FEATURE ARTICLE

Pioneering Mars: Turning the Red Planet Green with Earth's Smallest Settlers

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Abstract

Pioneering Mars: Turning the Red Planet Green with the Earth's Smallest Settlers (http://pioneeringmars.org) provides a partnership model for STEM (science, technology, engineering, and mathematics) learning that brings university scientists together with high school students to investigate whether cyanobacteria from Antarctica could survive on Mars. Funded by NASA, and aligned with the Next Generation Science Standards, this work engages high school students in every aspect of the scientific method, culminating with students designing and implementing experiments in a university lab – experiments that will be replicated on board the International Space Station. Beyond the potential scientific breakthroughs it may produce, Pioneering Mars provides a STEM education model for project-based learning using university and school partnerships. Our team consists of a university marine science professor, a STEM education researcher, four high school science teachers, and 85 high-achieving students. The model can easily transfer to leaders and learners across the United States who will be able to replicate and extend this effort in their own educational settings.

Key Words: *Marine science; experiential learning; students as researchers; cross-school-district collaboration; NASA funded mission to mars; International Space Station.*

> *If one day we were to see the planet Mars turn green with life, we'll know it was in part because of some high school students in Mississippi and Alabama.*
>
> A student participant in NASA's Pioneering Mars

Nationwide, STEM educators grapple with the following questions: How do we maintain students' interest? How do we make classroom practices meaningful? How do we keep students and teachers engaged and inspired by the content? How can we inspire high school students' interest in science careers? We hear responses like "Use more hands-on activities"; "Bring in real-world applications"; or "Integrate savvy technology-based applications." These are, of course, all easier said than done, especially with the growing responsibilities teachers must juggle on a daily basis.

Pioneering Mars: Turning the Red Planet Green with the Earth's Smallest Settlers, a project funded by NASA, attempted to address these issues by engaging high school students in real-world research that could have implications well beyond the classroom. There are three essential elements to our STEM education model: (1) collaborative learning among students and teachers across multiple schools, (2) close partnership with college or university educators and research scientists, and (3) commitment of off-campus time and transportation to support scientific exploration in a university setting. We are hoping our work will spawn national engagement in our project and inspire other implementations of similar projects, providing more students and their teachers with relevant and innovative STEM learning opportunities.

In the specific context of Pioneering Mars, our STEM model has been applied to investigate the hypothesis that cyanobacteria harvested from Antarctic ice could be cultured in the lab under Martian conditions. Simple proof of concept was our primary goal: Could cyanobacteria from Earth survive on Mars? Another was to design experiments that will be replicated on the International Space Station in microgravity culture chambers in 2015. However, groundbreaking science was only part of what Pioneering Mars was about – inspiring students with an exciting, multidisciplinary research topic and providing instruction through the application of our STEM education model was the key to collaborative, project-based learning. This was accomplished by entreating the science professor and teachers to guide students through the rigors of the scientific process, while the STEM education professor documents and adjusts the effectiveness of the collaboration itself as a learning tool. The collaboration works on many levels – two university professors, four high school teachers from different regional schools, and 85 students all learn from one another in a manner

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that encourages discovery and sets an exciting precedent for future projects.

Students at high schools in Bay St. Louis, Mississippi, and Mobile, Alabama, all had the opportunity to engage in hands-on research with a team of university scientists working on NASA's Mission to Mars project. The students involved found the potential impact of their self-designed research experiments thrilling. "High schoolers still have that imagination," shared one student. And another added, "We were feeling superior, learning things others hadn't learned in other classes and schools. Like we're being honored to be in this project, it's really cool." Their feeling of belonging to something "larger," relevant, and more scientific than they had ever experienced was equally important. What was more, students' exposure to and meaningful interactions with doctoral-level scientists and work on a university campus began to demystify their collegiate future while providing an understanding of the rigor of postsecondary science. One student shared, "The difference between here [the university lab] and school is that here they're treating us like adults. They give us the equipment, tell us to do something, and don't lean on us. We don't have to ask every time we need a slide. They just trust us."

○ Scientific & Educational Research

Under the tutelage of the marine scientist, high school students explored the efficacy of using cyanobacterial communities collected from natural Antarctic sea ice and cultured them in special incubators that could be manipulated to simulate the environmental conditions on the surface of Mars. Low-light, low-temperature culture chambers aboard the International Space Station will be used to replicate the physiochemical conditions of the Martian surface in a reduced-gravity environment. What makes the Pioneering Mars research truly extraordinary is that the project was specifically designed to provide high school students and their teachers with direct, participatory exposure to transformative, cutting-edge research that spans the STEM spectrum. Interaction with university researchers in their university-housed lab, as well as exposure to NASA protocols, was a critical component of this collaborative endeavor.

While the immediate goal of the experiments was simply proof of concept, the implications of such research could be transformative and far-reaching on an interplanetary scale. Scientists believe cyanobacteria to be one of the Earth's first terraformers. Could it also alter the Martian atmosphere over time if it can be successfully grown? Carbon fixation due to cyanobacterial production would effectively "scrub" the Martian atmosphere of carbon dioxide and alter the planetary environment with the primary production of organic carbon and a commensurate release of oxygen to the Martian atmosphere. The potential for this newly generated organic carbon to be consumed by methanogenic bacteria could lead to the release of methane, a greenhouse gas 30 times more effective at heat retention than carbon dioxide, into the atmosphere. Increased heating of the Martian atmosphere could subsequently melt the subsurface ice, liberating liquid water and thereby augmenting primary production and the general habitability of Mars. Fundamentally, Pioneering Mars and its products will expand our understanding of exobiological dynamics, interplanetary colonization, and planetary habitat/climate engineering.

In addition to the scientific goals and implications for the Martian surface, our team also documented and studied the STEM university–school partnership as well as the growth and development of all participants. We measured students' content knowledge, perceptions and views on scientific careers, understanding of the scientific process, whole-group interactions, and benefits of cross-school learning experiences. In our analyses, 100% of the students showed an increase in content knowledge, 64% of students showed an increase in interest and knowledge about STEM-related careers, and 85% of students expressed an interest in STEM as a career or postsecondary study as measured by post-responses.

○ The Calendar

The team administered the project in four parts, beginning with a series of core content lectures delivered by a university scientist in each of the four classrooms. Next, students and teachers from all four high schools participated in a scientific workshop designed to actively engage each student in the formulation of specific hypotheses and in the design of experiments, which would ultimately be used to test those hypotheses. Then each class visited the university laboratory multiple times to perform the students' experiments and begin analyses of their data. Finally, participants attended a conference at NASA's John C. Stennis Center to compare and present the results of their experiments.

○ The Preparatory Lectures

In order to provide students with the core content relevant to the project, three preparatory lectures were delivered by a university research scientist in each of the four participating high school classrooms during the fall semester (Table 1). The scientist designed the lectures to augment students' regular science curricula and delivered them in an informal, non-intimidating manner. The lessons began with a basic overview of planetary science (with a focus on important Earth–Mars comparisons) and led to deeper discussions of the challenges of supporting life on Mars, the photobiology of cyanobacteria (and why they make such good test subjects), issues critical

Table 1. Outline summarizing each lesson.

Pioneering Mars Lessons 1–3	
Lesson 1	• Project introduction • Proof of concept • Why cyanobacteria? • Planetary conditions • Light, gravity, temperature, orbit, atmosphere, water's triple point
Lesson 2	• Photobiology • Chemical and biological processes that power life on earth • Producers, consumers, carbon fixation, photosynthesis, cellular respiration • Experiment design issues and Martian environment
Lesson 3	• Experiment Planning • Logistics: Ordering cyanobacteria, flasks required, lab machinery used to collect data • Design: Liquid growth media and Martian head space

to experimental design, and the practical aspects of culturing algae for research purposes (http://pioneeringmars.org/classroom-materials/).

○ The Scientific Workshop

Following the lectures, the research team invited all 85 students and teachers to attend a scientific workshop at the end of the fall semester. Based on their exposure to project-specific content delivered in the preparatory lectures, students from each school served as Subject Matter Experts (SME) in one of four groups, according to personal preference:

- Team AER – atmospheric composition and climatology of Mars
- Team SAL – geochemical composition of Martian soils
- Team LUX – ultraviolet and visible radiation on the Martian surface
- Team VITA – fundamental requirements for supporting life on Mars

In preparation for the workshop, student SMEs were provided a number of research articles, specific to their focus area, to serve as background reading and as inspiration for group discussions.

Upon arrival, students received their group-specific workshop materials and assembled into four breakout sessions. The research team grouped students together from all four participating high schools with those who shared their subject-matter specialty. A high school teacher was assigned as facilitator for each of the four breakout sessions, where student SMEs were first acquainted with each other using a variety of icebreaker/team-building activities. Then student SMEs were given team-specific tasks that were presented for group discussion and consensus, the results of which ultimately served as the workshop products (i.e., critical research hypotheses and the experiments necessary to test them). Teacher facilitation of the student SME work-groups helped students make decisions regarding the experiment. They employed general instructions regarding management so that the workshop would function as much like a professional scientific workshop as possible. A critical component of this exercise was to discourage authoritarian input from the teacher facilitators, which could unduly influence the outcome of student SME deliberations. Providing facilitators with the following clear guidance for themselves, as well as specific tasks for their student SMEs to accomplish during the breakout sessions, set the professional tone:

1. Try to identify a student "rapporteur" who is willing to document the group's conclusion in a consolidated form, perhaps on the white board.
2. Facilitate task-oriented discussions. Try to engage each student in brainstorming on the task at hand in an open-discussion, round-robin format.
3. The students shouldn't worry about KNOWING the answers. It is more important that they focus on HOW we can figure out the answers through our experiments.
4. The students shouldn't worry about HOW to perform the experiments. It is more important that they define which variables are important, and the basic range of values we should be testing.
5. As long as they stay relatively on task, try not to nudge the direction of the student discussions too much. We want them to think critically, but also creatively.

AER MARTIS

ALPHA SESSION

TASK Alpha-1: Define the broad experimental parameters *within your area of specialty*.

(1) Which variables will be important to include in our experiments?
- Air Temperature: –87° to +20°C (or 186° to 293°K)
- Atmospheric Pressure: 6.1–12.0 millibars
- Mix of Atmospheric Gases:

CO_2	95.3%
N_2	2.7%
Argon	1.6%
O_2	0.13%
CO	0.07%
H_2O	0.03%

- Perhaps the students will suggest other variables.

(2) For each variable, what range of values should be tested?
- See above.

(3) What are your justifications for choosing these variables and range of values?
- Temperature ranges have been measured by various Mars landers, and these values will demonstrate whether cyanobacteria can survive daily freeze/thaw cycles.
- Pressures are also typical on the Martian surface (higher pressures in deep craters and valleys). Important to stay above 6.1 millibars, because H_2O cannot exist in liquid form if pressure is <6.1 millibars.
- Gas mix is precisely what has been measured by various Mars landers.

TASK Alpha-2: For EACH variable, define at least ONE hypothesis we will need to test. If you have multiple hypotheses for each variable, all the better!

(1) Try to structure each hypothesis in such a way that it can be easily answered by a numerical measurement, or by a simple "Yes-No" or "True-False" answer.
- Example (True or False): Cyanobacteria can survive daily freeze/thaw cycles.
- Example (Numerical Measurement): At which temperature and pressure combinations can water be maintained as a liquid?
- Example (Yes or No): Changes in temperature will also cause the atmospheric pressure to change.

Figure 1. Scientific workshop example.

6. Present each task and subtask to the students and have them engage in their discussions. If students begin to struggle, it might be necessary to provide them with a little help.

For purposes of brevity, we include just the morning (alpha) and afternoon (beta) session worksheets for Team AER – Atmosphere and Climate group in Figure 1. All workshop materials, including research articles, facilitator guidance, and session worksheets for all four subject-area specialties, are available at http://pioneeringmars.org/workshop-materials/.

This intellectual experience proved much richer than our research team could have hoped. A student shared the difference between his experience at the Workshop and a regular high-school-level science classroom: "We had never gone in depth before on any subject. We usually just go over it, move to the next topic, and remember for the test. Here we're going very slowly on something and then using it to learn from an experiment. It's totally different that way." Beyond the scientific content growth the students as a whole achieved, it was a rich social opportunity for bright, eager students to interact with other high school students in the workshop setting, as well as during breakout groups and lunch. Cross-school opportunities such as these create a situation where high-performing students have the chance to stretch and engage with other top students in the region. Broadening both intellectually and socially, students, especially gifted students, realize that there are other motivated and bright STEM students in the area who will be their peers when they get to the next academic level.

One student said of the experience, "I feel that [the Workshop] was the most informative. We're so used to working with the same people. When you get in a room with two teachers from another school, you learn all sorts of things you can't have thought of. It was by far the best part of the program." Equally important, the students are part of something bigger – a larger collaborative group of learners all focused on a scientific mission, one that NASA has found significant and worthy of pursuit. Industrial organizations have repeatedly asked for STEM students with better "soft skills," the ability to collaborate, discuss, and work as part of a team. Our model supports students' development simply by encouraging them to engage in scientific debate with their peers.

The students said a lot regarding the value of the experience: "I remember what was talked about because it was debated. I remember the discussions. It really taught us how to work together." One student shared that at his school, collaboration is kind of discouraged, "But it's so valuable to learn how to do it." And others reported, "It's way more complicated than I thought. It's very interesting how it works." A student even shared, "The collaboration is so hard."

○ The Lab Experiences

Throughout the spring semester, products from the workshop were consolidated and shared with students and their teachers. Ultimately, the workshop products were synthesized by a university scientist and a STEM education researcher in order to develop a series of laboratory exercises, fundamentally designed by the student SMEs. Students from each of the participating high schools visited a research laboratory at the University of Southern Mississippi and completed four different lab activities, all in preparation to perform the experiments designed by the students themselves.

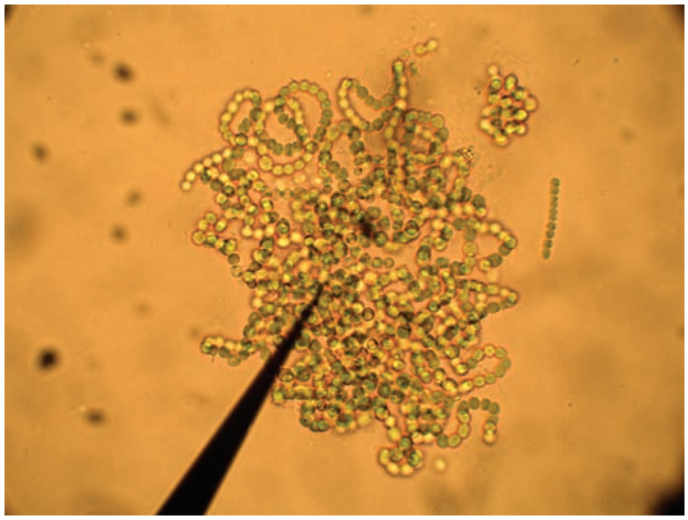

Figure 2. Photomicrograph of cyanobacterial cells growing in Martian meltwater, arranged in the colonial "string of pearls" habit typical of filamentous blue-green algae within the genus *Anabaena*.

Lab Activity 1: Using a Microscope

Our first lab was skill-building and provided a context for algal cultures. Students used research-grade light microscopes and prepared "wet mount" slides for cell identification and analysis. Students were given water samples taken from the coastal waters of the Gulf of Mexico and asked to visually identify the diversity of aquatic microorganisms found in the water samples (Figure 2). The group reviewed the various organisms' diversity in cell shape, size, and survival strategies. Students learned how to perform microscopial cell counts, where the cell abundance in precultured and postcultured samples could be used to demonstrate cell growth during culture.

Lab Activity 2: Mars Chemistry

In the second lab activity, students calculated the chemical concentrations that mimic the Martian soil content, using data freely available in the scientific literature. Much to their surprise, simple high school chemistry skills were all that was necessary to "recreate" Martian meltwater. Students figured the relevant chemical concentrations and, using a microbalance (and the appropriate safety precautions), measured the exact quantities of each chemical in order to produce a growth medium, chemically identical to Martian meltwater, in which the students would attempt to culture cyanobacteria cells.

In this exercise, students were able to experience the importance of precision in a laboratory setting. One shared, "If something doesn't go right, if you make a bad measurement, you got to throw it away. You have to measure everything precisely or you have to start over. In school we just keep going so you can never learn from mistakes."

Lab Activity 3: Algal Culture

The third lab activity provided students the opportunity to collect and culture microalgae, as well as to test whether Martian soil chemistry is inherently toxic to life. Using the Martian meltwater they had created in earlier lab activities, the students demonstrated the suitability of Martian soil chemistry for life from Earth (Figure 3).

Lab Activity 4: Measuring Chlorophyll

In the final lab exercise, students learned to collect, measure, and analyze chlorophyll *a* concentrations using colorimetry (an objective measurement of color intensity as a way to determine the quantity of chlorophyll *a* in a water sample). Since chlorophyll *a* is always present in photosynthetic organisms (like cyanobacteria), its concentration can be used to quantify the abundance of photosynthetic cells. During algal or plant culture, a colorimetric measurement of chlorophyll *a* performed before and after incubation can be used to determine whether photosynthetic cells are alive and reproducing (growing). By keeping track of the amount of time elapsed in the culture, it is also possible to calculate a simple growth rate. Then more advanced experiments can be designed, by changing the algae, the lighting, or the concentration of salts and measuring all the different growth rates to determine the "optimal conditions" for growth in Martian meltwaters and whether cyanobacterial growth is possible under strict Martian environmental conditions.

Figure 3. Triplicate cultures of microscopic algae, originally collected from coastal Gulf of Mexico (GoM) waters and grown in the Martian meltwater created in the laboratory by Pioneering Mars high school students.

Following the laboratory work, each classroom was provided with the data from its various experiments, so the students could discuss and analyze the results once back in their own classroom. Groups of students or individuals then wrote a detailed report and prepared presentations to share with the entire research group.

○ The Conference & Results

All four classrooms of Pioneering Mars students and their teachers gathered for a year-end conference at Stennis Space Center, a NASA facility in Mississippi. Ideally, at the end of the year, each high school team could prepare a scientific poster presentation of their laboratory results using a template. This could include a brief oral presentation as well. In this way, the students could come together for an end-of-year professional conference at a regional science museum or the like, where students present the project results in the morning and enjoy interacting with their peers in a museum after lunch.

Figure 4. Logo of Pioneering Mars team.

At the end of the year, the research team both assessed and surveyed all participating students again. Seventy percent of students showed an increase in content knowledge related to the subject. In our pre–post data analyses, students demonstrated positive gains in their reported abilities to (1) model scientific scenarios, (2) design science experiments, (3) test scientific hypotheses, and (4) apply findings from experiments. These are *all* skills described and required in the Science and Engineering Practices of the *Next Generation Science Standards*. Overall mean scores rose for every content-knowledge item on the assessment, across all four schools. The questions about the laboratory visits and experiences designing and developing the experiments showed the highest gains, supporting the importance of, and unique ability for, real-life experiences to affect learning. In addition to their reported increases in knowledge and skills, students also boosted their positive dispositions toward science as a whole, the use of science, their ability to master science courses, and their general curiosity about scientific discoveries. Our program did not intentionally discuss STEM careers, nor did we actively focus on scientific-career exploration. However, 64% of students surveyed reported an increased awareness of STEM fields, and 85% reported an interest in STEM postsecondary study and/or career. Obviously, students' exposure to scientists and participation in Pioneering Mars resulted in a growing interest in careers in science. Teachers, while not a primary focus of the project, also showed gains in every projected area, with an emphasis on Mars science, using collaboration in the classroom, and STEM career knowledge.

Involvement in such a high-profile project clearly positively affected students' self-esteem. As one stated, "If one day we were to see the planet (Mars) turn green with life, we'll know it was somewhat in part because of some high school students in Mississippi and Alabama."

○ The Future

The Pioneering Mars team has designed and tested experiments that will be replicated on the International Space Station 2015 (Figure 4).

As part of the project, the team has posted our curriculum materials online for free to the public. These include PowerPoint presentations, curriculum materials aimed at specific age groups for both middle and high school levels, related research journal articles, outlines, and guiding questions for teachers and student working groups. NASA plans to continue supporting this work, and we will continue to provide updates on our web page and provide open access to all our curricular products.

Our STEM learning model stretches all our participants, from students to teachers to scientists, in a way of learning valued and recognized by all involved. A pleased student summed up the Pioneering Mars philosophy as "It's all hands on. It should be in all topics. You see it. You put it to work. Hands on – you remember!"

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