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MISSION TO MARS AMIDST A PANDEMIC

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For years, the Air Force Research Laboratory (AFRL) in New Mexico has led an outreach effort called *Mission to Mars* to engage fifth grade students in applying science and mathematics concepts related to building a colony on Mars. Many organizations across the US canceled similar events due to the novel coronavirus (COVID-19) pandemic. This design case details the original program and the pivot made to continue the program. We share successes—including reaching more rural learners—insights, and challenges, and how these have shaped a more inclusive vision for future programs.

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INTRODUCTION

In this design case, we share insights gained through pivoting an established outreach program in response to the COVID-19 pandemic. The COVID-19 pandemic poses a huge challenge to education systems. With little time to prepare, educators found themselves trying to address students' needs, and in many cases, using technologies that were new to both educators and learners. Pivoting in a time of crisis presents a unique set of challenges and opportunities. Learning from these successes and acknowledging the challenges and tools needed to make the pivot may be useful to other programs as they adapt to the changes the COVID-19 pandemic brings, but may also shed light on creative ways to reach broader audiences of learners.

We share a design case of how *Mission to Mars*, a classroom-based Mars colonization simulation for fifth graders sponsored by the Air Force Research Laboratory (AFRL) STEM Academy in New Mexico, successfully pivoted to an online format. We describe the typical program, share design decisions, challenges encountered, and ways the pivot shaped our future plans.

This design case is written by a team. The three designers include two directors of STEM education and outreach programs (Cole Harmon, Gutierrez) and a STEM outreach specialist (Hospelhorn). These designers report to a director (Fetrow) of a unit focused on innovation, and he played a role in shaping the environment and encouraging the pivot. A professor (Svihla) with expertise in learning and design documented design conversations as part of a broader participant observation study. A graduate student (Velarde) with expertise in organizations, community engagement, and evaluation joined the team to help uncover aspects of the design process the team had become blind to and provide ideas about future design directions. This case is therefore polyvocal; when we use "we" in accounting for design decisions and process, we are sharing from the point of view of those involved at the time. All authors participated in reflection on the pivot and consideration of future design directions. Finally, some design conversations also included other staff whose roles included conducting STEM education (O) or public relations (A, T).

Following the tradition of design cases, this case is written from the perspective of the designers. However, to make the process of writing the case manageable, we audio recorded meetings in which the *Mission to Mars* program was brought up. Such meetings included initial discussions about whether to cancel, postpone, or pivot, as well as planning and debriefing conversations between the designers and the innovation unit director. To fill in gaps, we interviewed the designers and constructed a case based on all of these sources, identifying questions and additional gaps. The designers reviewed and revised this to ensure accuracy and fill in missing information.

CONTEXT

New Mexico can be characterized as a land of contrasts—with its pockets of great wealth adjacent to areas with some of the highest childhood poverty rates in the US; home to national labs and world-class research facilities staffed by PhDs, yet it remains near last in the nation on many education and technology access indicators. As the 5th largest state, New Mexico's low population density (45th) makes it challenging to serve the vast rural areas, especially as many of these communities lack adequate internet. Over 25% of New Mexicans lacked household internet access in 2016 (https://nces.ed.gov/programs/digest/d17/tables/dt17_702.60.asp), and critically, these areas lack broadband access, with some communities having less than 5% access (https://broadbandnow.com/New-Mexico). Thus, prior to the COVID-19 pandemic, many STEM education providers have sought ways to work directly with teachers, who then implement curricula in their classrooms. Alternatively, providers devote significant funds to transportation.

As home to many STEM professionals and researchers, the state's K12 science and mathematics standards have long reflected understanding of quality standards. For instance, the 2003 standards foregrounded science practices and were written as larger themes, rather than focusing on the mile-wide, inch-deep approach most states adopted at the time (https://webnew.ped.state.nm.us/wp-content/uploads/2017/12/MSB_contentstandards_CurrentScienceStandardsV2.pdf). The state adopted the *Next Generation Science Standards* in 2018 as the *NM STEM Ready! Science Standards*, adding six standards that emphasize the sociotechnical nature of science and engineering and the historic role New Mexico has played, especially in nuclear and space science. Compared to other states, the shift to these standards was relatively straightforward as they had much in common with the previous standards, as well as support from the *New Mexico Partnership for Mathematics and Science Education*, a grassroots organization with representatives from most of the major STEM outreach and education providers across the state.

With this as backdrop, we detail the original *Mission to Mars* program, a longstanding 5th grade science and mathematics project developed by the Air Force Research Laboratory (AFRL) in Albuquerque, NM. The original *Mission to Mars* program has typically served approximately 1000 students each year from New Mexico, working with 5-10 of the more than 90 school districts in the state.

We then describe the redesign process, prompted by the COVID-19 pandemic in Spring 2020, and share some of our insights and how this pivot has shaped the future of the *Mission to Mars* program.

MISSION TO MARS AS ORIGINALLY DESIGNED

Now in its 26th year, *Mission to Mars* is a supplemental activity designed to be engaging and hands-on while meeting many of the *Next Generations Science Standards (NGSS)*, *NM STEM Ready! Science Standards,* and *Common Core Standards*, including mathematics and English Language Arts. It offers fifth grade students in New Mexico an opportunity to plan and take part in a simulated mission to Mars (Figure 1 & 2). The students are given the objective "to build a colony of habitats to sustain life on Mars." We view this role-play as

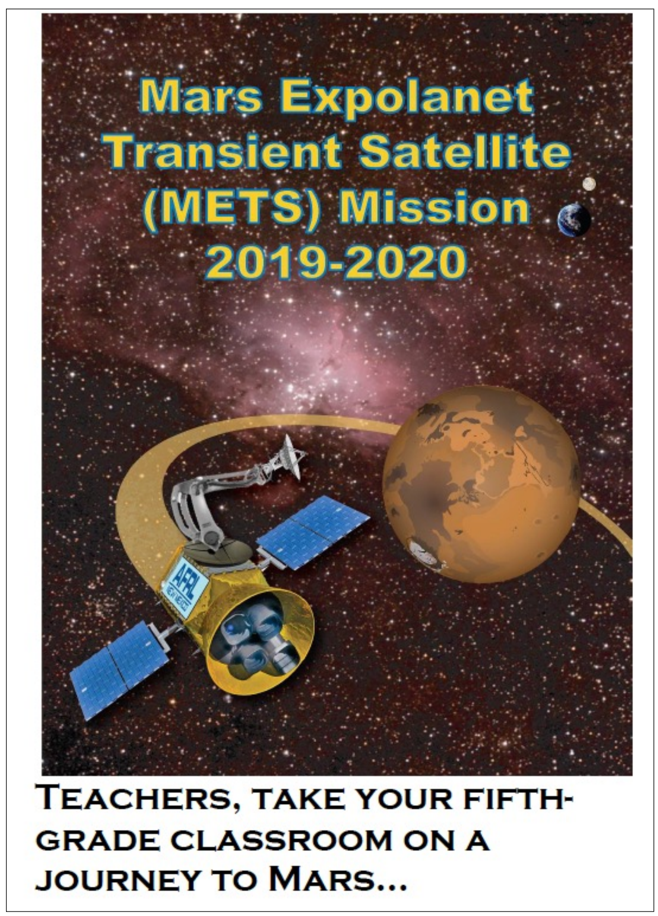


FIGURE 1. Flyer for teachers (used with permission).

providing opportunities for students to envision new futures for themselves in STEM.

Teachers who elect to participate attend a full-day training session in the Fall where we provide the curricula. In this training, the teachers engage as students, designing a mission patch, a life support system, and going through the activities that they will later implement in their classrooms. This helps them see that the activities are manageable and by working with other teachers, they get ideas for ways to implement. This is important as we emphasize that there is not a single right way to implement the activities, as we want teachers to think about how best to fit the activities into their curriculum so they are an "add-in" rather than an "add-on." This means that teachers pace through the activities as they need to, with some beginning the activities early in the Fall, others in the Spring.

Returning teachers—some of whom have participated for 20 years—join a shorter session to hear about any updates or changes, and to ask questions. Teachers guide student teams in their classrooms during the school year on assorted activities in preparation for the mission. For four months, student crews prepare through problem-solving activities. The crews create mission patches, write sagas, build life support systems, and communicate with crews from other schools. These activities are designed to fit in with what teachers are already doing, though with enough flexibility that teachers can adapt them and connect them to other activities.

The activities serve as an engaging learning experience reflective of authentic disciplinary STEM practices, in which such practices naturally overlap with other context. The activities are relatively scalable and flexible, requiring a minimum of 10 hours, but many teachers expand the activities or connect them to other topics they are teaching.

The *Mission to Mars* culminating activity—Link-Up Day—traditionally takes place in the Spring at the convention center. The organizers set up the previous day, taping off zones for each crew. Crews from various schools come together to simulate the Mars mission. They bring the work they have done in their classrooms to prepare for the mission. Each crew progresses through a series of stations to ensure they have completed the necessary preparations, such as confirming that they have their materials and uniforms, and presenting their life support system to a scientist or engineer. This gives them a chance to interact with scientists and engineers as role models. Prior to the event, they are matched to a crew from another school, and they have to use mathematics calculations and ASCII code to communicate with one another; at Link-Up Day, judges confirm the accuracy of this communication, which relates to their landing site on Mars. Then, students construct

YOU PROVIDE THE STUDENTS, THE ENTHUSIASM, AND THE CLASSROOM EXPERTISE, AND MAKE THE FOLLOWING COMMITMENTS:

- Complete and submit the Teacher Training Registration Form on the back of this flyer
- Attend an in-person or online mandatory teacher training session in September or October
- Ensure your school principal signs off on an EPA Modification form, and then submits the signed form
- Involve your fifth-grade class in the Mission to Mars
- Complete and submit a Crews Per Teacher form
- Provide miscellaneous materials for creating life support system models and decorations for the habitats
- Attend the **mandatory mid-year meeting** on **Tuesday, 11 February 2020**
- Arrange for a substitute teacher for mandatory in-person teacher training, and mid-year meeting sessions
- Arrange for transportation for your students to attend the Link-Up Day event
- Complete and submit Crew Registration forms
- Attend the **Link-Up Day event** on **Friday, 17 April 2020**, with your students, and provide other adult sponsors as necessary
- Complete and submit post-activity Teacher and Student Feedback forms

FIGURE 2. Flyer for teachers with information about the program.

FIGURE 3. Overview of linked colonies at Link Up Day 2019 (used with permission).

their habitats and link them to form neighborhoods in their colony. The event emphasizes teamwork and that every crew in the colony should survive, rather than making it into a competition. In 2019, over 1,300 students came together to complete their journey to Mars (Figure 3).

REDESIGNING *MISSION TO MARS*

In the spring of 2020 sudden social distancing requirements changed the trajectory for education worldwide. New Mexico's first cases of COVID-19 were announced on March 11, 2020. Governor Michelle Lujan Grisham implemented a "Stay-at-Home" order to help minimize spread. Like others, our work suddenly shifted from in-person whole-team standing meetings where we discussed our various STEM education and outreach programs, to Google Hangouts/Meets, and then to Zoom. The focus of these meetings shifted from reporting progress to strategy, decision-making, and design.

Cancel or Pivot?

Similar to previous years, approximately 60 teachers had already engaged their classes in *Mission to Mars* activities. Like many other programs, we considered simply canceling the culminating event and related program activities. We discussed this possibility on March 12th, recognizing that any such gathering posed too much of a risk, and considering that during the 2009 H1N1 flu, the culminating event was canceled. Many other events, including all convention center events were canceled through mid-April. At the time, we considered these cancellations to be "prudent" but also wondered if they were necessary. We discussed similar cancellations in response to the 2009 H1N1 pandemic and that the 2009 response seemed to some to be too severe. Although the initial order only closed school buildings for three weeks, we knew we could not bring 1000 students together face-to-face. The director of the innovation unit, Fetrow, to whom the others report, brought up the uncertainty at that time, and we discussed "when to pull the trigger" on making decisions final about what we should cancel, postpone, or pivot. He described *Mission to Mars* as "complex," but he also raised a point that the culminating event was really a celebration of months of work by students—work that had begun well before the COVID-19 pandemic.

The director of STEM outreach, Cole Harmon, suggested distributing equipment needed through the participating schools, then doing a virtual event, in which crews could check into "Mission Command" virtually. A STEM educator suggested the communication lag between Earth and Mars could even be simulated. The team liked these ideas, which meant *Mission to Mars* would be different, but also that this presented "an opportunity to do something cool," and to be like Apollo 11 astronauts, to adapt to new conditions.

At the March 30th meeting, Gutierrez described the experience they were having with another STEM education program they typically run that uses provided curricula. Hoping to draw inspiration, she had reached out to the provider for information on what other programs were doing. The provider knew that most sites cancelled and instead were focusing on development for the next year. The team agreed that we should share anything we developed to encourage others to not cancel STEM learning opportunities, and to continue to view this as a chance to be innovators.

Brainstorming Not Just *What,* But *Why*

A few days later, in the absence of the STEM outreach team, Fetrow met with his staff and updated them on plans for *Mission to Mars*, including that Cole Harmon had reached out to participating teachers about a virtual event. Fetrow warned that even if schools were allowed to resume face-to-face instruction, teachers might not have bandwidth to participate. He reported that Cole Harmon was working on a plan to make it virtual. The STEM educator and a public relations expert both suggested broadening the reach, so that even students whose teachers had not participated could join an event. The team agreed that with many parents working from home and trying to also manage their children, there was a real need for curated experiences that were engaging, especially as some districts primarily focused on sending packets of worksheets home to students in lieu of school. The group brainstormed further about this need, proposing parallels between social distancing and the Mars colonies they typically build, and considering material families might have, such as building habitats out of sheets, and growing potatoes for their mission. Reflecting on the experience of just a few days of working from home amidst family, the team cited the need for structured activities and synchronous, interactive experiences that provide a means for students to safely engage with those outside their own homes. Fetrow liked these ideas because he knew that Cole Harmon and her team really enjoy interacting with students. He promised to bring these ideas back to her to see "if she wants to jump on it," citing that for such a longstanding program, it would be a loss to not continue it in some form.

Meanwhile, the STEM outreach team recognized that—as they themselves were adjusting to teleworking—they did not really know how the COVID-19 pandemic was affecting teachers' and students' needs. They knew that many school districts didn't have plans for the teachers, the teachers didn't know what was expected of them, what they were supposed to cover, if they could give out assignments, or if they could give grades. Districts were preoccupied with trying to get computers and internet hotspots distributed to families. Initially, the STEM outreach team still envisioned that the teachers would be able to support *Mission to Mars* virtual activities to continue and culminate the mission. The largest district in the state was telling teachers to focus on "essential skills" that are typically tested (English language arts and mathematics); this made it increasingly clear that teachers would not be able to continue to facilitate *Mission to Mars* activities. As the STEM outreach team contacted participating teachers, they realized they would need another strategy.

Committing to Virtual

On March 27th, the governor extended the order, clarifying that school buildings would not reopen. For our team, the extension of the order brought clarity that there would be no chance for crews to gather even in a distributed way. Teachers struggled to reach their students. In many districts, the lack of technology access meant that teachers were asked to create paper packets of worksheets to send home to students, but with no expectation that students would turn in their work. In many cases, teachers were never able to contact their students again. Thus, many of our participating teachers were no longer able to support their students to continue to participate, or even to let them know that we were continuing the program. Based on this, we decided that we needed to extend our reach beyond teachers. We therefore shifted our communication efforts to parents, many of whom were suddenly more involved in their children's education. We used word of mouth through teachers and social media to reach parents.

We also made use of an existing video that included school buses in place of space shuttles (Figure 4). The original video was long and introduced the in-person link-up day. We typically provided it to teachers to play in their classrooms. The video had been created long ago, and the program had evolved somewhat since—even prior to the pandemic—so we took this as an opportunity to reuse parts of it to create a two and a half minute video (https://www.youtube.com/watch?v=6LqjYvGt57g). We used this video to invite students to continue or join the virtual mission, sharing the video broadly on social media platforms. The video provided context for the mission.

The decision to include new students meant that we needed to support two groups—those who had participated in at least some activities prior to the COVID-19 pandemic in their classes and newcomers. We also expanded from 5th graders to 4th-6th graders. We planned activities to help the newly engaged students learn the background material for the event. This included providing access to a year's worth of content on the website. Fortunately, many of the materials were already available in digital formats.

We recognized that students from the already participating classes also needed support. Typically, students bring their work to Link-Up day, where they use it to complete challenges and checks. However, any work they had done remained in their abruptly inaccessible classrooms. As teachers pace the activities according to their own needs and schedules, the classes that had been participating were all at different points. Thus, we decided not to differentiate between previously participating students and newcomers, but instead to pace all students through all activities prior to a redesigned culminating event. Although not ideal, perhaps, on reflection, this distributed revisiting might have reinforced ideas for the previously participating students.

FIGURE 4. School buses-as space shuttles en route to Mars in the video.

Providing Access to Virtual Activities

Although a learning management system might have seemed like the most expected way to keep track of learners and their work, registering children for yet another online tool may have seemed burdensome or even suspicious to many parents. Getting young learners to log into a system is a barrier to access and participation. We made the decision to use a combination of our existing website, email and Google Forms so students could register, access activities, and submit their answers. We explained that

> *"When you have an answer or solution for a completed task, you may be asked to share it with us or keep your answers handy to use during the virtual Link-up Day event. . . . For some tasks we ask you to share, there will be a button on this webpage that takes you to a form. Fill out the form and submit your answer. For some tasks we ask you to share, we will ask you to email your solution to our organizational email."*

Our STEM Academy website went quickly from being ornamental, with only 40 views per month, to functional, with over a thousand views, serving as the lifeline for the dissemination of program materials, curated external resources, and instructions for the culminating event (Figure 5). We had good access to and comfort with technology.

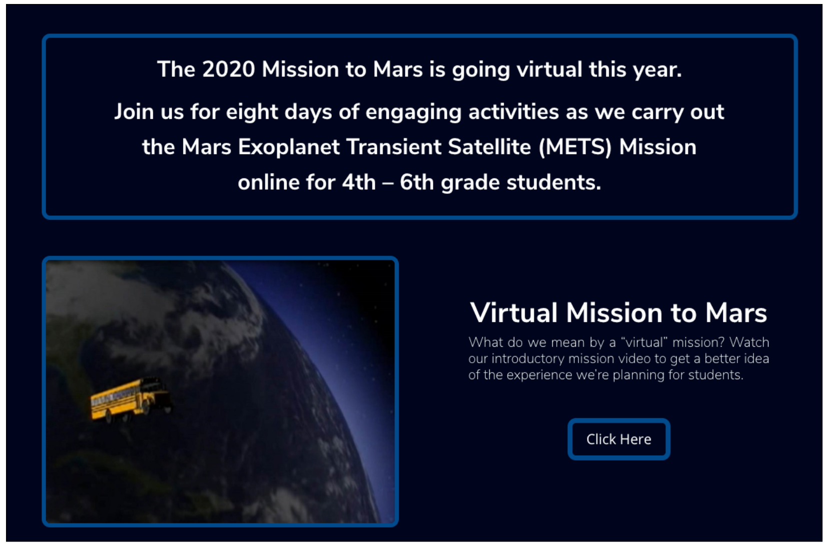


FIGURE 5. Splash page for virtual *Mission to Mars.*

STEM Academy Preparation	
Share Mars facts	Through webquest or question per day pos
Create Kahoot game	Combine Academy created questions with crew riddles
Display Mission Patches on social media	
Create challenge	?

FIGURE 6. Just days after the decision to pivot, the designers brought draft ideas and technologies that we tested at the team meeting on March 30th. At that point, questions remained about the culminating event, especially related to interactivity.

However, on the first day of our activities, we found our website was down. We later learned it was vulnerable to being attacked by bots, in part because of the sudden uptick in activity. We took steps to ensure it would be protected. At the time, however, it required multiple calls to our webhost to understand why it was not working and how to fix it. We set up a parallel site and redirected to it.

We also allowed students to register after the official launch, and 14% of registrants took advantage of this. Because of the asynchronous availability of the daily tasks, students who joined late could still participate in all of the activities.

Interactive and Flexible Formats

While some of the existing activities seemed to translate directly to online, shifting from what had been a very hands-on culminating event to an engaging virtual format was challenging (Figure 6).

We evaluated tools such as email, Google forms, Kahoot! games, Twitch, YouTube and Zoom, and experimented with these informally with colleagues to consider how they could achieve our goals. For instance, during our standing team meeting on March 30th, we played a Kahoot! game led by Cole Harmon, who framed the demonstration as "Today's goal: We're going to explore how to use Kahoot! as an interactive online tool to engage virtual learners and have some fun." She first described some of the options in terms of synchronous and asynchronous engagement, as well as various ways to access Kahoot! games. She selected existing questions and launched a game. We installed the app on our devices, and encountered an issue—one member immediately set up an account, rather than entering the pin. This clarified the need to send instructions, which Cole Harmon had anticipated because of the variety of ways to access Kahoot!

After playing, we evaluated the format, including wondering if a synchronous event where questions could be posed out loud, as they had been in the demonstration, might be more engaging. However, we also recognized that this could cause issues for those without broadband internet access. We raised concerns about having many students access it at the same time and wondered if there was a time we could test it with a larger group and test different types of questions.

FIGURE 7. Schedule of activities to support newcomers and previously engaged students to participate in Mission to Mars and the culminating event.

Another key shift related to access—driven in part by the decision to bring in new students—was spreading out what had been a single day event over 8 days of activities, including the culminating activity (Figure 7). Although this may seem like an obvious decision, we see it as noteworthy. In contrast, many academic conferences and university courses that occurred virtually early in the COVID-19 pandemic retained their timing, leading to inequitable access. That so many programs retained their timing suggests this precedent is influential and designers may need to explicitly question it. For us, considering the needs and contexts of our students—who might be sharing a single device with siblings and/or parents—spreading events like this out over multiple days means students can still find time to participate in relatively brief and asynchronous daily activities. And amidst the COVID-19 pandemic, it also made it feasible for more parents to become involved.

On reflection, we could have spread these activities out further, and we ultimately extended the deadline one week. We initially anticipated that most of the students would be those who had previously participated, but at least half were newcomers.

Another factor that we kept in mind was adequate internet access. Although some members of the team had adequate internet access at their homes to stream live video, others did not. We were fortunate to be able to provide access using an otherwise empty office building—using different rooms with a Mission Control background for one and a Mars Rover background for another.

That even our team members lacked adequate internet access helped keep the team mindful of the limitations many students would face in accessing content.

Scaffolding Progress

We invited participants with the following scenario:

> *"One of the supply landers that arrived before our colonists has landed in the wrong spot on Mars! It appears that the supply lander is near Jezero Crater. We have been watching that area because NASA has selected it as the landing site for the Mars 2020 rover mission.*
>
> *Jezero Crater is thought to have once been a lake that was as deep as 250 meters (830 feet). Scientists would like to examine the layers of sediment in the crater and the river deltas. Our supplies landed in a nearby basin that may once have been part of a vast ocean."*

We adapted existing activities, creating daily tasks that involved webquests to learn Mars facts, drawing blueprints of life support systems, and solving mathematics and decoding problems, such as identifying the location of a Mars rover (Figure 7).

As webquests, we also had to consider what resources to curate and what information to simply provide. For instance, in one activity, students are asked to pack a lunch that takes into account many of the requirements and constraints an astronaut would face (e.g., nutrition, packaging, waste). However, the constraint of "the total weight of your container that holds all your food must be less than 2 ounces" meant that students might search for the weight of a sandwich bag. However, the top search results are links to pages on cannabis. To avoid having students land on such pages, we provided curated information for them on topics like this.

With a typical minimum of 10-12 hours of activities, we sought to spread these out over eight weekdays. Normally, these activities had been teacher-facilitated; the STEM outreach team aimed to adapt them so that new students could complete them on their own. We used a consistent pattern of activities and scaffolded students to keep track of their own work with daily prompts:

> *"Keep a log of Mars facts as you find them while conducting each Mars Investigation. You will use your knowledge of Mars to create a riddle and to answer other riddles as part of a Kahoot! game on our virtual event day."*

This was reinforced by also including cumulative activities. For instance, on the first three days, students were given clues about the Lander's location and asked to solve smaller problems. They were then tasked with bringing their answers together to find the Lander:

> *"Use your answers from the Tasks you completed above and the topographic Mars map below to identify the location of the supply lander."*

To prepare students to use their Mars facts, we also tasked them with creating their own multiple choice questions to use in the culminating activity, explaining that

> *"Think about the Mars facts you have learned. Then create a multiple choice riddle using one of the facts about Mars. Don't forget to include four possible multiple choice answers with your riddle. We will include as many riddles as we can in the Kahoot! game on Friday."*

We provided an example of a question:

> *"Plants love me and I also make up most of Mars' atmosphere. What am I?*
>
> *a. Silicon*
>
> *b. CO2*
>
> *c. Oxygen*
>
> *d. H2O"*

We share a few examples of the questions students submitted, several of which reflect students' local knowledge (e.g., mentioning red chile, which is popular in New Mexico) or interest in popular culture (e.g., mentioning Thor and Loki):

> *Why is Mars the color red?*
>
> *a. Apples*
>
> *b. Red Chile*
>
> *c. Red Cloth*
>
> *d. Rusted Iron*
>
> *I'm a force that can determine your weight, and on Mars you'd experience 62.5% less of me. What am I?*
>
> *a. Density*
>
> *b. Gravity*
>
> *c. Temperature*
>
> *d. Your distance from the Sun*
>
> *We are twins in the sky named after panic and fear, and terror and dread. We fight with our father, the God of War. Who are we?*
>
> *a. Thunder and Lightning*
>
> *b. Thor and Loki*
>
> *c. Hail and Rain*
>
> *d. Phobos and Deimos*

In hindsight, some of the Mars facts activities were rather inert and more scaffolding was needed to help newcomers access and make sense of them. Yet, the Mars facts activities helped prepare students for the culminating Kahoot! game. This is also an equity issue, as some students had parents

FIGURE 8. Students could choose which system to focus on.

FIGURE 9. Examples of student work using various materials.

who had the time and confidence to help their children figure out how to solve problems, but others did not. In future, we plan to provide short videos to better scaffold students and provide a bit more context for their work.

Make it Work

Other activities, like the Life Support system and Habitat design, were very successful (Figure 8).

For instance, students had to choose which of the 8 life support systems to focus on. For each system, we provided a worksheet to guide them through the requirements. They submitted their results by email:

> *"You can sketch a design of your life support system on paper or on the computer or you can build a model using materials you find around the house. Your model does not have to actually function."*

In part because we had access to an intern who was interested in video editing, we considered filming an at-home version of link-up day, in which a member of our team would model building a habitat with chairs and blankets. One member raised concerns that not all families would have spare blankets and chairs, or the space available to do such an activity. Instead, we developed a set of example habitat ideas—inflatables, igloos built from regolith, ships, etc.—and again asked students to envision their habitat on Mars using the materials they had:

> *"You can draw a picture or blueprint of your design. You can also build a desktop model of your design using simple materials such as cardboard, construction paper, or even items that you throw away. Or you can create a simulation of your design using items you have around the house such as boxes, furniture, or blankets. For your model or simulation, include an explanation of the design and what materials are represented."*

In these activities, students submitted creative models and ideas (Figure 9). They showed their resourcefulness using what they had, but it was also clear that what students had in their homes—or had permission to use—was variable. By encouraging them to use whatever they could to create models, we enhanced who could participate. Had we required certain materials—even materials we might think of as commonly available such as large plastic bags, tape, and scissors, we would have made it difficult or impossible for many students to participate.

We showcased their work on our social media sites as well as on the live culminating event, and we received feedback from parents that their child was thrilled to see their work shown. This led us to also showcase student work on our website for our other programs.

Culminating Event

As we considered the culminating event, we valued interactivity and explored tools that would allow some capacity for feedback and commenting. During this time, our broader team was experimenting with a range of technologies. We began a weekly series of Facebook Live science events showcasing an activity you should not try at home, paired with an activity to try at home, but this drew a small audience and we worried that those who lacked a Facebook account or who didn't want to use Facebook might be put off by the platform. We had heard concerns from schools about Zoom and the risks of "zoombombing" (in which an uninvited person gains access and behaves inappropriately) and so we choose to use a Zoom Webinar as one option, as this felt more secure to one of the large school districts, because it did not allow participants to broadcast or share with the whole group. We explored other platforms, such as Vimeo, and even drew inspiration from those outside the organization. Cole Harmon cited that a colleague had described her church using YouTube Live to stream services, and this raised our confidence in such tools' capacity to reach broad audiences. These on-the-fly pivots others were making continued to serve as precedent where precedent otherwise felt inadequate. They also drew our attention to characteristics that might not otherwise have been salient, such as the length of delay platforms build in to live events.

Because of the varying time lags on the two platforms we chose—YouTube Live and Zoom Webinar—we decided the final Kahoot! game should be an asynchronous activity, launched at the end of the live event. This maximized participation in a more equitable manner, as Kahoot! awards points based on both accuracy and speed. Had we done it live, the varying delays—which in the case of YouTube Live, actually varied by user, even in the same building—some students would have been penalized for something over which they had no control.

Although we ran a dress rehearsal, we knew that coordinating multiple volunteers in a live event was risky. Early in planning this event, Cole Harmon noted that the team's experience was salient, as several of them had been classroom teachers, and "when you're a classroom teacher, you learn to wing it a lot when things don't go well." We also considered the Mars Rover as precedent here, conceptualizing the eight-minute delay in communications between Earth and Mars to be a back-up *feature*, rather than a *bug,* should we encounter issues during live events. We considered prerecording a few segments in case of connection issues, and ultimately drafted a script to coordinate the nine people involved (Figure 10). This included a commander at Mission Control played by Cole Harmon, Engineering played by Hospelhorn, and six volunteer scientists and engineers from AFRL who were "project engineers" in charge of the other life support systems. The event launched with roll call, in which each project engineer introduced themselves, and "Hab Comm" introduced the current scenario. This volunteer—a former *Mission to Mars* teacher—set up one of the plastic inflatable habitats from previous years in her backyard and acted as if she were on Mars in the habitat. She described the weather and warned of an incoming storm. She and her son—dressed in a flight suit—ad libbed live updates throughout the event.

Cole Harmon, in the role of commander, invited the student crew members—as the advanced technical team—to make key life support decisions to prepare a colony on Mars for the scientists who would carry out an exoplanet research mission. She reminded them to access the instructions on the website for joining the Kahoot! game, then Hospelhorn guided them to join for a "status check" that primarily served to ensure that students were able to join Kahoot!. Gutierrez managed the Kahoot! game, asking several simple, factual questions, such as the diameter of Mars and its gravity.

After the status check, we continued to use Kahoot! to present and poll students about life support systems. We framed this activity for the students:

> *"Your decisions will have lasting consequences that will determine the success of the colony once our researchers get here. So you need to select the best options for the colony. And to do that, we are going to give you a short briefing on several of the key systems and then ask for your feedback so we can make some good decisions, some informed decisions."*

For each life support system, we offered four choices, such as four possible ways to get breathable air. We tasked students with evaluating the choices three areas and reminded them that tradeoffs were inevitable as they aimed to optimize their choices:

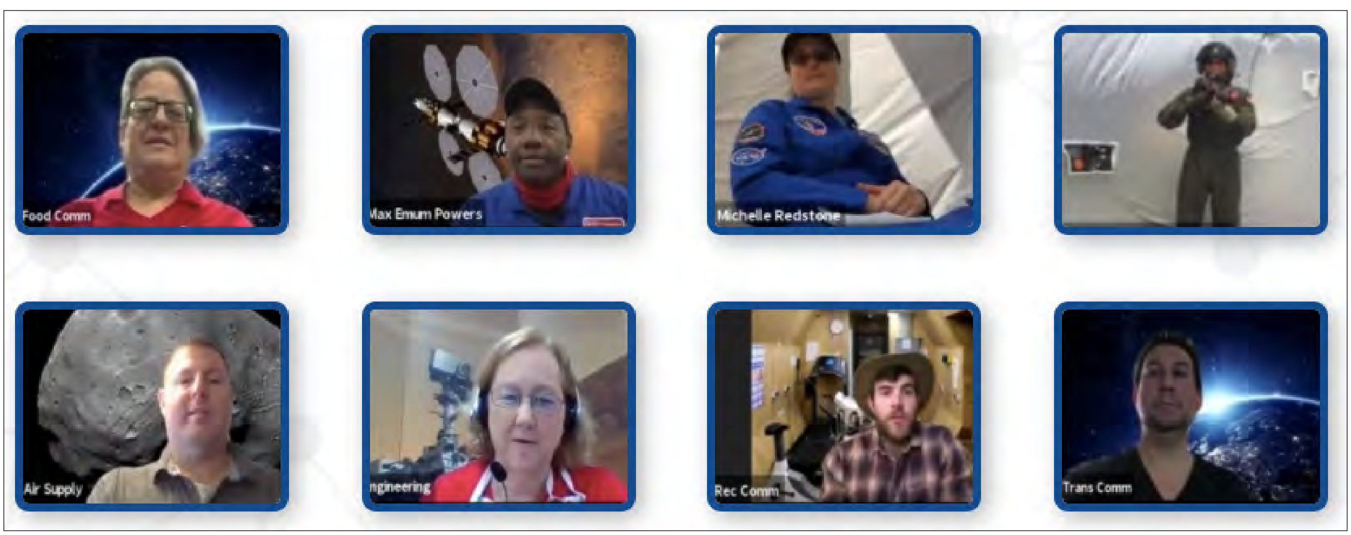


FIGURE 10. In addition to Col Harmon, who commanded Mission Control and Gutierrez who ran the Kahoot! game in the background, AFRL scientists and engineers played key roles during the live event.

- **Safety & risk:** Minimize the likelihood that people are going to get hurt. Best chance of protecting equipment from being lost or damaged. Meet deadlines. Does not have a single point of failure. Has flexibility if damaged.
- **Reliability:** Meets or exceeds the availability and operating requirements; not prone to breakdowns and has low maintenance requirements. Flexible as conditions or requirements change.
- **Suitability:** Fit to operate in the Martian environment. Can survive dust storms and very cold temperatures, and maintenance can be provided under those conditions.

As we presented each option, we spent 5-10 minutes reviewing the safety, risks, reliability, and suitability of each system. For instance, for air supply, we reminded them that bringing oxygen from Earth would mean transporting a volatile chemical, though the tanks present a highly reliable option. Then the students voted for the choice they wanted (Figure 11) using Kahoot!

In the case of air supply, most students voted for the *2H2O to 2 H2 Converter + O2 Tanks* option. We put their choices in our Mission Impact Calculator—an Excel tool that produced scores from 1 to 10 (with 10 being the best) based on each choice, as well as a cumulative score. In the case of air supply, this produced a risk & safety score of 8, a reliability score of 6, and a suitability score of 2. This reinforced the idea of tradeoffs (Figure 12).

The project engineer in charge of that life support system then provided brief feedback on the decision and offered to answer questions in the chat. Students generally enjoyed this aspect, though it was challenging to monitor the chat on both YouTube and in the Zoom webinar—we actually had three staff monitoring the chats to make sure it stayed safe and appropriate, though we did not have any major issues. On YouTube, students could chat with each other as well, and we wondered if we ought to have set up norms for more formal interactions, though we also saw value in letting them chat and have social time. Overall, the students enjoyed the opportunity to chat with the scientists and engineers, and we plan to enhance this aspect in the future, perhaps adding more synchronous chat sessions. For instance, we can have an engineer host a live session to discuss power systems on Mars, and to dig into the tradeoffs related to options.

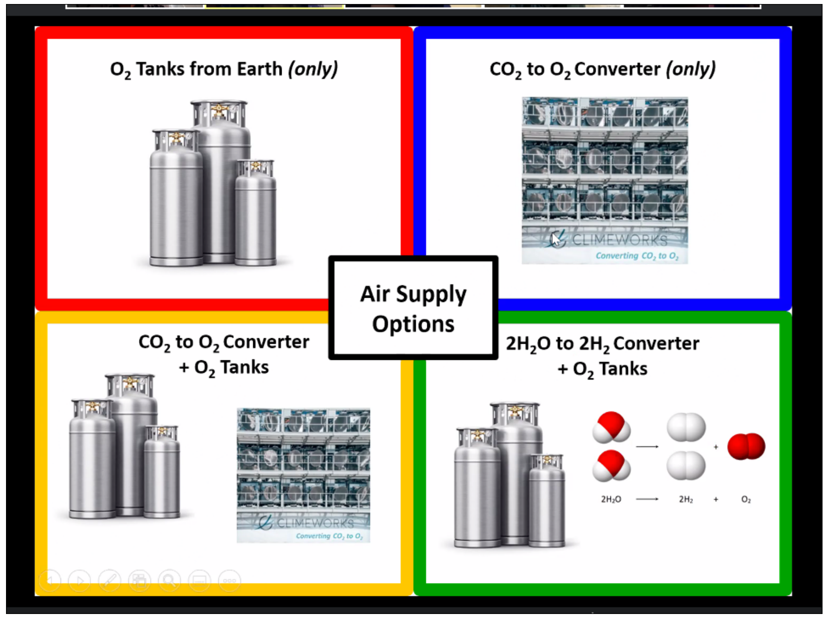
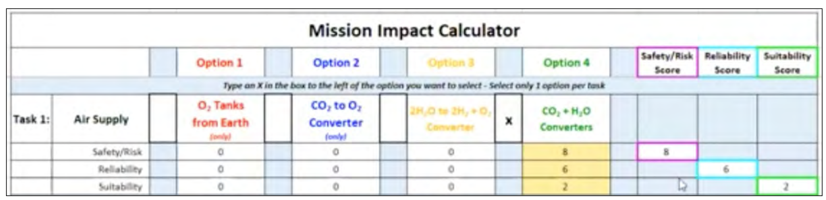


FIGURE 11. Example of using Kahoot! multiple choice questions to collectively choose life support systems



Mission Impact Calculator												
			Option 1		Option 2		Option 3		Option 4	Safety/Risk Score	Reliability Score	Suitability Score
Type an X in the box to the left of the option you want to select - Select only 1 option per task												
Task 1:	Air Supply		O_2 Tanks from Earth (only)		CO_2 to O_2 Converter (only)		$2H_2O$ to $2H_2$ + O_2 Converter	X	CO_2 + H_2O Converters			
	Safety/Risk		0		0		0		8	8		
	Reliability		0		0		0		6		6	
	Suitability		0		0		0		2			2

FIGURE 12. As students voted for particular life support system choices, Hospelhorn put their choices into the Mission Impact Calculator to produce scores for Safety & Risk, Reliability, and Suitability.

		Mission Success Probability		
		Low	Medium	High
Mission Impact Ranges		6-17	17-44	45-60
Safety/Risk	8			
Reliability	6			
Suitability	2			

FIGURE 13. The scores from each life support system choice tallied as cumulative scores for Mission Success Probability.

Each choice contributed to the overall score, with a goal of getting out of "the red" (Figure 13). After students made choices about all systems, this produced a result of high probability of success in terms of safety & risk and reliability, and a medium probability of success for suitability. Based on this, Mission Control congratulated the students:

> *"I'm pleased to report that all of our advanced team tasks have been successfully completed. It looks like the METS mission colonization is clear to proceed. All systems go.*

Congratulations crew on your successful completion of this part of the mission."

The live culminating event, though it took longer than we anticipated, went well with few technology issues. Students were able to interact with scientists and engineers. We had 70 participants on the Zoom webinar and 50 on YouTube Live, but with many multi-participant families. Overall, we liked the choose your own fate aspect of the live event. This approach could seem risky—students might have made choices leading to mission failure, and we needed to be ready to respond to the outcome on the fly. Our experience as both educators and scientists meant that we could easily respond in character regardless of the outcome. Because we wanted to stress the inherent tradeoffs of the engineering design process, and that each decision offered benefits and drawbacks, we were ready to discuss re-assessing decisions or looking for alternative solutions had the Mission Success Probability been low. Prior to ending the live session, we reminded students to participate in the final Kahoots! challenge game and extended the deadline to complete all work.

REFLECTIONS

The 26th annual *Mission to Mars* culminating event was realized and the learning that took place through this pivot will inform the design of the program for future years in an effort to make the program accessible to more students.

Although the pivot was a challenge, it laid the groundwork for future growth of the program. In shifting the culminating event to an online format, we reached students from other states as well as students from many communities across the state that we had never previously reached. This included students from 26 cities in 11 states, and from both the US and the UK. We observed that a silver lining of the COVID-19 pandemic is that geography mattered much less in terms of reaching students. The idea of spreading the program to have national reach was something we had not previously considered seriously, but this effort has demonstrated that with coordination and attention to time zones, we could reach and serve many more students.

Although we reached students from various places, fewer students overall participated. Ultimately 334 students signed up to participate in the virtual *Mission to Mars*, 211 of who had already participated in their classrooms. 128 students completed all activities in the virtual space, and additionally, some students submitted materials later or to their teachers. Prior to the COVID-19 pandemic, we anticipated having over 1000 students in the Link-Up event. Such participation in the past has depended on teachers engaging their students during the year in required assignments and bringing their classes to the event. With only a few teachers able to continue their participation after the COVID-19 pandemic began, many of our participants opted in of their own choice or with parental encouragement, meaning they received no grades, no credit for doing the work from their teacher. Thus, it is difficult to compare the whole-class required participation of typical years with the relatively small number of extracurricular participants at the virtual event. It might be most appropriate to compare the number of virtual participants in *Mission to Mars* to the number—zero—able to participate in the many programs that were simply canceled.

One of the biggest design failures we encountered in this process was one over which we had little control: the clearly inequitable access to technology and internet. In schools in which many students lacked access, leaders made decisions to level the playing field by focusing on packets of worksheets. We characterize this as a design failure because we see systems that produce and reproduce inequities as designed to do so, rather than unexpectedly producing such outcomes. This also means that they can be redesigned. While we might have had the resources to provide greater access, there was not infrastructure in place to support such efforts. We are working to build more relationships within districts and local organizations so that we can more responsively meet such needs.

Having a culture of continuous improvement helped us be adaptable, leading to a reimagination of the culminating event. We typically seek feedback formally and informally and use this to improve the program. Even during teacher workshops, we gain insight into new possibilities. We have heard from teachers that they liked the resources we developed and that they have ideas for ways to teach with these new resources. We plan to engage them in brainstorming about ways they can use the resources in coming years. We envision that even when we get to go back to a world where we are able to do an in person Link-Up day with a thousand students, we will use much of what we developed to enhance the program throughout the year. For the website, we plan to organize these on a landing page that is like a control panel. Students will be able to click on mission tasks. We plan to continue to use Google forms to allow students to submit work, but we'll also support it with instructional videos. For instance, students might benefit from just-in-time resources on how to use coordinates to find a location on a map of Mars. In future iterations, we also plan to include parallel online programs, so that even if a teacher is not participating, students can do so.

However, this experience also helped us understand how much teachers contribute to the *Mission to Mars* program, and ways we might better support them as the COVID-19 pandemic continues. Our insufficient scaffolding highlighted this, especially as we discussed what value teachers saw in some of the new resources—and specifically, the ways they would use such resources in their teaching. In anticipation of challenges both teachers and parents might face, we have developed booklets for students that go along with the website materials, and that provide additional information and details about the activities.

This pivot also informed our development of other programs, including summer camps. Even as the team faced technical difficulties on the launch day, they were already forming plans for virtual summer camps, adopting a "lean forward attitude." Making this pivot required quick action, an organizational culture that encourages innovation, access and familiarity with online learning tools, a dedicated team of educators and volunteers, as well as parent/student interest.

Our organizational culture and program practices were pivotal in the successful shift. *Mission to Mars* is steeped in the ideals of innovation and technology. Our organization likewise espouses these ideals and we aim to meet challenges with excitement and agility. This organizational culture shaped our attitude as we took in the news that we would need to cancel the physical event. Across our organization, we have members with varied experiences and expertise, and diversity of thought is integral to a culture of innovation and flexibility. Coherent with this stance, we see ours as a learning culture, and this pivot was certainly an opportunity for our own learning about tools, technologies, and ways to use these to reach students and support their learning. Finally, an unexpected benefit of not canceling the program was that, despite the risks and challenges, we found pulling together for the live culminating event to be a great boost to our morale. The complex social interactions it required, paired with the opportunities to interact with students—something that we enjoy as part of our typical work—was reinvigorating and has inspired us to consider how we can blaze new trails even amidst uncertainty.

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