.”

• Page 67, Paragraph 4: “… big ideas are at the ‘core’ of the subject; they need to be uncovered; we have to dig deep until we get to the core. Basic ideas, by contrast, are just what the term implies – the basis for work; for example, definitions, building-block skills, and rules of thumb. Ideas at the core of the subject, however, are ideas that are the hard-won results of inquiry, ways of thinking and perceiving that are the province of the expert.”
• Page 70:

In pedagogical practice, a big idea is typically manifest as a helpful
• Concept (e.g., adaptation, function, quantum, perspective)
• Theme (e.g., “good triumphs over evil,” “coming of age,” “go West”)
• Ongoing debate and point of view (e.g., nature versus nurture, conservatives versus liberals, acceptable margin of error)
• Paradox (e.g., freedom must have limits, leave home to find oneself, imaginary numbers)
• Theory (e.g., evolution via natural selection, Manifest Destiny, fractals for explaining apparent randomness)
• Underlying assumption (e.g., texts have meaning, markets are rational, parsimony of explanation in science)
• Recurring question (e.g., “Is that fair?” “How do we know?” “Can we prove it?”)
• Understanding or principle (e.g., form follows function, the reader has to question the text to understand it, correlation does not ensure causality)

• Page 76, paragraph 2: “Big ideas are abstractions, and the design challenge is to bring those abstractions to life and to make them seem vital.”

• Page 78, paragraph 2: “Core tasks with authentic challenges embody our educational aims...”
Chapter 4: Six Facets of Understanding

- Page 84, Paragraph 3

What we truly understand, we…

- Can explain—via generalizations or principles, providing justified and systematic accounts of phenomena, facts, and data; make insightful connections and provide illuminating examples or illustrations.
- Can interpret—tell meaningful stories; offer apt translations; provide a revealing historical or personal dimension to ideas and events; make the object of understanding personal or accessible through images, anecdotes, analogies, and models.
- Can apply—effectively use and adapt what we know in diverse and real contexts—we can “do” the subject.
- Have perspective—see and hear points of view through critical eyes and ears; see the big picture.
- Can empathize—find value in what others might find odd, alien, or implausible; perceive sensitively on the basis of prior direct experience.
- Have self-knowledge—show metacognitive awareness; perceive the personal style, prejudices, projections, and habits of mind that both shape and impede our own understanding; are aware of what we do not understand; reflect on the meaning of learning and experience.

Chapter 5: Essential Questions

Frame goals as “essential questions”

- Not trivial to answer.
- Big ideas – What are the reasons for building a lunar base? How can robots help?
  - Hitting on general, deep, universal themes gives more freedom here, e.g. the benefit of humanity. How can humans better ourselves through lunar exploration?
  - Gives us the why as a framing point for the how.
  - Generally framed in response to ideas relating back to people and how we think.
- Exploring different answers or facets thereof help teach the curriculum.
If they are general enough, they allow for inter-curricular connections.

There are four different meanings for the word *essential* in *essential questions*.

1. Important, recurring questions: What is justice/art/humanity?
2. Core ideas within a discipline, with unclear, still debated answers: What materials are best when building robots?
3. A question that allows students to better think about the material: How is a robot programmed to behave?
4. A question that will most engage the students: Aren’t robots awesome?

The important properties of essential questions: They should balance engaging the student, with being relevant to the unit: “Accessible, thought-provoking, challenging, and a priority”. Require students to support their opinions. If it seems feasible, make it a question over which students can disagree.

Goals:

1. Cause genuine inquiry into the big ideas and core content
2. Provoke deep thought, lively discussion, sustained inquiry, and more questions.
3. Require students to consider alternatives, justify their ideas, and provide evidence.
4. Stimulate rethinking of big ideas, assumptions, and prior lessons.
5. Connect with previous lessons and life experiences.

*The defining of a question as “essential” is context-based*, and is affected by how you are teaching it. Even interesting questions can be crushed by coverage-based or quote-the-book answers. The reverse is somewhat true as well: Common teaching wisdom says to avoid yes/no questions. This can be true, but exceptions exist: Is light a particle? Is the universe expanding?
Essential questions exist in all subjects. They are usually framed around 4 big ideas relevant to the subject: Key concepts (something related to the subject), purpose and value (relating the subject), strategy and tactics (what to do in situation X), and context of use (the inverse of strategy unless I’m misreading – When to do technique Y).

Specific questions are known as “topical”, whereas general ones are called “overarching”. Both should be used. Pair an essential question specific to the subject of the unit with a larger, more general one. Topical ones are more likely to be the yes/no or answerable ones.

Questions can be “open” – demanding creativity of the student to interpret and answer – or “guided”, in which they focus attention onto a specific idea. It’s best to use a mix of the two, so as not to leave students twisting in the wind or lock them in and not let them think creatively.

Creating essential questions – Find the big ideas and frame them as questions; look at content standards / curriculum guides; use enduring understandings (earlier).

Schooling must let students see how ideas are suggested, debated, verified, etc. So don’t be (too) afraid about using controversial lessons, as long as caveats are used.

Chapter 6: Crafting Understandings

What should students understand by the end of a unit?

You can tell somebody understands a concept when they can restate things in their own words, discuss the big ideas and meanings, infer related concepts, basically just speak intelligently about it.

Understanding takes facts and skills and focuses them on concepts, principles and processes (it’s important to note that understandings are not the facts themselves). They
generalize ideas so that they can be transferred (big theme this chapter). Understandings are best acquired inductively, as part of answering a question (see previous chapter). It should reflect important, hopefully useable principles in the subject.

Understandings can be “topical” or “overarching” – basically the distinction is which type of question it answers.

Teaching to the test is a challenge, since it means you still need certain facts (or their base inferences) included in your understandings. It makes life difficult for someone making a curriculum, especially one meant to be national and encompass all the standards.

What realizations based on inference should the student come away understanding? Figure out what it is the student should know (not what they should know about – e.g. “Know about trig” is not acceptable). Students should understand that...

Understandings should be enduring, meaning either that it’s endured over time and across cultures due to its importance and usefulness, or they should endure in the mind of the student due to its use, or ability to enable connections, etc.

A chart on page 137 (6.3) has some prompts for figuring out essential questions and understandings.

Remember never to teach an understanding as fact.

Younger students need to be inducted through things the teacher may think of as obvious. Throwing knowledge at students due to this is “the expert blind spot”. This blind spot also includes teaching all of the vocabulary to the learner immediately – Bring them up when they’re needed, not all at once.

If it requires significant explanation, it’s an understanding rather than a fact. Example: Pythagorean theorem.
To create understanding goals, it may help to work backwards from what you want the students to know. Things to be aware of:

- Common misconceptions or easy wrong answers - your goal is to teach, not to outwit.
- Other conclusions that may be drawn: Especially if it’s a current subject, or a vague one (what is the book about?)
- That some might just not get what you get: They don’t know exactly what you know, and vice versa.

Chapter 7: Thinking like an Assessor

The assessor’s questions:

- What evidence can show that students have achieved the desired results?
- What assessment tasks and other evidence will anchor our curricular units and thus guide our instruction?
- What should we look for, to determine the extent of student understanding?

An assessor is not a teacher – They’re different hats.

The author spends time ragging on current curriculums, saying that basically none of them are right (148).

Figure out your parameters. If your end result is for students to meet the standards X, understand that Y, consider the question Z, etc. then you need new evidence of the student’s ability to do what?

What kind of evidence do we need to find hallmarks of our goals and understanding? (E.g. students comparing, contrasting and summarizing key ideas.)

What specific characteristics in student responses, products or performances should we examine to determine the extent to which results were achieved? Rubrics come into play.
Does the proposed evidence enable us to infer a student’s knowledge, skill or understanding?

Designing using these methods is very counterintuitive. Design from the goals, not blindly, or based on other metrics like engagement.

Make sure to watch and test along the way to see that understanding is maintained at every step!

Use informal checks (soft), dialogues, tests and quizzes (medium), academic prompts (open-ended essay questions), or performance tasks (having students apply skills, hard).

Practice and build: Knowledge should be contextualized, need information and judgment to use, be applied, and finally be measured. Students should understand where and how the knowledge is used.

A problem is an application set in the real world, whereas an exercise is an academic situation simplified to show the knowledge at hand.

GRASPS: Goal, Role, Audience, Situation, Performance, Standards. Use it to design problems (167-8).

What evidence do we need to demonstrate understanding?

**Chapter 8: Criteria & Validity**

There are seven cross-curriculum dimensions:

1. Identify and cultural diversity
2. Healthy lifestyles
3. Community Participation
4. Enterprise
5. Global dimension and sustainable development
6. Technology & media
7. Creativity and Critical thinking
There are six-steps to analyze the students understanding and performance:

1. Gather samples of student performance that illustrate the desired understanding or proficiency.
2. Sort student work into different “stacks” and write down the reasons.
3. Cluster the reasons into traits or important dimensions of performance.
4. Write a definition of each trait.
5. Select samples of student performance that illustrate each score point on each trait.

It is very common to see students who forget and jumble together key facts. One way of fixing this problem is, while teaching, look at the student’s thinking process can be a clue of discovering why they couldn’t understand the material or the question. Or maybe it could be that they indeed understood the materials, but they’re missing a small note, and that’s why math teacher always say “show your work”, so they can follow the track.

It is important to compose tests that are equal in weight, but not equal in difficulty. You can design tests that are multiple choices, with an explanation of the reason choosing that answer.

**Chapter 9: Planning For Learning**

The planning for learning guidelines have five phases:

1. Understanding the context
2. Planning and resourcing
3. Implementation
4. Continuous monitoring
5. Evaluation and review.
For each of these levels there are readings, tools and related websites to support discussion and decision making. In the Implementation section there are school and cluster stories.

Benefits:

- makes the materials manageable by connecting similar content, processes and skills
- allows the curriculum to be taught more efficiently
- enables effective planning across key learning areas
- ensures that the students are able to be effectively taught in an integrated approach
- ensures a balanced coverage of all key learning areas.

**Chapter 10: Teaching for Understanding.**

Teaching for understanding promotes in-depth learning over covering a broad range of material, and applying knowledge to real-world problems over performance on short-answer quizzes, and active participation from students. It requires teachers’ commitment to understanding the challenges students face in working with intellectually demanding material and to using or designing strategies that make the material accessible to a variety of learners.

In order to teach, you need to be ready and comfortable of what you are going to talk about, and, most important, present your materials in a clear and organize way. To do so, you start by using the following four steps:

1. What topics are worth understanding?
2. What must students understand about the topics?
3. How can we foster understanding?
4. How can we ascertain what students understand?

Curriculum Design Tools Planners:
• Brainstorming Worksheet: While you are brainstorming or thinking it is helpful to have a notebook to record your thoughts and ideas in an organized way.

• Generative Topic Evaluation Worksheet: It will help you thinking about some of the characteristics of generative topics, so you can ensure that your topics are high quality.

Chapter 11: A Design Process

• You can start at any stage

• Can start with an existing unit and then build upon or refine it for your own needs

• Sometimes good to begin with a key resource, like a kit or pre-planned assignment

• Take these starting points and link them to specific purposes

Begin with content standards

• Look for key nouns

• Identify key knowledge and skill called for by content standards

• Ask what essential questions flow from or point to standard?

• Consider key verbs, think of them as a blueprint for key performance assessments

• List activities that will enable performance and will develop ability to understand big ideas

• Refine unit to ensure alignment across all three stages

Begin by considering desired real-world applications

• Clarify larger purposes and ultimate goals of the content

• Identify specific complex real world tasks that embody challenges or achievements of goals

• Determine the understandings, knowledge and skill learners will need to achieve mastery of tasks
• Sketch a learning plan that will enable practice, feedback, and competent performance
• Infer questions performers need to always consider as they try to master the content and the task
• Identify the content standards that explicitly refer to or imply such applications
• Align the elements of design as needed

**Begin with a key resource or favorite activity**

• Start with a ‘winning’ activity or sanctioned resource
• Consider “why” questions
• Clarify essential questions that will point students to those ideas as they consider the experience or text
• Identify skills, facts, and understandings the resource or activity is meant to yield
• Revise assessments and learning activities accordingly

**Begin with an important skill**

• Consider question, what complex and worthy performance does such a skill enable, how does this skill connect to other relevant skills?
• Identify content standard or standards that refer to such skills directly or indirectly
• Determine what kind of assessments are implied or explicit in relevant standard
• Identify strategies that are helpful in using such skills effectively
• Identify big ideas and essential questions
• Devise learning activities that will enable learners to use such skill in context and to self-assess and self-adjust
• Revise for alignment accordingly

**Begin with a key assessment**
• Clarify goals for which assessment exists
• Identify standards that address goals
• Infer relevant big ideas required to meet such a standard and pass such a test
• Develop and refine the performance assessment tasks that parallel the required assessments

**Begin with an existing unit**

• Given traditional lessons and assessments, place elements in template and look for alignment across three stages. Do goals match assessments?
• Ask whether lessons relate to richest aspect of your goals
• Focus on clarifying the big ideas and long term performance goals related to standards
• Keep asking what should students come away understanding?
• Revise assessments and lessons to do justice to revised stage 1 elements
• Revise design against design standards

Design process must be flexible, can’t strictly follow any single “recipe”

“For that matter, real cooking involves moving beyond recipes, too: Recipes, which began as such useful things, have become tyrants, leaving even the most well-meaning cook unsure of his own instincts. A slavish devotion to recipes robs people of the kind of experiential knowledge that seeps into the brain. . . . Most chefs are not fettered by formula; they’ve cooked enough to trust their taste. Today that is the most valuable lesson a chef can teach a cook.” (O’Neill, 1996, p. 52)
Rather, what designers need to become accustomed to is the back-and-forth rhythm between the creative brainstorming and trying out of ideas, and the careful and critical testing of the emerging design against the design standards. As the description of the various entry points earlier in the chapter suggests, it doesn’t matter too much where you start; it matters more that you end up with a design that meets the standards

**Unavoidable Dilemmas in design**

- Big ideas and transfer versus specific knowledge and skills
- Complex, realistic, and messy performance versus efficient and sound tests.
- Teacher control vs. learner control of the work
- Direct vs. constructivist approaches
- Depth vs. breadth of knowledge
- Comfort and a feeling of competence vs. a real challenge
- Uniform vs. personalized work and expectations
- Effective vs. merely engaging
- Simplified vs. simplistic
- Well-crafted plan vs. flexibility/open-endedness
- A great individual unit vs. larger goals and other designs

Dilemmas can only be balanced but never completely solved

Aggressively seek feedback as you work
Making Adjustments:

Use the feedback from the students to adjust the course accordingly to make the students reach the desired goals.
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Lunar Robotics

History of Lunar Exploration
- Cold War Space Race
  - Soviet Luna Missions
  - American Apollo Missions

Soviet Luna Missions
- Luna and Zond missions began in 1959
  - First geocentric impact
  - First flyby and far side image
  - First soft landing
  - First orbiter
  - First circumsolar probe to return to Earth

Apollo missions
- Missions 1-6: uncrewed tests and uncrewed missions
- 7-10: crewed exploration, no landing
- Apollo 11 put first men, Neil Armstrong and Buzz Aldrin, on moon July 20, 1969
- Sample missions explored, retrieved samples
- Missions 15-17 used lunar rover to extend range

Soviet Rover
- Lunokhod – Luna 17
  - First robotic control robot on lunar surface
  - Wheels independently powered
  - Powered by batteries charged by solar cell
  - Used fluoride based lubricants
  - Radiosonde tractor unit
  - Intended to last 5 lunar days (~3 months); actually lasted 11 months

U.S. Lunar Roving Vehicle
- Tires made from woven silicon-coated Loyden (cemented with silicon...) independently powered wheels
- Pedal and rear drive motors
- 20 volt, non-rechargeable aluminum-sodium potassium hydride batteries
- Passively cooled using reflective surfaces and change of phase heat transfer unit
- T-shaped joystick controlled every aspect of movement
- Navigation based on directionging compass and altimeter, computer kept track of direction and distance from landing module
Future Rover: Space Exploration Vehicle (SEV)
- Chassis and cabin modules separate
- Pressurized cockpit
- 12 wheels, each can pivot 360°
- Can support 2 astronauts up to 2 weeks
- Can hold 4 astronauts in an emergency
- Spacecraft ports and traditional docking airlock
- Allows for multiple attachments
- Cranes
- Vehicles
- Modules
- Cargo rack

Saturn Series
- Designed by Werner von Braun and a team of Germans
- Developed in 30s and 40s
- Based on Nazi rockets from WWII
- Used for Apollo missions
- Saturn V: 362,000 lbs to LEO, 500,000 to moon
- 5 stages

Proton Series
- Soviet rocket
- 450,000 lbs to GEO (High Earth Orbit)
- 15,000 lbs to GTO (Geostationary Transfer Orbit)
- 3 to 4 stages

Scientific Benefits
- Human survivability in low gravity
- Study Possible effects
  - Effect on nutrition
  - Bone deterioration
  - Loss of bone and muscle
  - reflex
  - Depressed immune system

Looking from the Moon
- Deep space observation
  - Observation
  - No atmosphere to allow imaging
  - More stable platform than Earth-based platform
  - Rubbing can create much larger surface
  - Telescopes on the sides could be shielded by the moon from the increasing effects of electromagnetic interference caused from Earth

Moon Money
- Tourism
- Mining
  - Silicon
  - Metals
  - Helium-3
    - Very rare, important for fusion progress
- Industry and construction
Future Space Travel

- Pioneer technology for use on Mars or future colony
  - Housing
  - Life support
  - Develop ways to grow crops
  - Sustainability studies, biologic recycling, etc.
- Jumping off point for future missions
  - Lower gravity makes launches easier and less costly

Moon Environment

Moon Characteristics

Distance: The Moon is approximately 384,400 km (239,000 miles) from the Earth.

Size: The diameter of the Moon is 3,474 km (2,160 miles). This is about 1/4 the diameter of the Earth (12,742 km or 7,926 miles).

Mass: The mass of the Moon is 7.35 x 10^22 kilograms, which is about 1/80 of the mass of the Earth.

- Density: The density of the Moon is 3.34 g/cm^3.
- Temperature: The average temperature of the moon during the day is 127°C, but during the night it drops to -153°C.
- Rotation: The Moon rotates around the Earth in an elliptical orbit every 27.3 days. The same side of the Moon always faces the Earth.
- Gravity: Because of its smaller size and mass, the gravity of the Moon is about 1/6 the gravity on the Earth (g = 1.62 m/s^2). That means that a person who weighs 160 pounds on Earth would only weigh 30 pounds on the Moon.

Moon Temperature
Temperature Risks:

• The Moon doesn't have an atmosphere like Earth.

• Earth's atmosphere acts like a blanket trapping heat.

• The temperature of the Moon can go down to -153°C during the night, where during day the temperature rises up to 107°C.

• Moon takes 27 days to rotate once on its axis. So any place on the surface of the Moon experiences about 13 days of sunlight (107°C), followed by 13 days of darkness (-153°C).

Temperature Risk Management:

• Temperature on the moon is a real problem to the astronauts or even robots who's going to live, work, and accomplish missions on the moon.

• Scientists already designed spacesuits that are heavily insulated with layers of fabric and then covered with reflective outer layers.

• Spacesuits minimize the temperature differences between when the astronaut is in the sunlight and when in shade.

• Space suits also have internal heaters and cooling systems, and liquid heat exchange pumps that remove excess heat.

Moon Craters

• A moon crater can stay virtually intact (as it is) for millions or even billions of years because the Moon does not have dynamic bodies of water on its surface. Where, damages or distortions to such craters cannot be caused by crevasses.

• A bad site for landing, robot transportation, or even a moon base.

• Crater with small, flat floors. Typical diameter is about 15 km.

• Small, cup-shaped craters with a diameter of about 10 km or less, and no central floor.

• The interior floor is wide and flat, with no central peak. The inner walls are not terraced. The diameter is normally in the range of 15–25 km.
• These complex craters are large enough so that their inner walls have slumped to the floor. They can range in size from 15–50 km in diameter.

• These are larger than 50 km, with terraced inner walls and relatively flat floors. They frequently have large central peak formations.

Radiation on Moon

Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves, and/or particles.

Radiation penetrates human flesh and can damage DNA, boosting the risk of cancer and other maladies:

• nausea
• vomiting
• headache
• some loss of white blood cells

Radiation can cause, diseases such as leukemia (cancer of the blood), lung cancer, thyroid cancer, breast cancer, and cancers of other organs can appear due to the radiation received.

• People in low Earth orbit receive radiation protection from the Earth’s magnetic field

• These cosmic rays are energetic and dangerous to life, go beyond this region of space, and this natural protection disappears.

• The Moon itself has essentially no magnetic field, and no atmosphere to protect astronauts from radiation.

• radiation can be seen (visible light) or felt (infrared radiation), while other forms like x-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment.
Ways to limit and avoid radiation from the lunar soil:

- A short mission to the Moon will be survivable for astronauts, mainly because exposure times will be low.
- Astronauts staying for longer periods will need shielding, to guard against the long-term effects of exposure.
- The thin walls of spacecraft will not be enough.
- Radiations that are coming from the moon’s soil can be solved and stopped by the special space suits or even the thin walls of the spacecraft.
- Astronauts will need radiation sensors placed on the surface, and at different regions, to assess the full nature of the Moon’s radiation environment.

Ways to limit and avoid radiation from the outer space:

- Radiation levels can increase enormously, and field drums can be absorbed by unprotected astronauts within minutes.
- At least one part of a lunar base will need to be equipped as a radiation shelter, to protect against the most extreme radiation events.
- Shieling will be thicker, and provisions will be made for stays of several hours or days.
- Astronauts will need an early warning system to alert them of an impending event. These warning come from a special satellites, that are observing the solar winds that are ejected from the surface of the sun and traveling toward the moon.
- The warning should be early in time, so the astronauts will have enough time to retreat to a shelter and take the necessary actions.

Overview: Robots

What is a robot?

- Just things out of science fiction, that can walk around and talk to people?
- Nearly everything? Cars and coffee makers both have microchips and some amount of intelligence. Smartphones have more processing power than the Apollo.

Our definition of a robot

- Capable of motion: When we talk about robots, we mean something that can move around.
- Capable of making decisions: Robots are given tasks by people, but will execute them independently.

What do robots do?

- Work quickly and accurately
- Work for long periods of time
- Work cheaply and cleanly without taking much room
- Work in hazardous environments
- Stay sturdy in situation that would hurt people
What can’t robots do?

- Learn from things outside of their program: Robots can’t adapt to new situations.
- Heal their bodies: A robot cannot recover from damage unless designed in order to be able.
- Interact well with humans: Humans communicate a lot with bad grammar, body language, sarcasm, and tone of voice.

How can robots be used on a lunar base?

- Build the base: Land first, and start construction.
- Mine: The moon’s surface has rare and expensive minerals.
- Power: Generate power, likely solar.
- Assist the humans: Grow food, entertain, or tend to the sick.
- Assist other robots: Change batteries, carry loads, or anything else.

Next Time

Robot Design and behavior

Robot Design

Locomotion: How do robots move?

- Wheels (Cars)
- Treads (Tanks)
- Legs (Androids and robots in labs)
- Gyroscopic Balancing system (Segways)
- Aircraft: Rotors (Helicopters), Planes (Jets)

Wheels

Cars to roombas, a lot of machines run on wheels. They’re simple, easy, and pretty effective.
Analysis: Wheels
Pros
• Easy to design and build
• Power-efficient
• Easily replaced
Cons
• Single weak point
• Don’t always work in uneven terrain

Treads
Used in tanks. A series of motors with a tread wrapping around them. Sturdy and effective.

Analysis: Treads
Pros
• Easy to make
• Remain stable on varied terrain
• Hard to jam
• Distribute weight well
Cons
• Slow
• Use a lot of power

Legs
The thing we have. Robots with legs are being developed by the department of defense and a number of private companies, such as Honda.

Analysis: Legs
Pros
• High speed
• Good in uneven terrain
• Can be very stable and adaptable
Cons
• Use a lot of power
• Hard to get to work
• Many moving parts means many points of failure

Gyroscopic Balance
A modification of other types, generally wheels, to make them more stable with fewer needed. Used in Segways.
**Analysis: Gyroscopic Balance**

**Pros**
- Small footprint
- Move more precisely
- Run well
- Easy to use

**Cons**
- More moving parts
- Can’t get over obstacles easily

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**Aircraft**

Helicopters, Quadcopters, and other hovering devices all use rapidly spinning blades to stay in the air and maneuver.

Most planes use engines and wing structure to move and stay aloft.

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**Analysis: Aircraft**

**Pros**
- Stability
- Ease of Use
- Speed

**Cons**
- Power/fuel use
- Works best in stable atmosphere

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**What works on the moon?**

Engineering is all about trade-offs.
- Size
- Cost
- Power use
- Speed
- Situational use
- Sturdiness

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**Wheels on the moon**

Practical, but care has to be put into hiding the axle from the regolith, to prevent jamming. The wheels would need to be large and wide, or very light, to avoid sinking too far into the regolith.

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**Treads on the moon**

Strong, but use a lot of power to move relatively slowly, so not always useful.
Legs on the moon
Practical, but high power use, and would need good dust shielding for all of its moving parts. Would also need wide feet to avoid sinking into the dust.

Gyrosopic Balance on the moon
All benefits of gyrosopic balance over normal wheels (smaller footprint, etc.) disappear when climbing a hill made of dust.

Air on the moon
There is no air on the moon, so rotors won't work. However, some jets could work well as scouts if fuel isn't in demand – and that's how we got to the moon to begin with.

Next Time
Challenges to Lunar Robotics

Robots on the Moon

Challenges faced
- Low Gravity
- Vacuum
- Regolith
- Radiation
- Temperature
Low Gravity

- Not a direct threat, but it makes designing things more complicated.
- Engineers have to do more computer simulation and less real simulation to test their designs.

Vacuum

- Heat Ventilation is difficult.
- Many electrical components need atmosphere.
- Solution: Don’t use those components, or make an airtight chamber.

Regolith

- Dust can foul up many mechanical parts.
- Sealing against dust increases cost, weight, and heat.
- Solution: Seal anyway, and compensate in other areas. Of course, regolith is still a threat.

Radiation

- Can foul up many sensitive electronic parts by changing values or interfering with electrical flow.
- Solution: Put delicate things in shielded areas of the robot.

Temperature

- With no atmosphere, temperature changes very quickly.
- Surface of the moon is exposed to extreme highs and lows of temperature.
- Any moisture in a robot would boil in the sun.
- Solution: Sterilize robots carefully, have layers on the outside of robots to trap or bleed off the heat.

Case Study: Lunar Rover

- First built in 1970
- Used Wheels
Why Not Wheels?
- Technology has changed since 1970
- It will change more in the future
- Advances make other things easier.

Sample Advances
- Treads: Batteries and energy storage have advanced.
- Legs, Gyroscopic Balance: Not even feasible in 1970

Conclusion
- How would you design a robot?

Energy Options for Lunar Robots

Energy Sources
- Direct Power from Base
- Battery Power
  - Solar Power
  - Wireless Power Using Microwaves
- Protecting the Circuit

Direct Power from Base
- Robots that work inside the base or do outside maintenance.
- Robots who work near the lunar elevator will also have the option of being powered directly by the base.
- Recharge robots near the lunar elevator working on mining craters
**Battery Power**

- Robots in charge of exploration and/or mining
  - (E.g. silver-zinc batteries used for Russian Lunar Rover)
- Battery Powered using any of the following:
  - Wireless Power using Microwaves
  - Solar Power

**Solar Power**

- Moon receives 13,000 TWs of Solar power
- In a lunar cycle there are 13.6 days of light available to the base and robots can receive and store some of that energy
- Robots outside of base can last longer without depending on base

**Wireless Power via Microwaves**

- For robots that cannot rely on solar power we can use microwaves to beam power to the robots who cannot rely on solar power
- Robots that do mining near the base
- Access Points set across robot paths

**More Efficient way of Providing power**

- One idea is having robots that do mining in craters have two battery packs that have robots replace their batteries
- Have small robots that are always directly connected to base change batteries for robots doing mining

**Protecting the Circuit**

- Electrical and Magnetic interference from solar flares
- Proton Storms disrupting circuit
- Using shielding around circuit we can prevent interference and degradation of signal caused by proton storm and lunar radiation