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The Martian Farm: Building Soil from Regolith

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Reasoning

As science teachers we know experiments are the best way to reinforce phenomena studied within the classroom. However, many of these experiments, while reinforcing phenomena, do not always teach our students what scientists do most: “collect data”. But to be clear we don't simply collect the data, we also chart it and find a way to disseminate it to our peers in a digestible manner. This understanding of charts is also a large component in many standardized tests which administrators are always keen to focus on. This project is formed by the fact that over the course of a year I built a vivarium in my classroom. We are all likely familiar with a terrarium which is a largely self-contained ecosystem. A vivarium focused on a living creature like *Lacertilians* (Lizards), *Lissamphibia* (Amphibians), and insects inside a simulated natural habitat. In building a biome step by step in front of the students I noticed engagement from all my students not just those asking questions, but every student took time when entering or leaving the class to examine the tank. First, I started with soil. The soil includes a fault bottom of stone and sand as a filter and a pump to recycle the water back to the top of the tank and create artificial flow. Then structures in the tank such as climbing zones for future animals and planting pockets for vegetation. Then by slowly adding plant species, isopods and amphibians I created a study of ecosystem construction students were actively engaged in.



Fig 1 - generated image of students examining terrariums

Students rush into my room every day simply to see what was new in the vivarium tank looking to observe and even give the inhabitants, the class has now adopted, names to be included with the species name as they were introduced. This unit has the ability to be adapted for use on many different grade levels depending on how in depth you are willing to develop the ecosystem. For the purposes of my 8th grade class, we will simply be creating a terrarium to start with the possibility of extending to insect life and worms will depend on how successful the ecosystem building is towards a self-sustaining biome. By moving from Earth to Mars, assuming the two systems are analogous, we can explore the same phenomenon in a seemingly new and unique way. Datasets can be collected in a much smaller footprint as they have one snapshot of one reason to consider given the limited data available from Mars. This provides the opportunity to explore life science here on earth by adapting it to an alien environment. By using the different approach students can see the benefits that could also apply to stabilizing or repairing earth's environment. Since the earth's environment does not possess the characteristics to show the effect quickly and we are assuming the two planets are analogous we should not expect to see changes overnight. Students need to adopt the adage, "Good things come to those who wait" so this unit will need to be taught in start and stop pieces with students logging data throughout the entire yearlong experiment.

There are many options when discussing colonization of another planet. We could be discussing whether life ever existed on Mars to begin with as would really fit in a planetary unit within general science class or be a complete science class on its own. We could be discussing options for overall global terraforming done remotely before humans arrive which would be an excellent endeavor for an environmental science unit in a general science class or on a high school or college level could be a course alone. However, all of these things are specific to the Martian trip and this unit is meant to be a stand in for earth's soil Biome. Working with the tools of curiosity we can establish a baseline for students who wish to learn more while advancing their science knowledge and hopefully encourage them to move forward not simply pass the current science class.

We all love our gardens on campus when we can build them provided lack of labeling does not lead to landscape crews destroying them. Also, the outside garden provides us with too much to start with to understand the complete soil building process to create the desired microbiome involved. This also gives us the opportunity to create experiments within our classrooms to avoid the trauma of our students losing their experiments midterm due to the landscaping crew or simply a bad growing season due to variables outside of the control of the students. And the key take away from this process is that we keep them asking questions and interested in their experiment through the entire year. The observation skills and the note taking skills that this year long experiment will be developing will follow them beyond this science class and serve them well into the future.

The Martian Farm: Bridging the Gap from Regolith to Soil

Imagine you are the lead botanist on a human expedition mission to Mars. Forget the “poop potatoes” [1] from the science fiction novel “The Martian” we’ve got something much cooler, and a lot less messy. You are standing in a high-tech greenhouse in the middle of Jezero Crater, staring at a pile of reddish, sterile dust called regolith. Your mission is to turn that regolith into living soil and feed a crew that is millions of miles from the nearest grocery store.

As exciting as it might be to take a class on a Martian field trip there would be many challenges not to mention a permission slip that felt like signing a home mortgage. So, we do what children do best, we imagine and pretend. We all know children learn best through play[2] and with fantasy being a form of play teams of students have conversations they normally would not. One of the first things that they learn is the logistics are staggering. Shipping two years of food for just four people adds seven tons of weight to a rocket.[3] As humanity examines the prospect of multi-planetary existence, a significant barrier to long-term Martian habitation is not the transit, but the ability to sustain life through localized agriculture. To survive, we must master in situ resource utilization which is basically space-talk for “living off the land”.

Students will be looking at data and images from the Mars 2020 Perseverance Rover and 2011 Curiosity Rover samples to determine how to transform Martian regolith a sterile, loose layer of toxic weathered rock into a functional soil capable of supporting plant life. The students’ essential questions are, what are the specific chemical, physical, and biological constraints that differentiate Martian regolith? How do we get from regolith to Earth’s fertile soil? What that means is we need to understand the components that make regolith which is nothing more than decomposed rock with no organic compound. As opposed to the soil on earth, which is a living microbiome ready to support the more evident life. By doing this the students will also understand the difference between biotic and abiotic.

Laying the groundwork

This unit is going to be used for my Title 1 8th grade science class in Tulsa, Oklahoma where the student body is 53% female and 47% male, with a diverse racial makeup and roughly 83% of students classified as economically disadvantaged. Thoreau Demonstration Academy is a magnet school and uses a lottery-based

enrollment process. While this unit is designed for my school the materials in it can easily be expanded or contracted and simplified if needed for a higher or lower grade level.

The project involves a long-term investment as soil building and it is not a rapid endeavor. The analogy related to the soil on earth would be the reversing of desertification to improve our overall environment on Earth. As students are working through this unit we will also be engaging in environmental science that relates to earth. By understanding how to reverse desertification of Mars it is an analogous for what we need to do on earth. Students will already have an understanding of how environmental systems work together to create the cycles on earth. This project simply allows them who gain an understanding in the same cycles by controlling them. Students will start with what is in essence a container of moist sand that is sterile. By adding the separate components outlined in this lesson, we can see how soil composition is built over time from pioneer species through layers of development to become a load that is capable of sustaining a myriad of food crops.

Know Your "Dirt"

Before you can plant anything, you must know what you are working with. Thanks to the Mars 2020 Perseverance Rover and Curiosity Rover, we have the composition of samples from Atmo Mountain, Crosswind Lake and those collected from the Jezero Crater. Going with Jezero Crater the regolith there is mostly weathered basalt consisting of rock-forming oxides like SiO_2 (Silica), Al_2O_3 (Alumina), MgO (Magnesium Oxide), and CaO (Calcium)[4]. It is quite fitting that we will be using data from the Curiosity Rover to inspire curiosity.

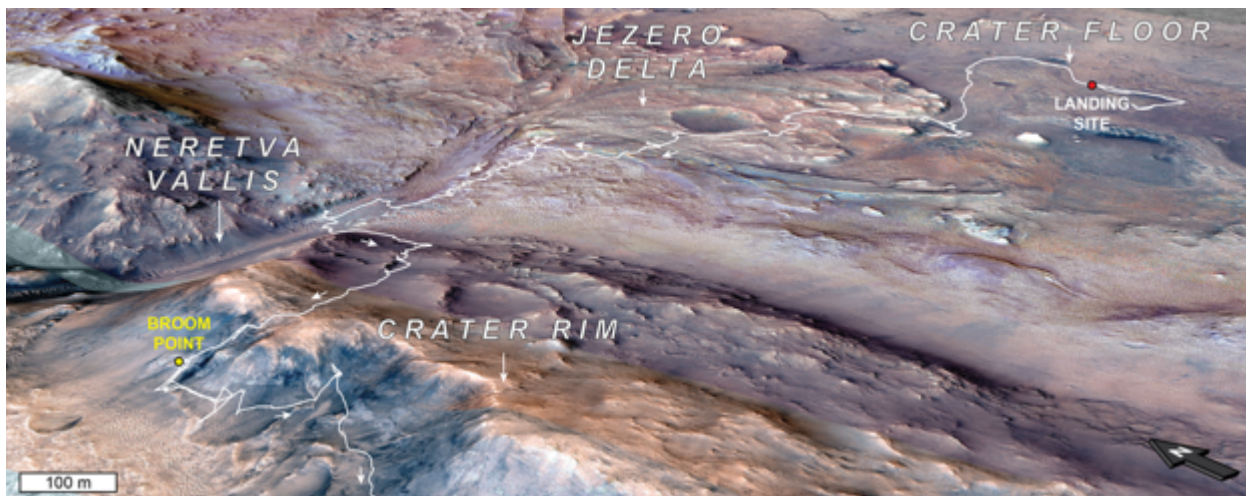


Fig 2 - This orbital map shows the path NASA's Perseverance Mars rover took from its 2021 landing site in Jezero Crater to the "Broom Point" location in mid-2025.

Credit: NASA/JPL-Caltech/MRO/HIRISE/UA/ICL -

<https://www.jpl.nasa.gov/news/nasas-perseverance-rover-reads-record-of-ancient-mars-impacts/>

As humanity moves toward long-term habitation on Mars commonly referred to as the Red Planet, the pedagogical challenge for educators shifts from teaching static facts to fostering a dynamic "Human-Machine Partnership". The Mars Curiosity Rover, which landed in Gale Crater in 2012, has amassed a vast dataset that

provides the perfect testbed for this evolution. By moving from manual data harvesting to AI-assisted synthesis, students can transform from passive observers into active "Lead Botanists," mirroring the real-world workflows used by NASA scientists to manage complex interplanetary missions.

Harvesting scientific data in this lesson involves manual data extraction, requiring students to identify the raw scientific benchmarks necessary for a Martian Farm. Students begin by pulling individual pieces of data from Curiosity's primary instruments to create foundational charts. For instance, they can examine sedimentary deposits for evidence of indigenous nitrogen, a critical nutrient deficiency that must be solved to turn regolith into soil. In previous sections such as "Bridging the Gap from Regolith to Soil" we are beginning to develop an understanding of how little value there is in Martian regolith until we begin to transform it to usable soil. Using data students can compile rock-forming oxide data (such as SiO_2 , MgO , and FeO) to establish a geochemical baseline for Gale Crater, which they then compare to the average Martian soil unit.

This phase fulfills the Oklahoma Academic Standard 8.ESS1.3, which emphasizes the analysis of data to determine the properties of solar system objects. In the classroom setting students will simply be examining the data provided from NASA rovers and analyzing the data to determine the best spot for their fictitious Martian base. Once students understand the nature of a dataset, the lesson evolves to incorporate Artificial Intelligence (AI) as a research tool. Rather than seeing AI as a shortcut, it is framed as a technological extension of the human mind, capable of managing massive datasets to identify patterns that might be invisible to the naked eye. However, by collecting the data and having students chart it on a line graph they can compare how sites are different and how sites are similar to determine the site they feel they can be most successful.

There are sources for simulated Martian regolith, but they are cost prohibitive for our district. For our project we will simply be using red lava rock for gas grills as Martian regolith is primarily 45% to 60% basalt. This is not a perfect stand-in however if you shop around for basalt that has a red color it is higher in iron and will give the correct color for appearance it will provide the correct chemical makeup. As part of preparation of the lava rock I will be roasting it to sterilize it as well as aid in mechanical weathering. Mechanical weathering is an excellent demonstration to do for classes as it is part of the soil building process. As this is a process that requires high heat it will be demonstration and preparation of materials for students. The process of using extreme temperatures to fracture rock is called thermal shock. This is the same stress that the Martian surface experiences as rapid temperature changes of about 100°C between day and night. When a rock is heated, its outer layers expand. Rapidly cooling the rock by a method such as dousing it with cold water causes the surface to shrink and contract at a rate faster than the inside, creating internal stresses that fracture the stone.[5] As most basalt is full of air pockets this can be a rather explosive experiment and should be tested before done in front of students to gain confidence, perfect the method to be used and ensure any necessary safety measures are observed. Because we all know the most memorable experiments for students are usually when something explodes. So as teachers, it is important to know the difference between controlled experiments and questionable practices. But done correctly a class in thermodynamics is easily achieved.

Water management

Water is the ultimate limiting factor in the space frontier. Working as Lead Botanists, students soon learn that water is not an unlimited resource as it is thought of on earth but rather a very limited resource to be conserved on the Red Planet. Water on Mars is very rare and chemically complex resource that must be engineered into existence as they design their Martian Farm. This pedagogical journey does not simply prepare students for a mission to Jezero Crater, but it compels a profound reflection on Earth's own diminishing potable water supply, recontextualizing a terrestrial crisis through an extraterrestrial lens.

One of many big obstacles to Martian agriculture is that most of the surface water exists as polar ice or "brines", liquid water so saturated with salts and toxic perchlorates that it is not suitable for biological use. To address this, the project looks at how using an advanced two-stage treatment system could work. Students' model for bio desalination will consist of marine cyanobacteria (*Synechococcus* sp.) that can reduce salinity by ~32 %. For our exparament gravity filtration through naturally porous basaltic rocks adsorbing inorganic salts will not be necessary as we do not have salt contamination we are simply building organic compounds in the soil.[6]

Also, the mass multiplier or gear ratio of space travel makes it logistically impossible to ship a two-year water supply from Earth. Thus, the Martian habitat needs to create an absolute process to meet a requirement for nearly 100% recycling capability. The closed loop mandate turns the farm into the living machine where every drop is recovered, purified and reused. However, the end goal will be to create an ecosystem in a jar that can do it perpetually after initial production of the water.

A mirror of scarcity that focuses on extreme efficiency is a stark contrast to the water reality here on Earth. Earth is often called the Blue Planet, but less than 1% of all water on Earth is fresh water. We are now facing our own silent crisis with groundwater, which provides 50% of the world's drinking water, being depleted to unsustainable rates in places such as India, China and Japan also referred to as the Asia-Pacific region. Students learn about the salinization of Earth's agriculture, what happens when intensive irrigation causes dissolved salts to collect at the surface, stunting plant growth and increasing soil erodibility, and the consequences for the planet. This terrestrial problem is a parallel to the Martian brine challenge, illustrating to students the reality that Mars' "hostile" chemistry is becoming a reality for farmers in water-scarce regions on Earth.

Their project demonstrates that the innovations required for Mars have immediate indirect benefits for Earth. For instance, the MELiSSA (Micro-Ecological Life Support System Alternative) project, designed for space habitats, in collaboration with private industry has already given rise to advanced filtration technology that currently purifies millions of cubic meters of water in towns across the globe today.[7] In a Holistic Management framework students learn to manage an effective water cycle where nothing is lost to evaporation or runoff. They also need to choose crops with a low water uptake/transpiration ratio such as turnips and lettuce, to maximize biomass while minimizing water demand.

When students learn water management is at the heart of their Martian Farm project, it teaches them that no matter where they are standing, in a greenhouse in Jezero Crater or a field in Oklahoma, water is a precious, finite commodity. They solve the puzzles of desalination and recycling on Mars and build the computational thinking and environmental responsibility needed to protect Earth's own parched landscapes. In the end, the project reaffirms the Earthrise view: the recognition that our home is a seamless whole in which sustainability

is not merely a mission objective, but a condition of human survival.

The Soil Contaminants

The dream of long-term human habitation on Mars is fundamentally a challenge of the biological transformation of a hostile, alien landscape into a life sustaining garden. Central to this effort is managing the chemical composition of the Martian surface. When we compare the contaminants in Martian regolith to the problems facing agriculture on Earth, a striking paradox emerges, while the specific chemical villains differ, the underlying strategies required for sustainable management are remarkably similar.

One of the primary chemical barriers on Mars is the presence of perchlorates and high salinity brines. While compiling this unit I reviewed many documents and papers including *Farming on Mars: Treatment of basaltic regolith soil and briny water simulants sustains plant growth*. It is by reading papers like this we stretch ourselves to be scientists that teach not simply science teachers. This paper along with the other cited and real data from NASA provide the foundation needed to teach this unit confidently. Martian regolith is largely weathered basalt containing salts such as sulfates and perchlorates. These perchlorates are toxic to plants and can severely inhibit seed germination. Unlike most Earth soil issues, these contaminants are indigenous; they are the products of the planet's unique, arid atmospheric interactions over billions of years. Furthermore, much of the available water on Mars exists as brines—liquid water so saturated with salts that it is unfit for direct agricultural use. These brines cause osmotic stress, where plants must waste excessive energy just to acquire water from the soil solution, leading to stunted growth or death.

In contrast, the contaminants on Earth are largely the result of human management or as some refer to the problem human mismanagement, as documented in Jo Handelsman's book *"A World Without Soil"*,^[8] Earth's agriculture is currently in a silent crisis driven by erosion, which is occurring 10 to 100 times faster than soil can be produced. .

While Mars faces natural toxicity due to the interaction between volcanic eruptions and UV rays, Earth's soil is contaminated by anthropogenic inputs. These include the overuse of nitrogen fertilizers, which leads to the emission of nitrous oxide a potent greenhouse gas, and the contamination of groundwater. Additionally, modern agriculture relies heavily on herbicides like atrazine and glyphosate, which, while killing weeds, can be toxic to the broader environment and contribute to the degradation of soil architecture. The concentration of dissolved salts, minerals, and nutrient management are key despite these different origins, the management problems converge in the realm of salinity. On Earth, intensive irrigation in regions like the Asia-Pacific has led to salinization, where salts from groundwater accumulate at the surface, stunting plant growth and heightening erodibility. This mirrors the Martian challenge of farming in a salt-rich environment. In both cases, success depends on maintaining a healthy soil solution and managing the practical sodium adsorption ratio to prevent the soil structure from collapsing.

Another similarity lies in the nutrient gap. Martian regolith is critically deficient in fixed nitrogen and organic carbon. Similarly, Earth's eroded soils are stripped of the very organic matter that holds nutrients in place, forcing farmers to prop up yields with excessive chemical supplements. Both systems require a shift toward bioregenerative cycles. A shared solution for both planets is biological. On Mars, researchers have demonstrated that using cyanobacteria (*Synechococcus* sp.) can effectively bio desalinate water, while

passing that water through porous volcanic rocks can achieve a 91% total reduction in salinity. Once the toxicity is managed, "pioneer species" like alfalfa can be grown to create biofertilizer, adding the missing organic carbon and nutrients needed for food crops.[9]

This mirrors the soil heroes on Earth who use conservation agriculture practices such as no-till planting, cover crops, and intercropping where deep-rooted perennials are used to rebuild soil health and sequester carbon. Just as Martian botanists must use Rhizobia bacteria and VAM fungi to turn sterile dust into living soil, Earth's farmers must steward the microbial workforce to naturally fix nitrogen and decompose organic matter into fertile humus.

The contaminants of Mars are a product of its ancient, alien nature, while Earth's soil problems are a product of modern industrial choices. However, both frontiers teach the same lesson: soil is a "living machine" that requires rock, water, and life to function. Whether engineering a greenhouse in Jezero Crater or restoring a field in Iowa, the path to sustainability lies in holistic management—treating the soil not as a chemical substrate to be "cleaned," but as a biological community to be nurtured.[10]

The wonderful world of soil microbes

The next step of the project will be research based and dependent on the students' ability to find an adequate pioneer species. The decision will need to be made whether that should be a food crop, a fuel crop, or simply biomass tilled back into the soil. This is one of the best chances in the unit to explore different farming techniques and how they are beneficial, detrimental and what would be appropriate. In our project we are planning on having students envision working in a dome. If this was done as planetary terraforming, dust storms would be a large consideration. As an Oklahoma teacher our students are generally taught about the 1930s Oklahoma dust bowl environmental disaster which was caused by many years of draught, high winds and poor farming methods which stripped the soil. The students understand that it was not simply a removal of soil but a loss of light. I will not have my students addressing the issue of 20% less light during a sandstorm however we will consider the fact that Mars only gets 50% of the light that earth does on a good day. Students again will engage with the data to determine growing times as well as light requirements to generate the most biomatter they can.[11]

This moves the process on to fungi and bacteria colonization of the fledgling soil. This opens us to the next set of critical thinking questions that students will grapple with such as, What type of microfauna is best and allows students to determine if their agricultural techniques are effective? We will engage in conversation of the different types of bacteria such as:

- **Bacillus:** Known as "plant growth-promoting rhizobacteria," species like *Bacillus subtilis* and *Bacillus megaterium* aggressively solubilize tightly bound phosphorus and potassium. They also produce enzymes that break down organic matter and help shield roots against pathogenic fungi.
- **Rhizobium:** These symbiotic nitrogen-fixing bacteria form nodules on the roots of legumes (like beans, peas, and clover). In exchange for plant sugars, they capture atmospheric nitrogen and convert it into a usable nitrate form for the plant to consume.[12]
- **Actinomycetes:** While technically a type of bacteria, they look and act like fungi. They are famous for their signature "earthy" smell and are critical for decomposing complex, woody organic matter and

humus.[13]

- Pseudomonas: These bacteria thrive around the root zone (rhizosphere), protecting plants by consuming resources that harmful bacteria need to survive and producing compounds that restrict pest activity.[14]
- Lactobacillus: Frequently cultured in natural farming practices using fermented starches (such as rice water), these bacteria help break down organic matter, improve soil pH conditions, and suppress the growth of foul-smelling putrefying bacteria.

While Martian regolith has some minerals, it is missing some minerals that are the major components to life. On Earth, soil is a living machine made of rock, water, and organisms. Martian regolith is essentially sterile; it lacks the organic carbon and fixed nitrogen that plants crave. This will introduce students to comparing these mineral components to the nutrients Earth-based plants require like nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg).

Meet the Pioneer Species

Drawing from Handelsman's book "A World Without Soil", students will learn that soil is not just "dirt," but a mixture of rock, water, and life. You can't just drop a tomato seed into raw Martian dust and expect a harvest. You need a "pioneer species" to do the heavy lifting required to be successful. This is an opportunity to reinforce the time span required before these processes can take place. Students can see how lifeless soil on Mars must be carefully constructed at the same time here on earth we are systematically destroying key parts of soil biome which could take decades to repair. During our investigations we determined that Mars has special needs beyond that of simple fertilizers. At this point the student should be understanding the length of time that is required to generate proper soil. We are in a step-by-step building process and every step is critical to minimize the time required to create food crops. To that end, we need to be selective in our pioneer species and what they can provide to the environment. This gives students a chance to investigate how different pioneer species are required for different biomes. In the case of Mars there are several good candidates that provide different benefits to the virgining soil. This is where cyanobacteria can come in not just to remove the perchlorates salt but "de-salt" Martian water, and then they can be processed in an anaerobic digester to create a super-concentrated liquid fertilizer with results that are incredible with just one gram of cyanobacteria can produce enough fertilizer to grow 27 grams of duckweed, a fast-growing, high-protein "super-crop".[15] It is a steppingstone game but once a crop like alfalfa is grown you can crush it up into a powder and mix it back into the regolith as biofertilizer. This process adds the missing nutrients and helps the soil hold water. Experiments show that this "alfalfa-treated" soil can boost the growth of food crops like turnips, radishes, and lettuce by as much as 300%. Students will have already researched nitrogen-fixing bacteria (rhizobia) and mycorrhizal fungi. It may be possible to have student produce a "microbial starter kit" that could be introduced to other sterilized Martian regolith to initiate nutrient cycling. This allows students to experience how chemicals released from living and dead organisms are the key to Earth's fertility in the rhizosphere, where plant roots pump carbon into the soil to feed microbial communities. This truly turns regolith into soil. Since the initial experiment is being completed on a smaller test area and the students are keeping a journal of each success and failure throughout the process it would be an easy process to create a "microbial starter kit" which would make expanding to a larger area easier and quicker to accomplish. In the Martian Soil Plant Growth Experiment, researchers found that adding Rhizobia bacteria and VAM fungi was a

total gamechanger. VAM fungi act like a massive extension of the plant's root system, increasing the surface area for taking up nutrients by up to 1,000%.[16] By using these tiny allies, we can utilize the nitrogen already in the Martian atmosphere instead of shipping heavy tanks of fertilizer from Earth. This can lead to other plant species whose job is strictly to develop the soil long term.

- Snake Plant (*Sansevieria* / *Dracaena trifasciata*): One of the most adaptable pioneer species for low light. It tolerates deep shade, drought, and neglect.
- Creosote Bush (*Larrea tridentata*): This is a quintessential native desert pioneer. It thrives in poor soils and low moisture. While it prefers sunlight, its waxy leaves help it survive filtered, low-light conditions.
- Cast-Iron Plant (*Aspidistra elatior*): Renowned for surviving extreme neglect, this plant is an excellent choice for deep shade and requires very little water once established.
- Mesquite Trees (*Prosopis*): In absolute desert environments, mesquites act as foundational pioneer trees. They anchor roots deep into the ground, fix nitrogen, and create the microclimate/shade needed for smaller, more sensitive understory plants to eventually grow.

The Arthropod Architect

The final frontier towards sustainable long-term survival on the Red Planet is the conversion of the sterile Martian regolith into a working, bioregenerative substrate true garden soil which is the pinnacle of the farm. Again, Earth's soil is not just a pile of crushed minerals. It is a complex living machine, the product of a complex marriage of rock, water and life. The lesson designs target the geochemical baselines of Jezero Crater, but the addition of arthropods, tiny insects and larvae, is a vital engineering step in establishing a self-sustaining ecosystem. These organisms are the physical architects and biological catalysts necessary to turn Martian “dirt” into a livable environment.

One of the main contributions of arthropods is the physical engineering of the internal infrastructure of the soil. “Surface capping” is a major hurdle to agriculture on Mars and Earth. This is when a hard, cemented crust forms on the surface of the soil which blocks air and water from reaching the roots of plants. Arthropods create complex networks underground, which provide essential porosity and aeration. The constant movement over the substrate allows mineral atoms to mix with organic “glues” such as polysaccharides and proteins released by plant roots and microbes. This process glues separate fragments into stable aggregates or “clods”. This creates a breathable environment in the rhizosphere.

In addition to their physical structure, arthropods are vital players in the “Mineral Cycle,” a fundamental component of Allan Savory’s Holistic Management System. When these organisms die their remains are broken down by fungi and bacteria on a microbial level after scavengers have eaten the soft inner tissue. This decomposition breaks down intricate polymers to bioavailable nutrients such as nitrogen and phosphorus, which are returned to the “soil solution” to feed the next generation of crops. A fascinating chemical indicator of this increased fertility is the release of melanin in the decomposition of soil insects. This pigment accumulates in the soil and imparts a darker hue, moving the composition away from the weathered basaltic red of Mars toward the deep black of highly productive soil. This adds the ability for students to make observational science on the ever-changing color of their soils.

In the project, students simulate the iterative testing phase of the project and observe how arthropods

accelerate the decomposition of 'pioneer species' such as alfalfa (*Medicago sativa*) a possible first crop into nutrient-rich green manure, thereby greatly increasing the biomass of consumable crops. This improves "Community Dynamics" and ecosystem resilience, which is a "absolute requirement" for deep space missions that require nearly 100% recycling capability. Arthropods are part of a biodiversity reservoir that retains important functions after environmental perturbations, for 8th grade students, the analysis of these interactions is a direct application of Oklahoma Academic Standard 8.LS1.5. Describe explanations that detail how environmental factors affect the growth of organisms. Students meet engineering standards (MS.ETS1.1) for defining the specific criteria and constraints of a closed-loop habitat by including arthropods in their bioprocess designs. At the end of the day, the challenge of making another world into a home is a socio-technological one, where human ingenuity and biological agency must work in inseparable partnership.

Thinking Like an Ecosystem

As the first plants are growing our team will advance from starting a system on Mars to managing the systems. Due to the closed system nature, this needs to be Holistic Management. Students will now manage four big ecosystem processes: the Mineral Cycle (recycling nutrients), the Water Cycle (making every drop count), Community Dynamics (getting plants and microbes to work together). And last, but in no way least, the Energy Flow is needed to capture every bit of sunlight and store it in the soil.

To manage a Martian farm holistically, you must treat it not as a collection of individual plants, but as a single, inseparable "living machine" where the soil, biology, and human management function together to achieve a holistic goal. Students will learn this is not the earth where natural processes exist to repair and revitalize the environment. This is Mars a cold barren dry region where all resources need to be managed.

In a holistic sense, the best manner to manage minerals is to move from the "Incomplete" cycle of raw Martian regolith to a "Very complete" cycle, where minerals are consistently recycled through many levels of organisms. Through the process of the unit the student started with raw mineralized Martian regolith but were given seeds which for the purposes of demonstration would come from earth. Water will be one of the main variables as the uncertainty of amounts of water on Mars are not conclusive. The Biogeochemical Engine focuses on humification which is the microbial transformation of plants and microbial litter into humus. So, students will essentially be turning dry dusty sand into a moist sponge capable of sustaining life. Humus acts as the dominant storage component for essential elements like carbon, nitrogen, phosphorus, and sulfur. Nutrient bioavailability is measured by soil solution, the liquid phase where chemical reactions happen. Management must ensure nutrients are in a bioavailable form rather than locked in unusable solid phases. This brings students back to their initial choice of microbiome for the soil and whether it now needs to be adjusted.

The Big Picture

This unit will provide more than just the core academic requirements it will expand students to think about how creating a Martian environment relates to research done here on earth. We are not growing Martian plants we are growing earth plants on Mars therefore studying the earth's environment is the prerequisite to any research. Also, students will gain an understanding of teamwork as this mission is too big for one person or even one country. It's a worldwide cooperative effort involving 13 space agencies. who are using the Moon as a "crawl-walk-run" testbed to perfect these systems before we head to the Red Planet.

- **NASA (United States):** Leads extensive Mars missions, including the *Curiosity* and *Perseverance* rovers, and is the lead for the "Moon to Mars" architectural roadmap.
- **ESA (Europe):** Operates the *Mars Express* orbiter and the *Aurora* exploration programme, and collaborates with other nations on missions like *ExoMars*.
- **Roscosmos (Russia):** Collaborates on the *ExoMars* program and maintains ambitious national projects for Mars exploration.
- **CNSA (China):** Has developed ambitious national projects to explore Mars and was the third country to launch its own astronauts.
- **ISRO (India):** Launched the *Mangalyaan* (Mars Orbiter Mission) and is involved in international coordination for future exploration.
- **JAXA (Japan):** Participates in global coordination and has ambitious national projects for Moon and Mars exploration.
- **Canada (CSA):** Provides specific expertise in **space robotics**.
- **France (CNES), Germany (DLR), and Italy (ASI):** Discussing future national missions and providing instruments for international missions.
- **United Kingdom (UKSA):** Involved in discussing future national missions and strategic planning.
- **Australia (CSIRO), Republic of Korea (KARI), and Ukraine (NSAU):** Listed as participating members of the ISECG framework for coordination.
- **The Global Exploration Strategy (GES):** A voluntary, non-binding forum where these 13 agencies share strategies to reach exploration goals more effectively.
- **International Mars Sample Return (MSR):** An international objective to return samples collected by the *Perseverance* rover to Earth for analysis.
- **The Artemis Accords:** NASA-led collaborations with international partners to ensure a safe and peaceful future in space exploration.

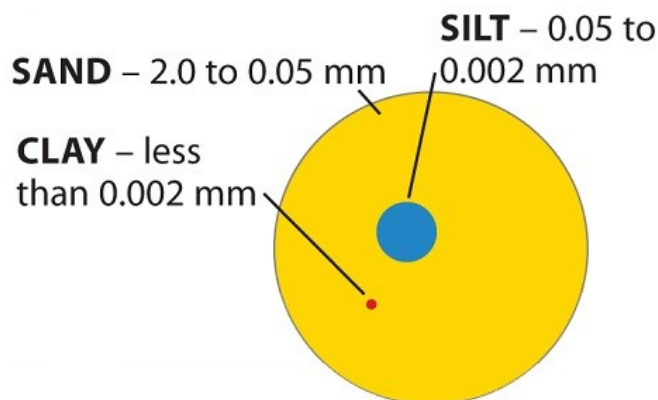
This is a long-term project, and my students are not tackling all aspects simply the soil. The social commentary and discussion that they have around topics that are not directly related are the questions that fuel inquiry. Mastery of this lesson is demonstrated when a student can take the synthesized characteristics in the physical chemistry of regolith with the biological requirements of terrestrial plants to propose a viable, engineered growing system. By the conclusion of the unit, students will understand that the transition to Mars requires not just a change in location, but the active creation of a "living machine" in the soil that makes human life possible. This mirrors the three-dimensional learning expectation of the Oklahoma Academic Standards, integrating Science and Engineering Practices with Crosscutting Concepts like "Stability and Change" and "Energy and Matter". By the time students finish this unit, they won't just be students, they will be part of a global movement to turn another world into a home.

Student Lab Activities

Building soil on Mars is a process of transforming sterile, toxic weathered rock into a "living machine" capable of sustaining plant life. The following student labs are designed for an 8th-grade science curriculum, moving from the geochemical baseline to a managed holistic ecosystem.

Lab 1: Analyzing the Martian Fingerprint (Geochemical Baseline)

Objective: Students will identify the mineralogical properties of Martian regolith using data from the Martian rovers that is available on NASA's website. Students will chart their data and analyze the data in the decision process of which site offers the best option for creation. Students will then share their findings and the reasons they have chosen a specific site with the class in order that a discussion of beneficial sites can be had. In this section we will also be starting our simulated regolith by having students manually cross basalt rock used for gas grills. After some effort by the students, they see a demonstration that simulates some of the mechanical weathering processes needed to create fine-grained soil. I will use thermal shock to break up basalt lava rock commonly used in a gas grill by using heating and cooling cycles if this fails to produce fine particles sand can be substituted.



- **Oklahoma Standard:8.ESS1.3** (Analyze and interpret data to determine scale properties of objects in the solar system).
- **Procedure:**
 - **Mineral Analysis:** Students compare the oxide concentrations (SiO_2 , MgO , CaO) found in data from the Martin **rovers reports provide by NASA**. - Students will present this data in a Graph forms showing different sites and different concentrations of mineral.
 - **Sieving:** students sort crushed basalt into grain sizes, targeting the **0.125-0.150 mm** range - Students will Formulate a hypothesis how to weather different particulate size affect the soil building process and how?
 - **Weathering Simulation:** Teachers demonstrate **thermal shock** by heating basalt lava rock to high temperatures and rapidly dousing it with cold water to fracture the stone, mimicking the breakdown of parent rock. This helps reinforce the laws of thermodynamics demonstrating the

correlation to earth mechanical decomposition cycle. - This provides an excellent segue discussion on the difference between mechanical and organic decomposition for the next lab.

- **Water retention test** - Place a filter paper inside the neck of the funnel or inverted top-half of the plastic bottle. **Add** 100 ml of dry uncompacted regolith simulant into the funnel over the filter. Place funnel and regolith in a catch basin over 200 milliliters this should avoid any possible spills. Slowly pour 100 ml of water evenly and not in one spot over the top of the regolith. Let all the excess water drip through into your catch container until it slows to an occasional drop. Pour the drained water from the bottom container into your measuring tool to find its volume. Subtract the drained water volume from your starting 100 ml. The remaining amount is what your soil retained

- **Scientific Inquiry:**

- The students will have achieved different qualities of regolith how does your result differ from other students?
- Does the particle size of raw regolith affect its ability to hold water and nutrients compared to Earth soil?
- Should our Martian soil development concentrate on a specific size for mixture in order to achieve the best water retainment?

Lab 2: The Desalination Challenge thru Inoculation Effect (Microbial Management)

Objective: Following discussions on soil contamination students begin building a closed ecosystem using their regolith simulant and cyanobacteria amendment for soil. If we had true regolith it would be contaminated with toxic perchlorates that our bacteria would not just be an organic building block but also work to neutralize the perchlorate that are damaging to plant growth. The criteria of desalination is a goal for success; however, there is no contaminant in the simulate we will be using. While they don't eat the salt, growing cyanobacteria can actually improve salty (saline) soils by adding organic matter, fixing nitrogen, and improving soil structure, which helps lower the overall stress of the salt on plants. This means the students will be learning to overcome the constraints of Martian soil without engaging in the process. Also, by adding a nitrogen-fixing bacteria like cyanobacteria student engage with microscopic living things that demonstrate how microbes function in the nutrient cycle by fixing nitrogen.

- **Oklahoma Standard:MS.ETS1.1** (Define the criteria and constraints of a design problem).
- **Oklahoma Standard:8.LS1.5** (Construct a scientific explanation for how environmental factors influence growth).
- **Procedure:**
 - **Grouping:** Students working in groups to Construct their Martian stimulated greenhouse in a jar using Sterile Simulant.
 - **Each team will need a sterilized jar and sterilized Martian stimulus.** For this lab dry heat sterilization will be adequate. In a lab or hot air oven you are required to reach a temperature is **160°C to 180°C (320°F to 356°F)** and maintain it for 60 to 120 minutes. I will prep this ahead of time Using the student prepared stimulated regolith in canning jars with the appropriate lid to create a seal as the jar cools.

- **Cautions given for the experiment:** each team will need to be careful as to minimize the amount of contaminants introduced to their jars throughout this year long experiment. - This is an excellent opportunity to talk to students about contamination and vectors.
- **Watering: the students will now decide as a team how much water their soil can hold and record their initial water investment. They will then measure out the appropriate amount of water and place it in a covered container.**
- **Soil inoculation: At this time, I will give each student a premeasured amount of beneficial starter bacteria. Once everyone has their bacteria and their initial water investment, they will carefully open their jar and place the water and bacteria in the jar closing it again.**
- **Monitoring and logging: this will be the first long-term observation and could take week to months. During this time students should be logging observations and adding water if necessary. Students may take the jar periodically to spread moisture and bacteria however they are not to be opening the jar. Observations can be done daily or weekly depending on our time and students will be observing the weight of the jar as well as any visual changes.**
- **Scientific Inquiry:**
 - How does the addition of Cyanobacteria increase water retention IE when you tip your jar does water run out of the regolith?
 - Do you think you have achieved creating soil and are you ready to plant?
 - Working at your fellow students' jars are you doing something different that is beneficial or negative and how could you improve the growth of your bacteria?

Lab 3: Meet the Pioneers (Building Organic Plant Matter)

Objective: Before the next phase of this project starts it is important for teachers to look at each of the jars that the students have created to see how well students have developed primitive soil up to this point. Through the teacher's observation, they will be able to decide if the students are indeed ready to move on to this section or if it is necessary to further augment the primitive soil. The largest question that needs to be answered by the observation will be: is the soil too wet, is there no biological growth to assist with bacterial growth. As many plants can grow hydroponically and initial growth requires little environmental import from the soil finding ways to move forward would be best. Students will utilize "pioneer species" to build the first layer of organic plant carbon in the fledgling Martian soil. The students will have examined many different pioneer species and how they establish environments on earth. For the purposes of my lab, I will be using alfalfa as it is easy to acquire though other species of plants could be substituted. If the initial plant failed to germinate it is possible to replant or change what type of seeds you are using to create a more dynamic experiment.

- **Oklahoma Standard:MS.ETS1.4** (Develop a model for iterative testing and modification).
- **Procedure:**
 - Repeat **Cautions given for the experiment:** each team will need to be careful to minimize the number of contaminants introduced to their jars throughout this year long experiment. - Again, providing an opportunity to talk to students about contamination and vectors.

- **Pioneer Growth:** Students will introduce **Alfalfa (*Medicago sativa*)** to their jar, because it is capable of growing in nutrient-poor environments. I will steer students to this crop as the one to be planted. Students using best practices to keep a sanitary environment will add the seeds, reseal the jar and shake the jar to bury the seeds in the soil.
- **Monitoring and logging:** students will continue to log data through observation and weighing their jars. The expectation is the seeds will germinate and grow if this is not the case reseed may be necessary.
- **Jar reaches maximum density:** as growth in the students' jar becomes prolific some biomaterial will need to be removed. Students will use scissors or simply pull out the plants leaving the soil behind. All plant matter removed from the jar should be placed in a paper bag and allowed to dry out.
- **Biofertilizer Production:** Once harvested and the alfalfa has dried it crushed into a powder. The next time that the jar is full and needs to be harvested the powdered plant matter should be reintroduced to the environment.
- **Scientific Inquiry:**
 - Why does alfalfa-treated soil boost the growth of food crops compared to untreated regolith?
 - What possible contamination vectors were introduced in this part of the experiment?
 - Is the overall weight of the jar increasing? Did you have to re feed your jar or not if so why?

Lab 4: The Arthropod Architect (Managing Community Dynamics / Don't drown the bugs)

Objective: Students will integrate macrofauna to engineer the physical structure of the soil and accelerate the mineral cycle. As we are introducing live animals into our environment it's important that students understand where the water table in their jar is. My recommendation would be to add some **Common Pill Bugs / Roly-Polies:** *Armadillidium vulgare* as they bring benefit to soil health by breaking down plant matter and improving soil structure by digging and aerating the soil. To be fair, placing an animal in a field environment could be a ticking clock on how long the animals survive. However, provided your student constructed the habitat effectively there should be significant environmental cycles present for this simple animal. At this time the students' observation of their jars will likely increase dramatically. Looking for an actual life form running around in their jar provides the level of inquiry that we as teachers seek. Detailed documentation of their environment at this point it should consist of weight and lengthy observations of plant, animal and bacterial growth.

Oklahoma Standard:8.LS1.5 (Environmental factors influence growth).

- **Procedure:**
 1. Again, Repeat **Cautions given for the experiment:** each team will need to be careful as to minimize the amount of contaminants introduced to their jars throughout this year long experiment. – Do the students understand how contamination happens and what vectors are at work in this experiment?
 2. **Structure Test:** Students may at this point observe the formation of a **"soil crust" (surface capping)** on wet simulant and its negative impact on root aeration.

3. **Macrofauna Introduction:** Students by adding **arthropods** to the soil to forge underground pathways that provide **porosity and aeration**. At this point the students should be aware if they cannot see their animals, it's because they are under the surface doing their job.
 4. **Observational Science:** Students log changes in soil color; as insects decompose, they release **melanin**, which shifts the soil from Martian red to fertile black.
- **Scientific Inquiry:**
 - **What was your first observation of your newly introduced animals to the environment?**
 - **Do you notice a change in bacterial growth since the introduction of the animals?**
 - **Have you noticed a difference in the plant growth since the induction of the animals?**
 - **Has the color of your soil changed over the course of the experiment if yes why?**

Notes

[1] (Weir 2014)

[3] (Hedges et al. 2013)

[4] (Ramalho et al. 2026)

[5] (Hausrath et al. 2025)

[6] (Hausrath et al. 2025)

[7] (Ramalho et al. 2026)

[8] (International Space Exploration Coordination Group 2013)

[9] (Handelsman and Cohen 2021)

[10] (MSc 2026)

[11] (Hausrath et al. 2025)

[12] (Kasiviswanathan et al. 2022)

[13] (Kliman et al. 1993)

[14] (Sposito 2008)

[15] (Sposito 2008)

[16] (MSc 2026)

[17] (Kliman et al. 1993)

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Relevant Oklahoma Academic Standards for Science (OAS-S) and Middle School Engineering standards:

1. Earth and Space Sciences (ESS)

- **8.ESS1.3:** *Analyze and interpret data to determine scale properties of objects in the solar system.*
 - **Application:** Students use raw data from the **Curiosity and Perseverance rovers** to identify chemical benchmarks and determine the best locations for a Martian base.

2. Life Sciences (LS)

- **8.LS1.5:** *Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.*
 - **Application:** Students explain how factors such as **perchlorates, reduced light (50% of Earth), and the addition of arthropods or microbes** influence the success of their Martian crops.

3. Engineering Design (ETS)

- **MS.ETS1.1:** *Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution.*
 - **Application:** Students must define the specific boundaries for a **closed-loop habitat**, accounting for the logistical gear ratio of shipping mass to Mars.
- **MS.ETS1.3:** *Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each.*
 - **Application:** Students use **AI tools** to compile and compare datasets from different rover sites to optimize their agricultural designs.

4. Physical Sciences (PS)

- **8.PS4.3:** *Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information.*
 - **Application:** Examining how data from Mars is transmitted and synthesized via **Artificial Intelligence** to manage a remote "Human-Machine Partnership".

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