



OPEN INNOVATION

BOOSTING NASA *HIGHER, FASTER, AND FARTHER*



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OPEN INNOVATION AT NASA: MORE THAN THE SUM OF ITS PARTS

The Traditional NASA Community: The Agency, Industry, and Academia

NASA's civil servant workforce of scientists, engineers, managers, and others has been critical to designing, developing, and operating numerous space and aeronautics research and technology projects. Our highly skilled employees, numbering some 18,000 today, remain essential to NASA's innovation and exploration success.

NASA's accomplishments, however, have hardly been NASA's alone. Tens of thousands more individuals from academic institutions, private companies, and other space agencies also contributed to achieving NASA's ambitious goals. Today, more than 80 percent of NASA's funding supports work the agency solicits and awards competitively. Companies of all sizes and experts in academia undertake this work through contracts and grants. NASA also collaborates with international space agencies and various organizations on a no-exchange-of-funds basis via signed agreements.

Expanding the NASA Community through Open Innovation

The agency is expanding the NASA community to broaden its capacity for innovation and discovery even further. Many federal agencies and global organizations harness the perspectives, expertise, and enthusiasm of "the crowd" outside their walls to reduce costs, accelerate projects, enhance creativity, and better engage their stakeholders. NASA is doing the same, collaborating with diverse entities nationally and internationally through "open innovation" initiatives. These initiatives include problem-focused challenges and prize competitions, data hackathons, and citizen science and crowdsourcing projects that invite the public to

lend their skills, ideas, and time to support NASA projects. NASA also uses open innovation internally to share knowledge across our workforce.

NASA has supported hundreds of open innovation projects over the past two decades. These approaches are a valuable tool in NASA's innovation toolkit, expanding our ability to collect and analyze scientific data, make discoveries, develop technologies and data applications, and solve complex problems. Our public collaborators and partners benefit by gaining visibility, honing and acquiring new skills, building companies, and more.

Open Innovation: Boosting NASA Higher, Faster, and Farther shows how open innovation projects advance NASA's mission and benefit participants. Involving more people as contributors to NASA's work yields creative solutions to allow humans to operate on the Moon and robots to unlock the solar system's secrets. Public collaborators working with NASA bolster scientific understanding of the Earth and worlds, stars, and galaxies beyond. Meanwhile, NASA's open innovation work is strengthening science, technology, engineering, and mathematics capabilities and inspiring communities of solvers. It has also addressed critical societal issues, including aiding in understanding and mitigating the health and environmental impacts of the COVID-19 pandemic.

The projects featured were completed in fiscal years 2019 and 2020. We hope these outcomes will show open innovation's value and encourage you to join NASA in the pursuit of knowledge, innovation, and exploration.





Above: COVID-19 International Space Apps competitor, “The Masked Scales” created a homemade instrument to gather environmental data and measure changes in street noise, vehicular traffic, emissions and light intensity during the pandemic. Credit: Artash Nath

RESPONDING TO COVID-19 USING THE CROWD TO PROBLEM-SOLVE IN A PANDEMIC

As was the case for all U.S. government agencies, NASA faced the COVID-19 pandemic and met one of the most urgent worldwide issues of the 21st century head-on. During a time of global concern, the space agency rallied in unique ways. NASA enabled a rich diversity of know-how through open innovation, both here in the United States and abroad, to help tackle the growing spike of the contagion.

NASA leveraged several open innovation tools to accelerate the pace of problem-solving during this urgent crisis, such as the International Space Apps COVID-19 Challenge.

NASA as a First Responder During the Storm

Open innovation enabled NASA to generate a fast-paced, short sprint of creativity to meet urgent needs. For example, during a time of quarantines worldwide, **NASA's International Space Apps COVID-19 Challenge** brought together entrepreneurs, scientists, designers, storytellers, artists, and technologists for a weekend of virtual problem-solving.

Challenge participants used Earth observation data from NASA and its partner space agencies in creative ways, showing how satellite information can aid in the understanding of the COVID-19 outbreak on both global and local scales. They also explored themes such as the economic and psychological consequences of the pandemic and their impact on society. This NASA-led initiative was organized in collaboration with Booz Allen Hamilton, Mindgrub, and SecondMuse. All told, over 15,000 participants in 2,000 virtual teams from 150 countries participated in a worldwide hackathon weekend that mixed the abilities of NASA and four other space agencies: the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA), and France's National Center for Space Studies (CNES). They used Earth observation and other open data to propose solutions to one of twelve challenges related to the COVID-19 pandemic.

Through this challenge, NASA successfully prompted global, real-time collaboration to address critical, time-sensitive issues. "Instead of people working separately

on a problem, we got people from different disciplines working together to take on the problem and find solutions. There was a cross-pollination of ideas," says Shobhana Gupta, open innovation and community applications manager within the Applied Sciences Program of NASA's Earth Science Division. Combined with the new normal of teleworking, the rapidity of action seen with the Space Apps COVID-19 challenge will likely have lasting effects on how NASA conducts business. The effort inspired Sarah Hemmings, lead associate in Earth science policy in NASA's Science Mission Directorate. "You get goosebumps when you see people work on these projects. The things they come up with are truly amazing and [you see] how science can touch so many in other countries. A trend that I think is interesting is 'science diplomacy'—how science could be used as a diplomatic tool."

Space Apps judges selected six winning teams in the general competition. The project team G.I.D.E.O.N. (Global Impact Detection from Emitted Light, Onset of Covid-19, and Nitrogen Dioxide) took home Best Use of Data by integrating Earth observations, in-country economic data, human mobility data, and global infection case counts for a holistic assessment of COVID's impact on various countries. Best Use of Technology went to Australia-based Elavo, which leveraged NASA-developed technology from the 1990s to use ultraviolet light to clean air that may have droplets infused with COVID-19 or other pathogens. Shelter in Space was the U.S. team selected for Best Mission Concept, which involved using

Below: Team "Food 4 All" participated in the Food for Thought segment of the COVID-19 International Space Apps Challenge, and considered the journey of food to your plate, determine how disruptions from the COVID-19 pandemic are affecting the food supply locally and globally, and propose solutions to address these issues. Credit: Food 4 All





Above: Stafford Sheehan, co-founder and chief technologist of Air Co. works on the company's demonstration system for Phase 2 of the NASA CO₂ Conversion Challenge. A key feature of Air Co.'s process that made them successful in Phase 1 of the competition is that the initial production of alcohols from CO₂ creates a valuable feedstock for making more complex compounds like sugars. This also allowed the alcohols to be used as-is for immediately practical uses such as hand sanitizer. Air Co. leveraged partners to create packaging and labeling for the hand sanitizer and worked around the clock to produce approximately 2,000 two-ounce bottles per week. Credit: Air Co.

an app the team developed that provided a game-like environment for people to play with their friends who live apart while tapping into other wellness and social apps as well as NASA resources. A Chilean team called PANAL won Galactic Impact with its app designed to approximate a user's risk of coming into contact with a COVID-19 patient given their location and data about the immediate area. A Canada-based sister-and-brother team (Arushi and Artash Nath) won Most Inspirational using an app to combine NASA data with ambient noise made to see how noise levels were reduced as human activity decreased during the pandemic. Finally, the Best Use of Science went to U.S.-based team Michiganders Researching Coronavirus, a group of students that collected artificial light data from NASA and JAXA to find patterns informing greater population density and thus a more significant risk for the spread of COVID-19.

Alex Hsia of Michiganders Researching Coronavirus provided her reason for participating in the form of a call to action: "Even if you don't have a computer science background, you should definitely participate in the NASA

hackathon because diversity of thought, I think, is a great thing, and especially if you have people not from the area of computer science, they might have interesting ideas to contribute to your team that you might not have previously thought of."



"NASA is a community of people that want to innovate and help NASA succeed in its mission...They are always willing to help and share what they know."

**-Carissa Callini,
former lead for
NASA@WORK**



Racing to Respond

Speed was also a factor among NASA's workforce, as civil servants and contractors jumped at the opportunity to help the world combat the pandemic through NASA's internal crowdsourcing platform, NASA@WORK. In April 2020, NASA launched an agency-wide call for ideas on NASA@WORK. Managed by NASA's Center of Excellence for Collaborative Innovation (CoECI), which is part of the agency's Space Technology Mission Directorate (STMD), the platform is accessible across the space agency, civil service, and contractors. "It's a

way to connect people across the agency centered on things that people need help solving, to get ideas, solutions, and a path to move forward beyond obstacles," says Carissa Callini, former lead for NASA@WORK.

In just two weeks, participants submitted 250 ideas and 500 comments to the NASA@WORK platform. Nearly 5,000 people logged on to see what was happening with the COVID-19 challenge. “It was a huge team effort. The chief technologist at every NASA center helped evaluate ideas, what was feasible for NASA to move forward on,” Callini adds.

A Silver Lining as the Clouds Part

These challenges gave participants the opportunity to study COVID-19 and its impacts through the lens of space technology and remotely-sensed satellite data. “We challenged people to use Earth observation data to solve issues related to COVID-19, such as what’s the effect of social isolation from the pandemic? We had people looking at population dynamics and other environmental variables. We also used some of the data that NASA has on the astronaut crews that are socially isolated in space,” says Hemmings.

Challenges also provided individuals an easily accessible avenue to help fight the pandemic in a meaningful way. Several ideas submitted through the NASA@WORK platform included early work on projects to support the development of technologies to model and forecast the spread of COVID-19, and ideas were incorporated into the Space Apps COVID-19 Challenge. 3D-printing-

related capabilities at NASA centers, which informed NASA’s approach to center-specific efforts, including the formation of center-level NASA COVID-19 3D printing response teams were submitted. Center directors authorized these teams to reach out to local health care providers to evaluate local personal protective equipment (PPE) needs that could be solved via 3D printing. Several ideas called attention to NASA innovators’ concepts for sensors that can improve the detection of the virus in the environment or a viral infection in a person. Implementation of some of these ideas is in progress. Lastly, alongside multiple federal agencies, NASA shared 3D-printing ideas with the America Makes 3D printing for COVID partnership to connect the need for medical PPE with manufacturers capable of 3D printing safe equipment.

“NASA is a community of people that want to innovate and help NASA succeed in its mission. Our people always surprise me, whatever the challenge might be. They are always willing to help and share what they know,” Callini concludes. A post-challenge survey for Space Apps revealed the same for laypeople and other citizen scientists: people were motivated by helping others. As Gupta says, “That was a very heart-warming sentiment. That was the number-one reason they wanted to take part.”



Above: In addition to the NASA@WORK challenge, the agency workforce developed ideas and worked with partners to quickly respond to the health crisis. NASA engineer Mike Buttigieg worked on the Aerospace Valley Positive Pressure Helmet, a device that was successfully tested by doctors at Antelope Valley Hospital in California. Credit: NASA

RETURNING TO THE MOON

SUPPORTED BY A CAST OF THOUSANDS



NASA's return to the Moon, this time to stay, is a discrete step-by-step program, one that envisions eventually constructing a 21st century Artemis Base Camp at the lunar South Pole. That base camp is a foundation for the future, offering a sustainable foothold on the lunar frontier as crews initially move from short stays on the Moon to one- to two-month excursions. However, NASA must overcome many new technical and logistical obstacles before turning this vision into a reality.

NASA hosted a series of challenges encouraging the public to participate and better tackle these obstacles. Ten challenges were underway during calendar year 2020, remarkable when considered against the backdrop of a global pandemic. These challenges invited everyone to embrace the Moon as a technological testing ground to prolong human stays there and lay the foundation for human exploration to Mars and beyond. From bucket drums that a robot digger could use to collect lunar regolith to novel design concepts for low-mass, compact toilets for use in space and on the Moon, open innovation provided NASA with a variety of solutions to vexing problems associated with lunar living.

Helping NASA Get There, One Challenge at a Time

The Artemis program is, of course, composed of large, complex hardware and infrastructure being developed by NASA, contractors, and international partners. But there are also smaller-scale needs that require attention, the kind of attention that students of all ages, small businesses, and citizen scientists can handle. Though relatively small, these needs are no less important. Open innovation is a well-suited strategy to address these important needs and consider new solutions.

NASA received cost-cutting, multi-purpose innovations through challenges focused on the human element—from enabling efficient movement in a micro- or low-gravity environment to using the bathroom. Consider **A Common Restraint and Mobility Aid System for Multiple Gravity Environments Challenge**, led by challenge owner Robert Howard, the Habitability Domain Lead in the Habitability and Human Factors Branch, and the Co-Lead of the Center for Design and Space Architecture at NASA's Johnson Space Center in Houston.

Human habitats for varying gravities—on orbit, transit, or the surface—were the objective as a cost-cutting measure. “The challenge was an untapped resource. I was amazed by the participants,” says Howard. He adds that the intent to come up with one system that works no matter where crews go is a “real-need” challenge that hadn't been addressed before. NASA's **Lunar Loo Challenge** asked the global community to mull over novel design ideas for compact toilets that can operate in microgravity and lunar gravity, concepts the agency may adapt for use in Artemis lunar landers. Michael Interbartolo at NASA Johnson in Houston, says, “We knew the response would be dramatic and considerable. The ideas were all across the board and yielded things we had not thought about.”

Other challenges helped progress NASA's ongoing pursuit of sustainability in space, focused on technologies relating to practical problems of long-term residence on the Moon. The **Moon to Mars Ice and Prospecting Challenge** led to insights about what works best and what doesn't to mine and utilize possible lunar reservoirs of ice or frozen water resources on Mars. This is a key capability for long-term human presence on the



Above: NASA led a challenge with the GrabCAD Community to design a common restraint and mobility aid system that works in four gravity environments for astronauts. Credit: NASA



Above: Space Robotics competitor teams acted as mentors to middle school student teams competing in the Space Center Houston Student Space Robotics Challenge. Credit: NASA



Above: Participating in the 2019 NASA Moon to Mars Ice and Prospecting Challenge students from Northeastern University (L-R) Andrew Panasyuk, Daniel McGann, and Daniel Goldstein checking the electronics of their drilling device that will penetrate a frozen Mars surface substitute to extract water. Credit: NASA/David C. Bowman

and Mars. Meanwhile, the **Honey, I Shrunk the Payload Challenge** looked for instrument designs that could help support a sustained human lunar presence. The clear benefit to NASA was a streamlined approach to acquiring high-end devices at extremely low cost, says Andrew Shapiro-Scharlotta at NASA’s Jet Propulsion Laboratory in Southern California. “What was gained was a class of measurements that can be useful for a very low price that is of utility to the Artemis program. The challenge approach appears to be supporting success,” Andrew adds.

Some challenges helped close key technology gaps for operating and conducting science on the Moon. NASA’s two-phase **Watts on the Moon Challenge** seeks solutions for energy distribution, management, and storage that can be further developed for space flight and future operation on the lunar surface. Sponsored by the agency’s Space Technology Mission Directorate, NASA

and crowdsourcing company HeroX ultimately received submissions from 60 teams with original concepts for powering human and robotic outposts on the Moon. Under Phase 1 of the challenge, the agency selected seven teams for a combined \$500,000 award in May 2021. Dr. Marla Pérez-Davis, director of NASA’s Glenn Research Center in Cleveland, said that “not only could these award-winning concepts make a difference in space exploration, but technologies discovered during the competition could drive clean energy innovation and make a positive impact on Earth.” Phase 2 of the challenge, a \$4.5 million technology demonstration competition, is anticipated kick off in early 2022.

In addition, the **Lunar Deep Freeze Challenge**—supported by TechConnect Ventures—gathered ideas for storing samples taken from the lunar south pole and transporting them to Earth for analysis. Chad Hammons, who managed the challenge through the Gateway

Operations Integration and Utilization Office at NASA Johnson, explained the scientific importance of lunar ice samples: “The analysis of these ultra-cold lunar samples will enable a new generation of scientists and curators to refine their techniques and help us prepare for future missions to the Moon. We rely on the global community of innovators to provide valuable ideas to address the challenge of keeping those samples cold and transporting them back to Earth.” The winner, Isaac Blankenau, was awarded \$40,000 in January 2021.

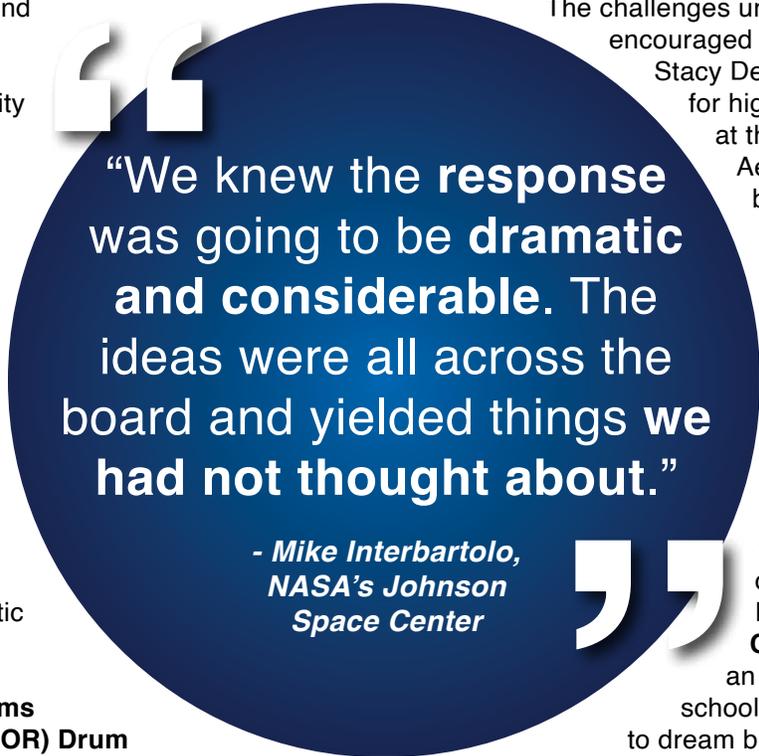
Other challenges produced a variety of technologies enabling lunar exploration: the **Space Robotics Challenge** advanced robotic software and autonomous capabilities; the **Regolith Advanced Surface Systems Operations Robot (RASSOR) Drum Optimization Challenge** produced designs for a new bucket drum for RASSOR to capture regolith and keep it from falling out; and the **Advanced Lightweight Lunar gantry for Operations (ALLGO) Challenge** generated creative solutions using computer-aided design (CAD) models of a mobile lunar gantry or crane based on a structural framework of inflatable components.

Kevin Kempton, Program Element Manager in NASA’s Game Changing Development Program, attested to the pace of these challenges: “The ALLGO challenge was open for submissions for six weeks. We received well over a hundred high-quality concepts. Since we received so many great submissions, narrowing the finalists down to only a few winners was challenging. The submissions included 3D models, renderings, loads analysis, and even animations. In such a short timeframe, we could not have developed the wide variety of innovative concepts using in-house resources.”

To the Moon and Back Again: Earthly Benefits

While these challenges are designed to help NASA execute the Artemis program, the innovations generated by these challenges also benefit citizens here on Earth now. The challenges pushed participants to grow their talents and skills, encouraging out-of-the-box thinking. Open innovation continues to inspire NASA civil

servants and contractors to go above and beyond work obligations, as well as making it possible for people all over the world to be a part of our return to the Moon.



The challenges undertaken in 2020 also encouraged educational development. Stacy Dees is a portfolio manager for higher education challenges at the National Institute of Aerospace, formed in 2002 by a consortium of research universities to support NASA’s Langley Research Center in Hampton, Virginia. Stacy says the Moon to Mars Ice and Prospecting Challenge for students “gave them an instant resume boost,” a valuable experience important to the future workforce of NASA and all of the aerospace industry. For the **Artemis Moon Pod Challenge**, NASA provided an opportunity for primary school students across the country to dream big, to perhaps inspire them to think of STEAM (science, technology, engineering, the arts, and math) careers. Students across the nation wrote to share their visions of a week-long mission to the Moon’s South Pole. Over 1,000 educators, professionals, and space enthusiasts served as volunteers for the first round of judging and selected 155 semifinalists in March 2021. The list was narrowed to nine finalists in April, and three winners were selected the following month. “I can’t tell you how inspiring and energizing it’s been to read these essays and see the students’ enthusiasm and creativity in action,” said Mike Kincaid, NASA’s associate administrator for the Office of STEM Engagement. “The future of space exploration is in good hands.”

At a more intimate level, the challenges produce results that may lead to solutions for down-to-earth problems that can be provided by the private sector one day. For instance, on the Lunar Loo Challenge, Interbartolo points out that “there are possibilities that some of the toilet innovations could spin back into helping people here on Earth.” Air entraining and vacuum systems, use of no water, or turning water into greywater for other uses like laundering clothes or bathing are examples. “That’s why NASA does these things. We are chartered to create spinoffs for the benefit of Earth while we create technologies for use in space.”



EXPLORING & LIVING IN SPACE

BECOMING A SPACEFARING CIVILIZATION
WITH OPEN INNOVATION

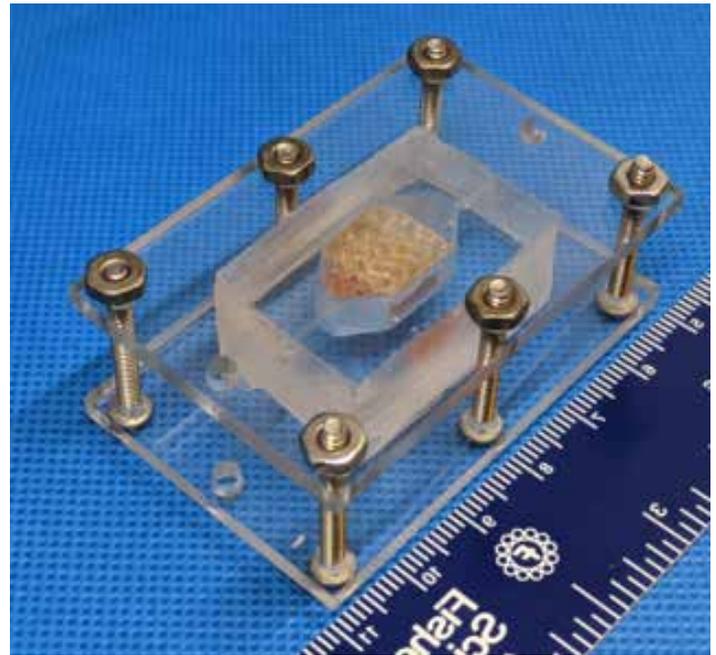
Open innovation has enabled individuals and teams to contribute solutions designed to maximize human physiological and psychological responses to the unique environments of space, a process that has also illuminated results that may improve the physical and mental health of people in general. People across the world have participated in NASA prize competitions related to space-based habitation, from facility construction to environmental control systems that in turn may spin off to inform more efficient building construction and improve air quality back on Earth. Crowdsourced research into artificial intelligence (AI) software is enabling robots to supplement human capabilities on the Moon and Mars, technology that may contribute to safer operation of self-driving vehicles on Earth.

Helping NASA Identify Safe and Healthy Real Estate

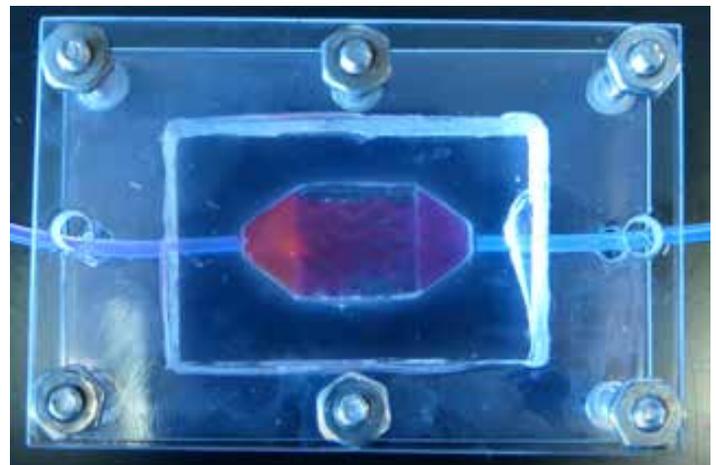
The health and welfare of its explorers are essential to NASA's mission success, but the work done toward this end can also inform medical diagnostics, emergency medicine, and health and nutrition for all of us here on Earth. What is learned will also be applied to future astronauts, pioneers, and settlers.

Two NASA challenges through the agency's Space Technology Mission Directorate helped to advance technologies for physiological health and medicine. First is the **Vascular Tissue Challenge**, conducted in partnership with the non-profit Methuselah Foundation's New Organ Alliance. This challenge sought innovative ideas that advanced the field of regenerative medicine through a \$500,000 prize competition. Teams developed organ analogs that could be used to study deep space environmental effects on living tissue. Two teams of scientists from the Wake Forest Institute for Regenerative Medicine (WFIRM) in Winston-Salem, North Carolina, won first and second place in the challenge. Competing as teams Winston and WFIRM, each used a different approach to create lab-grown human liver tissues that were strong enough to survive and function in ways similar to those inside the human body. The teams each used a varied 3D printing technique to construct a cube-shaped tissue about one centimeter thick and capable of functioning for 30 days in the lab. Team Winston, the first team to complete its trial under the challenge rules, received \$300,000 and has the opportunity to advance its research aboard the International Space Station (ISS) U.S. National Laboratory. Team WFIRM received the second-place prize of \$100,000.

The **CO₂ Conversion Challenge**, initiated in late 2019, produced innovative solutions to convert carbon dioxide (CO₂) into sugars such as glucose as a step to creating mission-critical resources. Successful approaches could enable NASA to manufacture products using local,



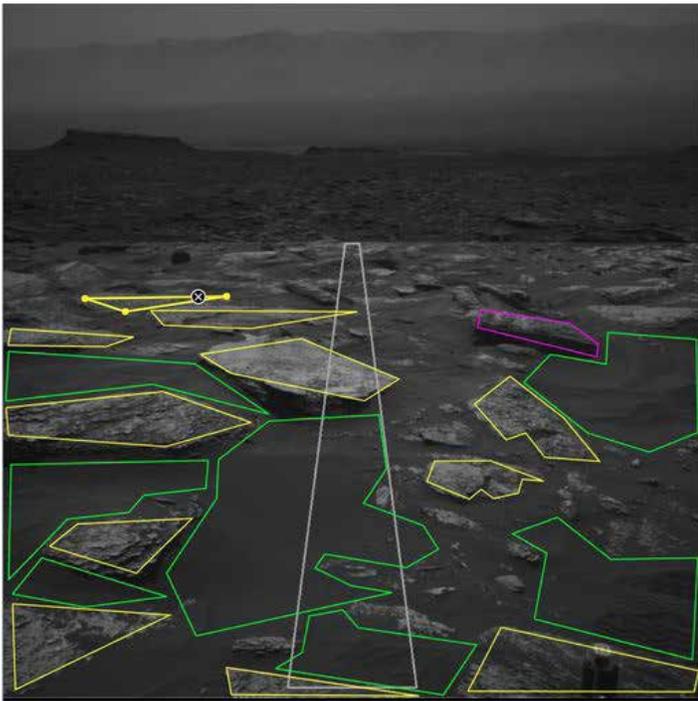
Above: Team Winston, the first-place winner of NASA's Vascular Tissue Challenge, used a chamber to hold the printed tissue and test a process called perfusion. Credit: Wake Forest Institute for Regenerative Medicine



Above: Team Winston, the first-place winner of NASA's Vascular Tissue Challenge, took this image during a perfusion test of its lab-grown human tissue. Fluid passed through the tissue without leaking. Credit: Wake Forest Institute for Regenerative Medicine

indigenous CO₂ extracted from the Martian atmosphere. Three teams of solvers have demonstrated prototype systems capable of converting CO₂ from the air into glucose and other useful sugars. Teams Air Company of Brooklyn, New York; Hago Energetics Inc. of Thousand Oaks, California; and SSweet from the University of California, Berkeley took home equal shares of the \$650,000 base prize. All three teams also won bonus prizes for designing systems with spaceflight in mind. The judging panel evaluated each submission for bonus

Left: Team Air Company, one of the winners in NASA's CO₂ Challenge, prepares materials for judging. Credit: NASA/ Amanda Adams



Above: The AI4Mars challenge asked solvers to use a web-based tool to annotate images taken by the Curiosity rover. These annotated images, pictured above, could teach future rovers how to identify terrain types. Credit: NASA

points based on efficiency, scalability, and reliability. Air Company received a \$50,000 bonus, while Hago Energetics and team SSwEET received \$25,000 each.

Isolation and confinement are aspects of the human exploration missions in particular that are being investigated via the ongoing **Scientific International Research In a Unique terrestrial Station (SIRIUS)** project. SIRIUS builds on previous work relating to analog missions, extending human stays in isolated, confined systems for periods exceeding a year. Data are compared with similar, real-world missions on the International Space Station. The SIRIUS missions are conducted at two facilities, including Johnson Space Center’s Human Exploration Research Analog (HERA) and at the Institute of Biomedical Problems of the Russian Academy of Sciences, also called NEK. SIRIUS analog missions are helping NASA gain knowledge about the physiological and psychological “exploration stresses” of remoteness and confinement in humans, all in preparation for

sustained Artemis expeditions to the Moon and eventual long-duration flight to Mars.

Crowdsourcing helped to solve problems related to autonomous operations, a set of capabilities that enable robotic explorers to conduct missions with minimal or no human intervention. Autonomous robots are needed to scout distant, unknown destinations or traverse hostile environments in humans’ stead. The ongoing **NASA AI4Mars** challenge, conducted with the help of crowdsourcing partner Zooniverse, has been aiming to improve a Mars rover’s ability to identify different, sometimes perilous terrain without a human involved in the navigation process. This kind of technology can also inform the robotic exploration of caverns and lava tubes under the lunar surface since these environments could prove ideal for human habitation in the future.

The **Exploring Hell – Avoiding Obstacles on a Clockwork Rover Challenge** received 572 submissions from the public for a similar autonomous capability for a wind-powered rover on Venus. While it’s unlikely we will ever dispatch a human mission to the formidable surface of Venus, learning about this planet next to Earth can help shed light on the nature of our home planet through comparative analysis. Three winners of a combined \$30,000 were announced in July 2020, with several additional solutions recognized by NASA as promising. First place went to Youssef Ghali, an Egyptian architect and product designer, for the “Venus Feelers” vehicle featuring relatively simple obstacle avoidance sensors.

Second place went to California-based Team RoveTronics “Skid n’ Bump” rover, which redirects following a low-energy collision with obstacles. Finally, third place went to Callum Heron, an Australian engineer who developed a rover that detects obstacles using a rake-like device. NASA awarded an additional \$4,000 for concepts recognized for best prototype and most innovative, with winners from Latvia and the United Kingdom, respectively.

Jonathan Sauder, a JPL engineer who led the Exploring Hell challenge, underscores how open innovation benefits NASA’s exploring and living in

space objectives: “You start to understand aspects of the problem that you may not have realized by yourself. You can identify problems much sooner. One of the amazing things about prize challenges is that there are a lot of novel ideas out there. People

“Because all our challenges have Earth applications, we recognize that prize competitions can lead to establishing business opportunities outside the space industry.”

- Monsi Roman
program manager
for NASA’s Centennial
Challenges

come up with innovative workarounds to problems.”

Opening Doors to Business and Opportunities

The public competitions and crowdsourcing efforts associated with exploring and living in space will inform research and development here on Earth. The results of the Vascular Tissue Challenge, for example, could be used in pharmaceutical testing, disease modeling, and organ transplants. While this represents clear research and development objectives in the applied sciences, it also represents opportunities for businesses by developing advanced technology processes, stimulating innovation and research, and demonstrating solutions that have the potential for application to business partners.

NASA’s 3D-Printed Habitat Challenge is another Space Technology Mission Directorate challenge that will enable long-duration and more autonomous exploration missions while still benefiting life on our home planet. NASA designed this challenge to advance the construction technology needed to create sustainable housing solutions for space and Earth. In the final round of the

four-day competition, two teams faced off for 30 hours of 3D printing to create subscale shelters out of recyclables and materials that we could find at deep-space destinations, like the Moon and Mars. The structures had to be a one-third-scale version of their architectural designs. Each team employed robotic construction techniques that allowed minimal human intervention. Their vision, dedication, and innovation helped further NASA’s deep-space goals and provided viable housing solutions right here on Earth.

Monsi Roman, program manager for NASA’s Centennial Challenges, identified several benefits to partners and participants. “Participants are motivated to do good for the Earth,” Roman says. “Because all our challenges have Earth applications, we recognize that prize competitions can lead to establishing business opportunities outside the space industry.” Some participants are inspired by the challenge itself. As Monsi points out, “some of them want to compete because they want to be part of the NASA mission –to be part of something bigger than themselves related to NASA’s missions that may one day take us to Mars and beyond.”

Below: NASA’s Jet Propulsion Laboratory (JPL), under a grant from the NASA Innovative Advanced Concepts program, ran a public challenge to develop an obstacle avoidance sensor for a possible future Venus rover. Credit: NASA





REACHING NEW FRONTIERS IN SCIENCE: INCLUDING CITIZEN SCIENTISTS AS PART OF THE NASA TEAM

Left: Citizen Scientist Hugo Sanchez practices his photography under a sky filled with a green aurora, as part of the Aurorasaurus citizen science project. Credit: Hugo Sanchez; NASA/Krista Trinder

Beyond NASA's civil servant and contract support core exists a vast, diverse domain of creative and skilled people with a willingness to solve complex problems. Supplemented with powerful mobile devices and an increasingly efficient internet, the potential for participation by people all over Earth is enhanced considerably. This is the domain of citizen scientists, who are making a difference in advancing scientific understanding in many fields.

Citizen science is a collaboration between scientists and members of the public. Citizen scientists (volunteers) collaborate with scientists by posing science questions, inventing new tools, and leading research efforts. Many exciting discoveries from NASA citizen science are serendipitous or spearheaded by the citizen scientists themselves.

Augmenting NASA's Brain Trust

NASA uses citizen science to gather, sort, and upload data relating to Earth, the solar system, and stars. The obvious benefit of citizen scientists observing Earth is that they are already on-site, with their smartphones, act as sophisticated sensors located all over the globe! In some cases, citizen science projects can continue for many years, providing a cost-effective means of augmenting scientific observation to produce very large data sets. Dr. Elizabeth MacDonald, a space plasma physicist with NASA's heliophysics research program

and developer of the Aurorasaurus project, captured the essence of citizen science support to NASA: "I feel it has made me a better scientist. It has exposed me to new things, new techniques, and the worth of interdisciplinary science. A lesson learned from citizen science is that the more you look...the more you find. It helps NASA do better science."

Aurorasaurus is a web-based citizen science project that gathers real-time data about public sightings of the aurora that result from interactions between the Sun and Earth's magnetosphere. The data are stored and can be used to support studies of space weather, information critical not only to spaceflight operations but also to forecasting and preparing for geomagnetic storms that can impact power grids.

Citizen scientists can also help capture data related to a variety of environmental phenomena that can pose a threat to safety, health, and even survival. Ground-based data gathered by individuals can be uploaded via the internet and ultimately merged with data gathered from above by aircraft and satellites. An example is **Landslide Reporter**. Landslides affect nearly all countries, but they are difficult to both predict and detect, even by satellites. Citizen scientists can submit landslides witnessed in-person or discussed online to a global database called the NASA Cooperative Open Online Landslide Repository. Shifting from land to water, **NeMO-Net** is a single-player iPad game where players help NASA



Above: NeMO-Net is a single player iPad game where players help NASA classify coral reefs by painting 3D and 2D images of coral. Currently, over 55,000 classifications have been completed and reviewed. Credit: NASA

classify coral reefs by painting 3D and 2D images of coral. Using a competitive format, players interact in a way that can help NASA classify and assess the health of coral reefs around the world. Data from the NeMO-Net game is fed to NASA NeMO-Net, an open-source deep convolutional neural network that leverages a NASA supercomputer called Pleiades.

A clear benefit of citizen science is how this open-source approach meshes well with education, from primary school through graduate-level research. For 25 years, the **Global Learning and Observations to Benefit the Environment (GLOBE)** program has promoted active engagement of students, teachers, scientists, and citizens to discover and learn about the intricacies of Earth's environment while gaining perspective concerning the overall health of our world. During the past quarter-century, more than 10 million students from 113 countries have contributed well-over 130 million measurements. The introduction of the GLOBE Observer (GO) mobile app in 2016 boosted participation outside of the formal school setting to include individual citizens of all ages. Together with working groups established by GLOBE, the collective whole supports community initiatives in the areas of science, education, evaluation, and technology, as well as the development of new science and education content, among other tools. Allison Leidner, GLOBE Program Manager at NASA Headquarters, points out that "one of the values of the GLOBE program is to enable students to pursue careers in science, technology, engineering, and mathematics and to better understand their environment, regardless of what career they pursue."

Beyond Earth, citizen scientists contribute to our understanding of our solar system and astronomical

objects further still. Asteroids, for example, have become a topic of great interest since it was discovered that the dinosaurs were effectively wiped out by an asteroid impact 65 million years ago. Could such an impact happen again? What are asteroids made of, and where do they come from? **Target Asteroids!** is an ongoing citizen science project that enables amateur astronomers to help NASA understand these questions.

NASA's Juno orbiter, which arrived at Jupiter in 2016, five years after launch, gathers data about the gas giant's turbulent atmosphere, including high-resolution images using its **JunoCam**. Citizen scientists contribute as a virtual imaging team, supporting the mission's objective of understanding Jupiter's origins and its influence on the solar system by processing over 8,000 images and flagging notable activity worthy of further investigation. It also serves as a form of inspiration, combining the wonder of nature with those that have an artistic impulse. **Backyard Worlds: Planet 9** enlists the public to scan the huge library of images obtained by NASA's Wide-field Infrared Survey Explorer (WISE) to seek solar-orbiting celestial objects. Is there a Planet 9? Does the Sun have a dim stellar companion? Those are questions being investigated with the help of citizen scientists.

Advancing beyond the rim of the solar system, we encounter opportunities for citizen scientists to contribute to our understanding of interstellar space. Launched in 1999, NASA's Stardust mission successfully collected material from the coma of comet Wild 2 in 2004. In doing so, it also may have captured interstellar dust, a possibility announced by NASA eight years after the samples returned to Earth in 2006. **Stardust@Home** is an ongoing project designed to enable citizen scientists to contribute observation time, browsing a huge database

Below: Students participate in a GLOBE Learning Expedition in New Delhi, India prior to COVID-19. GLOBE provides opportunities for students and interested members of the public to contribute their observations to a collective database used by other students, scientists, and researchers. Credit: The Globe Program





Above: The Global Learning and Observation to Benefit the Environment (GLOBE) program provides outdoor learning opportunities in the midst of a pandemic. Credit: Camp Discovery in Blythewood, South Carolina

of images of the aerogel collectors for micron-size tracks that could indicate the existence of microscopic interstellar particles. Stardust@Home citizen scientists, who call themselves “dusters,” found eight interstellar dust grains through this process, the only known samples of interstellar material ever to be analyzed in a laboratory.

Speaking of solar systems, citizen scientists have also played an ongoing role in identifying and characterizing extrasolar disks, the telltale sign of solar systems being born in our galactic neighborhood. Through crowdsourcing partner Zooniverse, NASA’s **Disk Detective** invites volunteer sleuths to comb through data gathered by NASA’s WISE mission. This project discovered a new kind of long-lasting circumstellar disk. The existence of these “Peter Pan” disks help explain the orbits of planetary systems around low mass stars. Similar successful citizen science

efforts have been undertaken by NASA in recent years to help identify extrasolar planets. Planet Patrol and Planet Hunters TESS both leverage data gathered by the Transiting Exoplanet Survey Satellite (TESS) spacecraft.

“It has exposed me to new things, new techniques, and the worth of interdisciplinary science. A lesson learned from citizen science is that the more you look...the more you find. It helps NASA do better science.”

-Dr. Elizabeth MacDonald, NASA’s heliophysics research program

Being a part of something bigger

Citizen scientists are of immense value to NASA. But the relationship also benefits the volunteers dedicating time to support the agency’s mission. They directly contribute to the profound enterprise of discovery being undertaken by NASA, a globally recognized brand of excellence in science and technology. They want to be a part of making the world a better place and help NASA explore the universe. Citizen collaboration with professional scientists, conducting cutting-edge science, and making real discoveries is why citizen science counts and is such a vital part of the crowdsourcing ecosystem at NASA.



CREATING THE NEXT GENERATION OF EXPLORERS

BUILDING A DIVERSE, EQUITABLE, AND INCLUSIVE
WORKFORCE FOR THE NATION'S FUTURE

NASA not only depends on tapping an educated population for its workforce but also must inspire creative thinking about challenging problems, to push the envelope beyond what we know. Open innovation provides a natural means to engage students in a manner that enhances the educational experience while also promoting technological innovation. Younger generations have the capacity to think outside the box, with their imaginations less restricted by experience. They can help NASA brainstorm solutions to complex problems.

Budding scholars around the world are energizing NASA's Artemis program through a set of student-based open innovation initiatives that build upon existing prize competitions and crowdsourcing efforts. These include Human Exploration Rover Challenge, LUNABOTICS, Micro-g NEXT, BIG Idea Challenge, First Nations Launch, Spacesuit User Interface Technologies for Students, and Student Launch.

The **Human Exploration Rover Challenge** was established over a decade ago as NASA anticipated human exploration of the Moon and Mars following the retirement of the space shuttle. The challenge aligns with NASA's objective to return astronauts to the Moon by emphasizing the design, construction, and testing of technologies, tools, and mobility devices necessary for surface exploration. In 2020, 111 teams from the United States and 11 other countries competed, providing rovers designed to traverse rocky terrain, retrieve samples, and conduct spectral analysis. Due to the global pandemic, an on-site competition was not possible, so a virtual competition was successfully undertaken instead. **LUNABOTICS**, a challenge started in 2010, is a complimentary challenge featuring robotic lunar excavator designs submitted by university teams. Because the Artemis program objective is to enable a sustainable presence on the Moon, excavation of lunar resources will be necessary.

Left: Nearly 100 teams took part in the 2019 Human Exploration Rover Challenge, held at the U.S. Space & Rocket Center in Huntsville, Alabama. The competition challenges high school and college teams to design, build and test human-powered roving vehicles. Credit: NASA

Whether in orbit, on the Moon, or on Mars, hand-held tools will be required in order for astronauts to conduct exploration, construction, and maintenance activities. These tools and how astronauts will use them are the subject of the **Micro-g Neutral Buoyancy Experiment Design Teams (Micro-g NEXT)** challenges. Student teams design tools that address specific needs identified by NASA in support of the Artemis program. Prototyped tools are then tested at Johnson's Neutral Buoyancy Laboratory (NBL).

Of course, human exploration of the Moon will require spacesuits. While NASA has decades of experience with spacesuit design and optimization, an area identified as a technology gap centers

on communication. Specifically, how can astronauts gather and process information about the lunar environment to support exploration and resource utilization?

The **Spacesuit User Interface Technologies for Students (SUITS)** challenges students to create information displays within augmented reality environments. Students and one faculty advisor from each selected team are invited to test selected technologies in Houston.

Both lunar surface activity and tool use introduce certain challenges related to the generation of lunar dust, the subject of the 2021

Breakthrough, Innovative and Game-changing (BIG) Idea Challenge, a prize competition for university students that NASA's Space Technology Mission Directorate supports annually. Each year, university students have the opportunity to design, build, and test technologies to support the challenge's theme, which changes annually. The effort culminates in a BIG Idea forum in which selected student groups present their work.

Begun nearly a decade ago, **Student Launch** is a research-based, competitive project that prompts U.S. universities, colleges, high schools, and middle schools to design, build, and fly payloads or vehicle components. The payloads fly aboard high-powered rockets at high altitudes on suborbital trajectories. The payloads provide research designed to support NASA's Space Launch System (SLS), the rocket that will take astronauts to the Moon as part of the Artemis program.



*- Wisconsin Space Grant Consortium Assistant Director
Christine Bolz*



Above: Student Launch is a research-based, competitive, experiential exploration activity. It strives to provide relevant, cost-effective research and development of rocket propulsion systems. Students pictured here participated in the challenge prior to COVID-19 restrictions. Credit: NASA

Open innovation is allowing the “Artemis Generation” to actively participate in preparing for exploration of the Moon instead of only witnessing events from a television or computer monitor, as the generations that followed the Apollo missions were limited to doing. In addition to bolstering NASA’s Artemis program, open innovation activities promote student involvement and embrace inclusion—ingredients that inform creative solutions to vexing problems or highlight new ways of thinking.

Consider NASA’s **Swarmathon**, a prize competition to engage underrepresented and underserved students in NASA education and research. This competition started in 2016 in partnership with NASA’s Minority University Research and Education Program (MUREP). Four Swarmathon competitions involving 1,500 students have been held, each pitting university and high school teams to develop integrated robotic platforms, or “swarms,” that work on their own, performing multi-tasking duties far speedier than lonely automatons. While Swarmathon has ended, it helped spark the NASA MUREP Innovative New Designs for Space (MINDS). **NASA MINDS** is reserved for Minority Serving Institutions located within the United States. Theresa Martinez, MUREP Science, Technology, Engineering, and Mathematics (STEM) engagement manager at Kennedy Space Center, describes the important role Swarmathon played in the students’ curriculum: “What we required was that the faculty be an active part of leading the teams. We provided faculty a stipend to do so. We also required that participants had to be a class or were being given course credit or they

were part of a senior design class. It was more structured to help with retention...and we had very high retention rate with Swarmathon.”

These challenges encourage students across disciplines to consider career paths not only in space but also in aeronautics. A considerable amount of focus has been applied to NASA’s space missions, as dramatic as human and robotic missions are. But, as NASA’s Elizabeth Ward points out, “the public doesn’t realize NASA does work on airplanes. We don’t necessarily invent airplanes, but we invent technologies that make aircraft fly safer and also be more fuel efficient and quieter.” Ward is the principal investigator for multidisciplinary research student programs in NASA’s Aeronautics Research Mission Directorate. The 2020 **Aeronautics Design Challenge** called upon students across multiple disciplines to address weather tolerant operations for Urban Air Mobility (UAM). As envisioned, UAM will involve small autonomous aircraft flying short distances within urban areas carrying passengers and cargo. The issue: weather conditions depend on location and are market-dependent. This NASA challenge focused on developing UAM vehicle hardware concepts that could operate in the “most prevalent” weather for a specific urban market. Since 2001, hundreds of college students and high school students have taken part in NASA aeronautics contests like this one. Many of those involved in NASA aeronautics contests and challenges say it stimulated their interest in studying aerospace. For Elizabeth Ward, it’s the “motivation for continuing to offer and administer

the aeronautics challenge. In my opinion, the more young people we attract to aeronautics, the more change will come. That's because they are not rooted in the way things have always been done."

Open innovation allows NASA to actively involve students that might not otherwise have considered a STEM career, let alone work in an aerospace field. These projects help ensure that young Americans, regardless of who or where they are, can pursue STEM educational opportunities that may lead to careers in aerospace as well as other disciplines, ultimately enhancing the brain trust of the country into the future. For example, **First Nations Launch (FNL)**, an ongoing prize competition initiated in 2008 by a partnership between NASA and the Wisconsin Space Grant Consortium (WSGC), provides students who attend Tribal Colleges and Universities (TCU), Native American-Serving Nontribal Institutions, or who are members of collegiate chapters of the American Indian Science and Engineering Society (AISES) with the opportunity to design, build, and launch a high-powered rocket. WSGC Assistant Director Christine Bolz, who has overseen FNL since 2014, said that "with this program, we're literally changing lives, and we're impacting the communities that many of our students are part of. What I love more than anything is the excitement that we're seeing in the next generation about going back to the Moon and how they can be a part of that. When you can say the word 'Artemis,' and people know exactly what that means, that's exciting."



Above: One of the nearly 100 teams to participate in the 2019 Human Exploration Rover Challenge, hosted by NASA's Marshall Space Flight Center. Credit: NASA



Above: Student Launch offers multiple challenges reaching a broad audience of middle and high schools, colleges, and universities across the nation. Pictured here is the team from Lucy Rede Franco Middle School from Presidio, Texas prior to COVID-19 restrictions. Credit: NASA



EMPOWERING COMMUNITIES

NURTURING INNOVATION AND A PASSION FOR FINDING SOLUTIONS

The NASA brand is easily recognizable almost anywhere. On the one hand, it represents the pinnacle of achievement, the ability to do the impossible. But NASA is also an integral part of humanity's ecosystem and a leader in the exploration and discovery of space. It is a leader in technological development and research for the U.S. aerospace industrial base. It is consistently rated the best place to work in the U.S. government. And, as this publication shows, NASA plays an important role by inspiring and engaging the public to participate in its mission, regardless of scale, from the bold endeavor represented by Artemis and the robotic exploration of the solar system to trying to figure out the best way to design a microgravity toilet.

Ensuring NASA's Future by Partnering with the Community

As a part of the global community, NASA has an interest in helping solve practical problems relating to everyday life on Earth. NASA recognizes that sometimes the best ideas can be found anywhere in the world, and the agency engages an inspired and innovative public in finding solutions.

An excellent example of enlisting the global community to solve a diverse set of problems that relate to NASA's mission is the **International Space Apps Challenge**, inaugurated in 2012. A hackathon spanning communities across the planet, the objective is for competing teams to propose solutions leveraging NASA's freely available data in a whirlwind of innovation spanning just 48 hours. Teams of technologists, scientists, designers,

entrepreneurs, artists, and others collaborate to answer some of the most pressing challenges on Earth and in space. Each met at specific locations to enable collaboration, though these can also serve as virtual hackathon hubs. In 2020, over 250 locations were involved.

The Space Apps values statement includes a phrase that captures the spirit of the challenges: "We strive to ensure that Space Apps is a place where every person feels they belong, where they are comfortable being authentic, and where they are empowered to contribute to their fullest." The virtually connected hackathons take place on a weekend and reflect a central theme of Earth and space. Due to the global pandemic in 2020, two Space Apps Challenges were conducted. As previously highlighted, the May 2020 hackathon was unique as it was inspired by a global emergency and centered on solutions to help mitigate the impact of the COVID-19 pandemic. The second hackathon took place in October 2020. Over 26,000 registered participants were involved in 23 separate challenges.

While a global reach can produce impressive problem-solving results, sometimes solutions can be found in the neighborhood. In addition to their regular work, NASA civil servants and contractors can tap the talents of fellow colleagues across the agency. **NASA@WORK** mobilizes the NASA community that provides agency employees with an unconventional way to contribute solutions designed to advance projects or solve specific problems. The motive is to encourage collaboration across NASA,

learn what other colleagues are working on, and think outside the box. Through NASA@WORK, an employee can present a problem. Fellow employees from anywhere in the agency can contribute solutions. The benefit to NASA is that individuals or offices have a direct need, and problems can be solved relatively quickly.

Building an On-Ramp for Promising Ventures

By mobilizing communities to support NASA's mission, the agency also ignites the entrepreneurial spirit. Entrepreneurs, start-up companies, and NASA benefit from this joint community by:

- Stimulating technological innovation.
- Using small businesses to meet federal R&D needs.
- Fostering and encouraging participation in innovation and entrepreneurship by socially and economically disadvantaged small businesses.
- Increasing private-sector commercialization of innovations derived from federal R&D funding.

NASA partnered with aerospace innovation catalyst Starburst to jointly inaugurate the **Entrepreneurs Challenge** in June 2020. The objective is to identify U.S.-based entrepreneurs and early-stage ventures with business plans demonstrating promising technologies that can advance the state-of-the-art. This challenge can serve as an “on-ramp” for selected small businesses that can lead to awards from NASA's Science Mission Directorate. The first challenges focused on physics-based transfer learning and artificial intelligence, advanced mass spectrometry, and quantum sensors. 75 parties submitted white papers, with six concepts being selected in the final round in October 2020. Michael Seablom, NASA's chief technologist for science at the time, was enthusiastic about the potential for this challenge to produce results. “There's a lot of energy and fresh thinking as a result of the entrepreneurial spirit that has emerged in our field over the past few years,” Seablom said. “We want to be sure we're not leaving good ideas on the table or missing the contributions some of these potential partners could make to the exciting science missions coming up.”

According to Nicole Rayl, NASA's acting chief technologist for science, “today's novel ideas enable tomorrow's cutting-edge research—and we sponsor and support such technology development through every step of that process. We're always so excited to see the creativity launched by challenges like this.”

Launched in 2020, the **Safeguard with Autonomous Navigation Demonstration (SAND) Challenge** was an opportunity for small businesses to compete in an autonomous unmanned aerial vehicle competition. At the heart of the competition was the use of NASA

Langley Research Center's patented Safeguard technology to navigate a simulated post-natural disaster event, specifically the destructive power of a hurricane. Safeguard is designed to help build trust in autonomous systems. According to Lena Little, SAND Project Manager, SAND addressed safety-critical risks associated with flying unmanned aerial vehicles (UAVs) in the national airspace. “Our goal was to provide an environment that interacts between the technical readiness level of UAVs and real-world situations to commercialize this technology. We want to insert autonomy into operational environments, to fly beyond visual line of sight, and then build on that experience. SAND counted on the help of industry and academia to achieve this outside of our NASA gates.”

The benefits NASA accrued from SAND were internal, from evaluating the legal risk posture to finding ways to reduce paperwork and for NASA to better engage with start-up private firms. However, the COVID-19 pandemic derailed the effort mid-way, and the competition could not be completed. “Still, we definitely set the groundwork for this approach and demonstrated that we can do it again,” according to Little.

Through prize competitions and crowdsourcing, open innovation by definition brings together a diverse set of individuals from across the globe to solve problems that advance NASA's mission. The nature of collaboration, combined with innovations that would not have otherwise occurred without the spirit of community, serve as investments designed to create a sustainable aerospace industry that can support NASA's long-term goals.

NASA Solve: A One-Stop-Shop for Mobilization

The NASA Solve website (www.nasa.gov/solve) shares opportunities for members of the public to collaborate with NASA via challenges, prize competitions, and crowdsourcing, and citizen science projects. NASA Solve provides listings for challenges and prize competitions, hackathons, and crowdsourced and citizen science projects. Each project listing provides information about who can participate, any awards available, and a link to register or learn more about the project. NASA Solve gets the word out about new opportunities through social media (@NASASolve), a periodic newsletter to which members of the public can subscribe via the website, and appearances at major public events and STEM-related festivals. “Our website serves as the gateway for the public to participate and connect with NASA open opportunities. It's a wonderful way for different communities to mobilize and participate together, whether it be teachers and students, families, retirees, or people who simply want to do science to get involved,” said NASA Solve Senior Communication Manager Karen James.

FY19 AND FY20

NASA OPEN INNOVATION BY THE NUMBERS



56 Public prize competitions and challenges



29 Citizen science and crowdsourcing activities



2M Citizen science participants



\$2.2M
Amount awarded in FY19 and FY20



11K+
Solutions submitted



140
Citizen scientists named as co-authors on scientific papers



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