National Aeronautics and Space Administration

Artemis Generation Spacesuits

Educator Guide

ENGINEERING AND LIFE SCIENCES

Next Gen STEM – Moon

For more about Next Gen STEM visit https://www.nasa.gov/stem/moon

Education Product	
Educators and Students	Grades 6-8

Contents

Preface

Artemis Generation Spacesuits was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each activity is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of July 2022.

STEM Education Standards

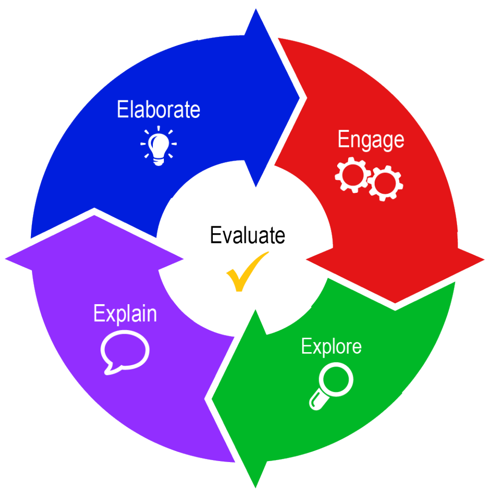
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) middle school disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) Standards for Students. The four focus areas for engineering were adapted from the National Science Teaching Association (NSTA) and NGSS science and engineering practices. The four focus areas for mathematics were adapted from the Common Core State Standards (CCSS) for Math middle school content standards by domain.

Activity	STEM Disciplines															
	Science				Technology				Engineering				Math			
	NGSS Disciplinary Core Ideas				ISTE Standards for Students				NSTA and NGSS Practices				CCSS Content Standards by Domain			
	Physical Sciences	Life Sciences	Earth and Space Sciences	Engineering, Technology, and the Application of Sciences	Knowledge Constructor	Innovative Designer	Computational Thinker	Global Collaborator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Construct Explanations and Design Solutions	Ratios and Proportional Relationships	The Number System	Statistics and Probability	Geometry
Spacesuits Are Spacecraft		✓		✓		✓		✓		✓		✓				
Made To Suit		✓		✓		✓		✓	✓	✓	✓	✓				
Heads-Up Display	✓						✓	✓		✓			✓	✓		✓
Astro-Tools				✓	✓	✓		✓	✓	✓	✓	✓				

5E Instructional Model

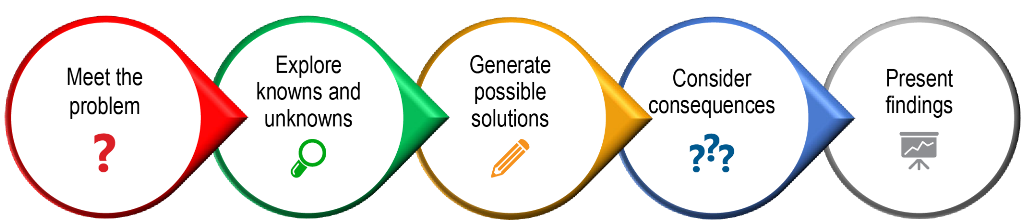
The 5E instructional model is a constructivist learning cycle that helps students build their own understanding from experiences and new ideas. This five-stage model was originally developed for the Biological Sciences Curriculum Study (BSCS) Life and Living curriculum (https://bscs.org). Learn more about the 5E instructional model with NASA eClips™ at https://nasaeclips.arc.nasa.gov/teachertoolbox/the5e.

- **Engage:** Pique students' interest while pre-assessing prior knowledge. Students make connections between past and present learning experiences, which sets the groundwork for upcoming activities.
- **Explore:** Get students involved in the activity by providing them with a chance to build their own understanding. Students usually work in teams during this stage, which allows them to build a set of common experiences through sharing and communicating.
- **Explain:** Provide students with an opportunity to communicate their understanding of what they have learned so far. Students at this stage can communicate what they have learned by introducing vocabulary in context. Correct or redirect misconceptions.
- **Elaborate:** Allow students to use their new knowledge and explore its implications. Students expand the concepts they have learned, make connections, and apply their understanding in new ways.
- **Evaluate:** Determine how much learning and understanding has taken place. Students can demonstrate their learning through journals, drawings, models, and other performance tasks.



Problem-Based Learning

- **Meet the Problem**: Identify the problem, introduce new vocabulary, and discuss previous experiences with the problem.
- **Explore Knowns and Unknowns**: Use resources to explore the knowns and unknowns.
- **Generate Possible Solutions:** Brainstorm possible solutions based on resources and prior experience with the problem.
- **Consider Consequences**: Examine the pros and cons of each solution to determine a viable solution.
- **Present Findings**: Communicate and discuss the process and solutions as a team.



Computational Thinking Model

The seven core practices of the K–12 Computer Science Framework have been incorporated into most of the activities within this guide. More information about these core practices is available at https://k12cs.org/navigating-the-practices/.

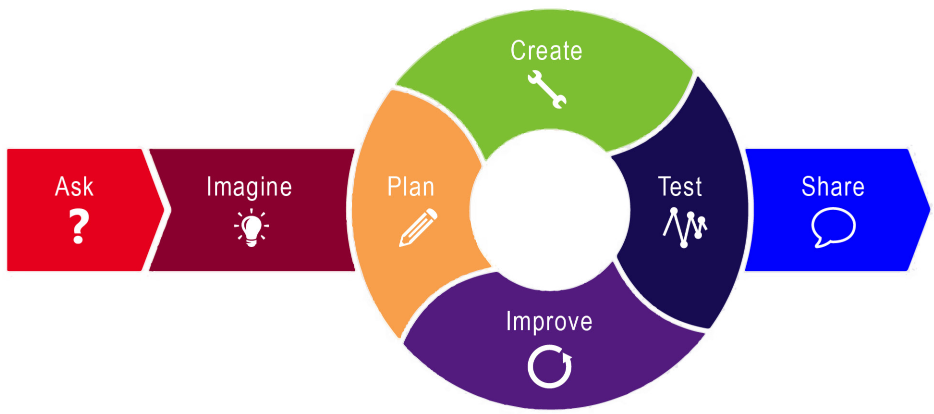
1. **Fostering an inclusive computing culture:** Everyone needs computers, but not everyone uses computers in the same way. An inclusive computer culture requires advocating for features and approaches that make technology as accessible and accommodating as possible.
2. **Collaborating around computing:** Two heads are better than one, but only when the team shares mutual respect and understanding. This includes making sure that workloads are split fairly and feedback is constructive.
3. **Recognizing and defining computational problems**: Computers can help with many (but not all) situations, and the usefulness of computers depends on simplifying complex, real-world problems into small, repeatable pieces that a computer handles better than a human can.
4. **Developing and using abstractions**: While every sandwich is different, most sandwiches involve something between two slices of bread. Systems can often be more versatile and efficient when they are designed to reflect the “big picture” rather than one specific situation.
5. **Creating computational artifacts**: Ideas are great, but at some point, progress requires a clear plan and, ultimately, the creation or modification of a program, video, robot, or other technology.
6. **Testing and refining computational artifacts**: Computers do not “think” the same way humans do, and end-users do not always think the same way the designer did. This means that all technology must be thoroughly tested to minimize errors and maximize performance, reliability, usability, and accessibility.
7. **Communicating about computing**: The best technology in the world is useless if nobody knows that it exists or how to use it. It is important to create documentation (such as a user manual) and to justify the benefits of any new technology. It is also important to fairly and responsibly attribute or license any intellectual property that came from others.

K–12 Computer Science Framework’s 7 Core Practices. (Adapted from K–12 Computer Science Framework, Creative Commons license CC BY-NC-SA 4.0.)

Engineering Design Process

The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. Students can use the seven steps outlined below for many of the activities in this guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at https://www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. **Ask**: Identify the problem, the requirements that must be met, and the constraints that must be considered.
2. **Imagine**: Brainstorm solutions and research what others have done in the past.
3. **Plan**: Select and sketch a design.
4. **Create**: Build a model or a prototype.
5. **Test**: Evaluate solutions by testing and collecting data.
6. **Improve**: Refine the design.
7. **Share**: Communicate and discuss the process and solutions as a group.



Teamwork

Everyone is a scientist and an engineer! It is important that everyone on the team be able to participate and contribute throughout these activities. If one student does all the building, the other students may be very bored during the building process. If one student is the leader, other students may not have a chance to share their ideas. Here are some possible roles that students can take:

Student Role	Description
Communications and Outreach	Takes notes of all team decisions and actions for use in a final presentation. If a camera is available, takes video and/or photos throughout the investigation or challenge for use in a final presentation.
Logistics	Makes sure that the team has all the resources they need, that resources are distributed fairly, and that the team knows when resources are running low.
Mission Assurance	Makes sure the team is following the plan. Keeps track of time and makes sure that everyone has a chance to have their voice heard.
Safety	Ensures all team members are wearing their safety goggles and following safety protocols.

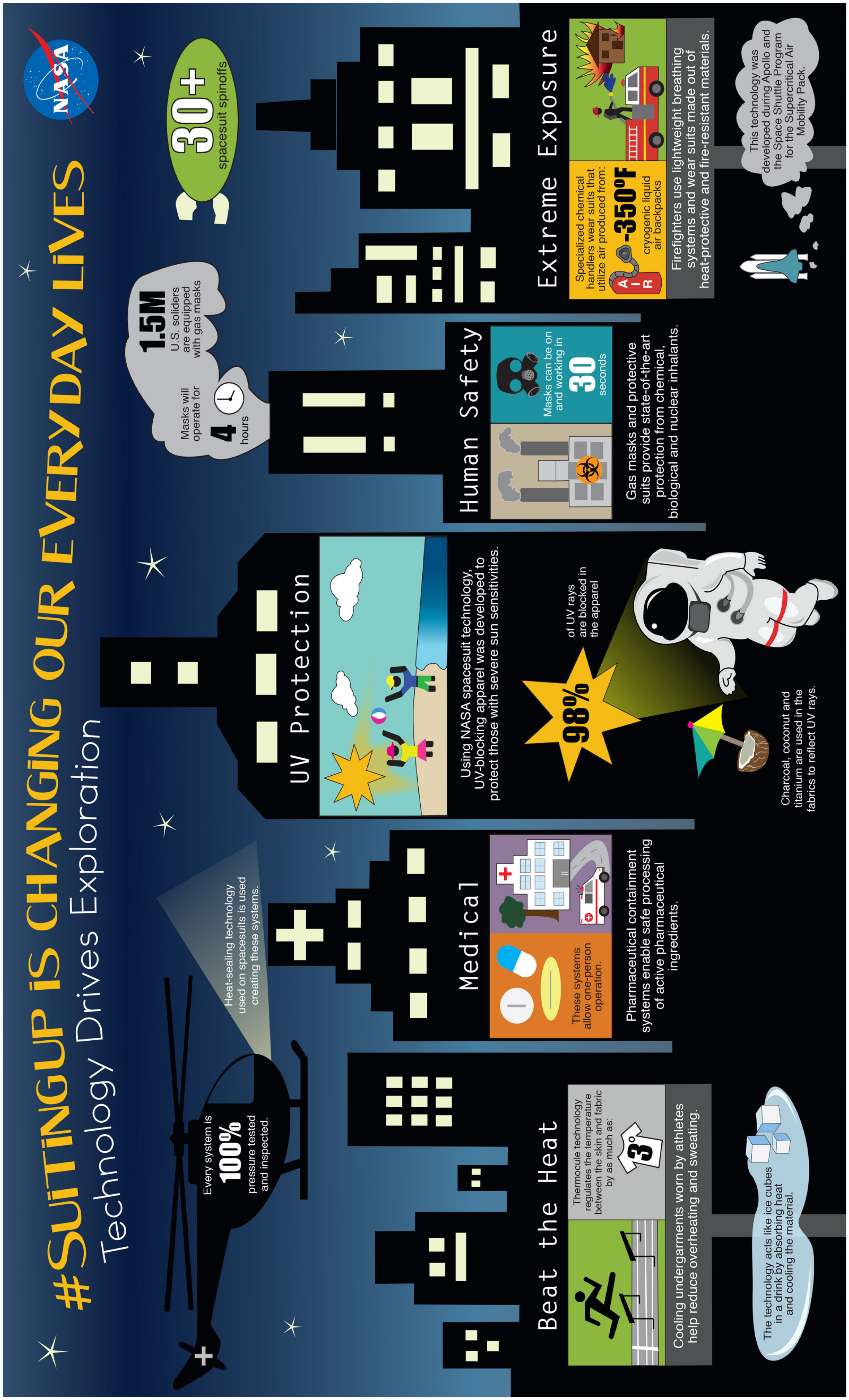
Curriculum Connection

In this module, students will take on roles as scientists and engineers for a next-generation spacesuit for the Artemis Generation of astronauts. At first glance, NASA's new Artemis mission spacesuit might look like the suits astronauts currently use for spacewalks outside the International Space Station. However, future moonwalkers will be able to accomplish much more complex tasks than their predecessors, thanks to strides in technological advances that started even before the Apollo program. Each activity in this module encourages collaborative teamwork by applying the 5E instructional model, problem-based learning techniques, the computational thinking model, and the engineering design process. Activities suggest a variety of additional resources such as videos, articles, extension activities, and websites that help encourage students to immerse themselves in being an actual part of the Artemis Generation spacesuit design team.

NASA "spinoffs" are NASA technologies that benefit life on the Earth in the form of commercial products. NASA technology has resulted in more than 2,000 spinoffs since 1976. There is more space in our lives than we could ever imagine!

More than 30 spinoffs have resulted from spacesuit technology. The spacesuit spinoffs highlighted in the infographic on the next page illustrate how NASA works with companies in developing the innovative technologies that drive space exploration. Spacesuit technology has been used to create cooling undergarments for athletes to help reduce overheating and sweating. Technology used to create spacesuit fabric that blocks the Sun's ultraviolet rays has also been used in the development of apparel to protect people who have Sun sensitivities. Even gas masks and protective suits that protect humans from chemical, biological, and nuclear inhalants have benefited from NASA technology.

For more information on these and other NASA spinoffs, visit https://spinoff.nasa.gov/.


#SUiTiNGUP iS CHANGiNG OUR EVERYDAY LiVES
Technology Drives Exploration
NASA
30+ spacesuit spinoffs
1.5M U.S. soliders are equipped with gas masks
Masks will operate for 4 hours
Every system is 100% pressure tested and inspected.
Heat-sealing technology used on spacesuits is used creating these systems.
Beat the Heat
Thermocule technology regulates the temperature between the skin and fabric by as much as: 3°
Cooling undergarments worn by athletes help reduce overheating and sweating.
The technology acts like ice cubes in a drink by absorbing heat and cooling the material.
Medical
These systems allow one-person operation.
Pharmaceutical containment systems enable safe processing of active pharmaceutical ingredients.
UV Protection
Using NASA spacesuit technology, UV-blocking apparel was developed to protect those with severe sun sensitivities.
98% of UV rays are blocked in the apparel
Charcoal, coconut and titanium are used in the fabrics to reflect UV rays.
Human Safety
Masks can be on and working in 30 seconds
Gas masks and protective suits provide state-of-the-art protection from chemical, biological and nuclear inhalants.
Extreme Exposure
Specialized chemical handlers wear suits that utilize air produced from:
AIR
-350°F cryogenic liquid air backpacks
Firefighters use lightweight breathing systems and wear suits made out of heat-protective and fire-resistant materials.
This technology was developed during Apollo and the Space Shuttle Program for the Supercritical Air Mobility Pack.

Introduction and Background

Spacesuits Are Spacecraft

History of Spacesuits

Spacesuits are much more than a set of clothes that astronauts wear. However, like a set of clothes, different suits serve different purposes. Space exploration usually includes two different kinds of spacesuits, both of which protect astronauts from the extreme environment of space, just as a spacecraft does. One kind of spacesuit is worn inside a spacecraft during launch and ascent to space and again on the way home during reentry (descent) into Earth's atmosphere and during landing. The other kind is designed specifically for spacewalks—when astronauts go outside of their spacecraft to explore. NASA refers to a spacewalk as an "*extravehicular activity*" (EVA), so this type of suit is often called an EVA suit. Educators and students can learn more about the hazards of deep space in "Hazards to Deep Space Astronauts," an educator guide filled with activities for middle school students: https://www.nasa.gov/stem-ed-resources/hazards-to-deep-space-astronauts.html.

The full-page infographic on the next page depicts NASA spacesuit designs across the years. NASA astronauts first flew into space during the Mercury program (1958 to 1963), and NASA's first spacesuits were made for Project Mercury. The Mercury suits were only worn inside the spacecraft; NASA's first spacewalks would not take place until the Agency's second space program, Gemini (1965 to 1966). The suits used for Gemini were more advanced than the Mercury suits but much simpler than those worn today. The Gemini suits did not contain their own life support. A hose connected the astronaut to the spacecraft, and the astronaut breathed oxygen from the spacecraft through the hose.

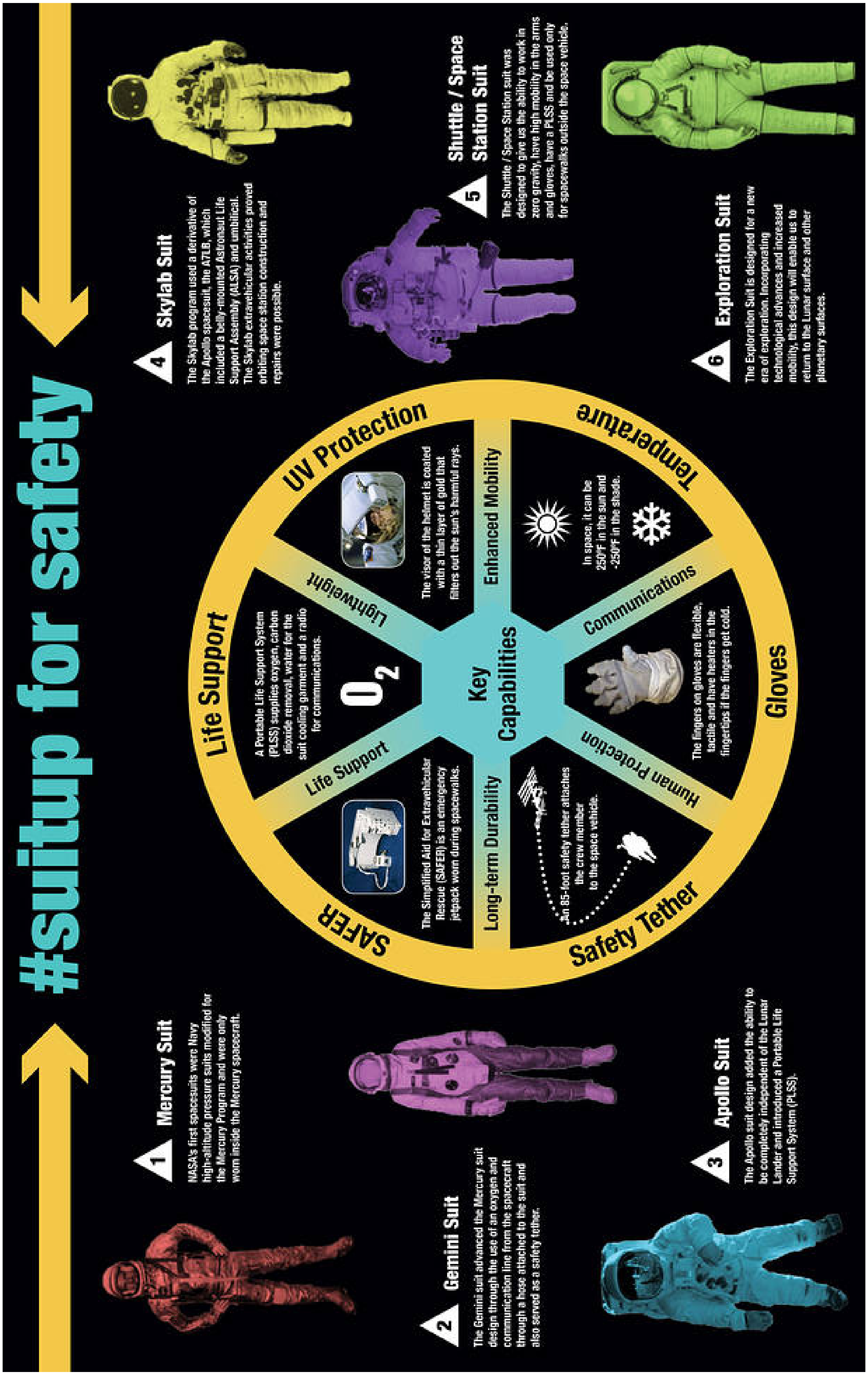
Spacesuits for the Apollo program (1967 to 1972) had to do things the Mercury and Gemini suits could not. These suits had to protect astronauts while they were walking on the Moon. The Apollo suits had boots made for walking on rocky ground, and they had a life support system. Astronauts could walk far away from the lunar lander because they were not connected by a hose. Following the Apollo program, NASA conducted three astronaut missions aboard Skylab (1973 to 1974), a small space station in low Earth orbit. The Skylab spacesuits resembled the Apollo suits in some ways, but they connected to the spacecraft with a hose during EVAs, like the Gemini suits. During the Space Shuttle Program (1972 to 2011), astronauts wore orange pressure suits for launch and landing. These suits were only worn inside the spacecraft. Astronauts wore heavy white spacesuits for spacewalks outside the space shuttle.

Astronauts on the International Space Station currently use spacesuits that were designed more than 45 years ago for the Space Shuttle Program, and they rely on these refurbished and partially redesigned spacesuits for EVAs. Over the past 20 years, however, NASA has been researching and developing groundbreaking spacesuit technology that has resulted in a prototype known as the Exploration Extravehicular Mobility Unit (xEMU). The xEMU will be used to support the creation of a new generation of spacesuits by commercial partners for multiple NASA programs. Specifically, this research will be used in the development of spacesuits for use on the International Space Station and on Artemis missions involving Gateway and the Human Landing System (HLS).

Orion Crew Survival System
(NASA/Joel Kowsky)

Artemis Generation Spacesuits

Like earlier NASA missions, the Artemis missions will require two spacesuits: one worn inside a spacecraft during dynamic activities such as launch and reentry through Earth's atmosphere, and another worn outside a spacecraft during spacewalks that will function as a self-contained personal spaceship. Before astronauts launch on Artemis missions to the Moon, they will suit up in a bright orange spacesuit called the Orion Crew Survival System (OCSS), pictured at right. They will continue to wear this suit while they are inside NASA's Orion spacecraft. The OCSS is designed with a custom fit and equipped with technology to help protect astronauts on launch day, during emergency situations, throughout high-risk parts of missions near the Moon, and during the high-speed return through Earth's atmosphere.


#suitup for safety
1 Mercury Suit
NASA's first spacesuits were Navy high-altitude pressure suits modified for the Mercury Program and were only worn inside the Mercury spacecraft.
2 Gemini Suit
The Gemini suit advanced the Mercury suit design through the use of an oxygen and communication line from the spacecraft through a hose attached to the suit and also served as a safety tether.
3 Apollo Suit
The Apollo suit design added the ability to be completely independent of the Lunar Lander and introduced a Portable Life Support System (PLSS).
Key Capabilities
Life Support
A Portable Life Support System (PLSS) supplies oxygen, carbon dioxide removal, water for the suit cooling garment and a radio for communications.
O2
UV Protection
The visor of the helmet is coated with a thin layer of gold that filters out the sun's harmful rays.
Lightweight
Enhanced Mobility
Temperature
In space, it can be 250°F in the sun and -250°F in the shade.
Communications
Gloves
The fingers on gloves are flexible, tactile and have heaters in the fingertips if the fingers get cold.
Human Protection
Safety Tether
An 85-foot safety tether attaches the crew member to the space vehicle.
Long-term Durability
SAFER
The Simplified Aid for Extravehicular Rescue (SAFER) is an emergency jetpack worn during spacewalks.
Life Support
4 Skylab Suit
The Skylab program used a derivative of the Apollo spacesuit, the A7LB, which included a belly-mounted Astronaut Life Support Assembly (ALSA) and umbilical. The Skylab extravehicular activities proved orbiting space station construction and repairs were possible.
5 Shuttle / Space Station Suit
The Shuttle / Space Station suit was designed to give us the ability to work in zero gravity, have high mobility in the arms and gloves, have a PLSS and be used only for spacewalks outside the space vehicle.
6 Exploration Suit
The Exploration Suit is designed for a new era of exploration. Incorporating technological advances and increased mobility, this design will enable us to return to the Lunar surface and other planetary surfaces.

Exploration Extravehicular Mobility Unit (xEMU) prototype. (NASA/Joel Kowsky)

The second Artemis Generation spacesuit, designed for use during EVAs, will be based on the xEMU prototype pictured at right. This is the spacesuit NASA designed through decades of research and development of advanced suit technology. The new generation of spacesuits will need the technologies and capabilities NASA incorporated into this spacesuit to enable EVAs in deep space, on the lunar surface, and eventually on the surface of Mars.

How Does the Human Body React to the Vacuum of Space?

Unprotected traveling from the surface of the Earth to the upper atmosphere and beyond affects the human body in several different and potentially drastic ways. Barometric pressure decreases as altitude increases due to the lack of air molecules. Because the human brain is extremely sensitive to changes in oxygen levels, a sudden, significant drop in pressure will result in a range of symptoms—from increased heart and breathing rate, facial flushing, and confusion to loss of consciousness and, ultimately, death. At approximately 16 kilometers (10 miles) above Earth, there is not enough air to breathe. At this altitude, normal body functions are affected as cells and tissues start to lose oxygen. Without protective gear, the human body will experience symptoms such as difficulty concentrating, shortness of breath, nausea, and fatigue. When sudden decompression occurs, humans have only 5 to 10 seconds to correct the situation with supplemental oxygen. High-altitude pilots and astronauts are trained to react quickly to help themselves and others in these situations. The Federal Aviation Administration requires that an oxygen supply must be available for pilots and passengers in the event that a plane's cabin pressure suddenly decreases.

Above 19 kilometers (about 12 miles) from the Earth's surface, the ambient pressure is equivalent to water vapor pressure, and body fluids will literally "boil off." The edge of space is defined as 100 kilometers (about 60 miles) above the ground. At this altitude, space is a near vacuum. What would happen if no protection were available? Although depictions in popular movies may suggest otherwise, human bodies in the vacuum of space will not instantly freeze solid or burst. As humans travel higher into the atmosphere, the loss of pressure will cause water in their noses and mouths to boil. Water vapor will rush out of their bodies and rapidly cool their mouths and nose tissues to near-freezing temperatures. Within a short time, the liquid water in the soft tissues that line their lungs will also boil and cause their bodies to swell. Because skin is strong and porous, air will gradually leak out through their skin rather than bursting through their bodies. As long as blood keeps circulating through their bodies, the pressure of the heart pumping blood in their circulatory systems will keep the water in their blood below its boiling point. Within 1 minute of vacuum exposure, however, the heart will stop pumping, causing blood to stop circulating and, eventually, to boil, putting vital organs at risk.

NASA works tirelessly to ensure the safety of its pilots and astronauts. As research continues, scientists and engineers continue to improve the pressure suits that provide many layers of protection against the harsh environments of the upper atmosphere and space. Pressure suits are necessary for space exploration. Because pilots and astronauts must complete their work in a near-vacuum or absolute-vacuum environment, the protective suits must exert pressure on the body to simulate Earth's environment to keep the pilots and astronauts safe at all times. The first activity in this guide will allow students to explore the bare necessities of survival in space. Students will research essential components of spacesuits and then design a prototype using off-the-shelf products, demonstrating the structures and functions of their new design.

Made To Suit

Spacewalking astronauts face many hazards, such as radiation, dust, debris, and extreme temperatures. Temperatures on spacewalks may vary from as hot as 250 °F (121 °C) in the sunlight to as cold as –250 °F (–121 °C). Spacesuits designed for EVAs regulate temperature, provide the proper pressure for the body, and supply astronauts with water to drink and oxygen to breathe.

The commercial companies NASA has partnered with will be developing new suits to be worn on spacewalks for the International Space Station and Artemis missions. The newly designed spacesuits will include several new features and technological advances to keep crew members safe and healthy while allowing them to accomplish their tasks when working outside their spacecraft in the harsh vacuum of space. The infographic on the next page illustrates many of these important features.

A Whole New Definition to the Word "Suit"

Cooling Garment

Spacewalks typically last multiple hours with astronauts working very hard. To avoid heat accumulation in the suit, crew wear a special cooling garment lined with water tubes to keep them cool throughout the spacewalk.

A spacesuit can have up to 16 LAYERS

Gloves

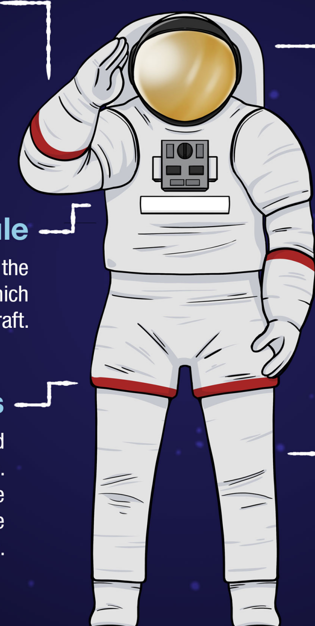
Your hands get the coldest while out in space – so these aren't just any gloves. They are equipped with heaters for their fingers and still allow for dexterity for astronauts to be able to use tools.

Display Control Module

At the center of the HUT is the brains of the suit – this box houses a control panel which operates the backpack of our mini-spacecraft.

Colored Stripes

Red or white stripes are used on this strip of the lower torso. This enables us to identify the individual spacewalkers while they are on the spacewalk.



Helmet

This isn't the helmet you wear to ride your bike or play sports. The helmet used for spacesuits has a visor with a special gold coating that protects the astronaut from the strong sun rays. It also has a ventilation system that provides astronauts with oxygen.

Portable Life Support System (PLSS)

This high-tech backpack has everything astronauts need while they explore space! Electricity, a fan, carbon dioxide removal system, water tank for the cooling garment, and a 2-way radio.

Hard Upper Torso (HUT)

The HUT connects the internal workings of the suit with the appropriate systems in the PLSS.

Lower Torso

The lower torso keeps legs and feet safe from the harsh space environment. Along the waist there are a series of rings which are used to tether astronauts to the space station or to attach different tools that might be needed during the spacewalk.

Communication

Communication is essential between spacewalking astronauts. They must be able to talk to the astronauts inside an orbiting spacecraft and the mission control team back on Earth.

MANUFACTURING

Design Integration
+
Modeling
+
Procurement
+
Fabrication

Spacewalk Ready

The longest U.S. spacewalk was performed by Susan Helms and Jim Voss and lasted **8 Hours : 56 Minutes**

#SUITUP

Every time an astronaut goes out into space (called a spacewalk) – they wear a special suit. It's actually a personal spacecraft. It keeps the astronaut safe while they perform tasks outside the International Space Station, and when they explore the lunar surface beginning in 2024.

The two main parts of a spacewalk spacesuit are the pressure garment and the portable life support system. The pressure garment is the form-fitted portion of the spacesuit that protects the body and enables mobility. The primary components of the pressure garment are the cooling garment, upper torso, lower torso, and helmet. The portable life support system (PLSS) located on the back of the spacesuit is a backpack that houses the supplies and equipment to make the suit work. This backpack contains the oxygen that astronauts breathe and pressurizes the suit. A regulator in the backpack keeps the suit at the correct pressure. A fan circulates oxygen through the suit and life support system, and the carbon dioxide that astronauts exhale is removed from the suit. The backpack provides electricity for the suit and holds a two-way radio for communication. The backpack also contains water for the cooling garment, a chiller to cool the water, and a pump that circulates the chilled water.

The development of new spacesuits is a critical step toward achieving NASA's goals of returning humans to the Moon, continuing safe operations on the International Space Station, and exploring Mars and other deep space locations.

For EVAs such as spacewalks or lunar surface exploration, astronauts require advanced spacewalk systems, which include the spacesuit itself and the hardware that physically connects the spacesuit to the International Space Station and other space vehicles. In the second activity in this guide, students explore spacesuits of the past and examine their differences. Using this knowledge, students will redesign one of the Artemis Generation spacesuits to better suit a new extreme environment such as Mars, Mercury, or Europa, one of Jupiter's moons.

Screenshot from a NASA prototype wrist-mounted display.

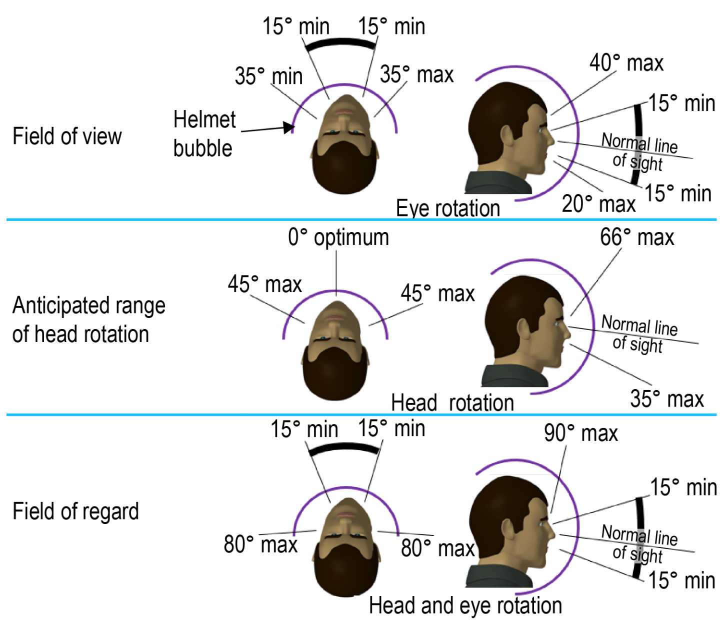
Heads-Up Display

The image shown at right is a screenshot from an actual prototype of a wrist-mounted display for use with the newly designed spacesuits. Developed at the NASA Glenn Research Center in Cleveland, Ohio, the display contains vital suit information such as the amount of oxygen remaining and the current battery charge, as well as diagnostic information such as electrical current and voltage for a variety of suit components. The discipline of developing such informational displays is called *informatics*, which has connections to other fields such as graphic design, computer programming, and electrical engineering.

Types of Displays

Field of view (FOV) is what the eye can see while the head remains still. *Field of regard* (FOR) is the sum of what the eye can see as the eyes and head move around. These two concepts, illustrated in the figure at right, are important considerations in designing spacesuit helmets.

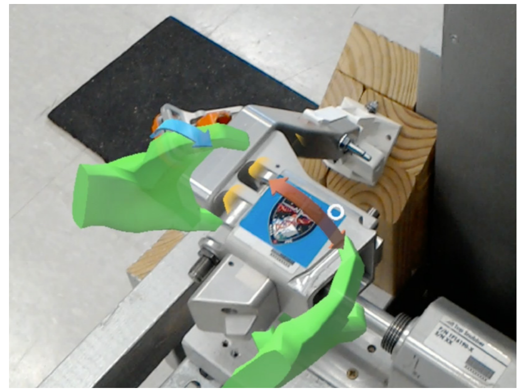
For a helmet-mounted display, *interface* designers have three main options. One option is to put a traditional opaque display slightly outside the normal FOV but still within the FOR so that the astronaut's vision is not blocked or limited. The astronaut would turn their head to look at the display off to the side or above the window in their helmet, which could be awkward or uncomfortable. Another option would be to completely



Differences between field of view and field of regard. The purple line represents the transparent part of a spacesuit helmet (the "bubble").

replace the transparent part of the helmet with a monitor that is connected to a camera or other sensors. The downside is that if the display malfunctions, the astronaut becomes effectively blind. Between these two extremes is a third approach. New technology has allowed engineers to create a partially transparent display directly in the astronaut's FOV. The astronaut gets the convenience of the display right where they need it while still having a window to the world in the event of an emergency.

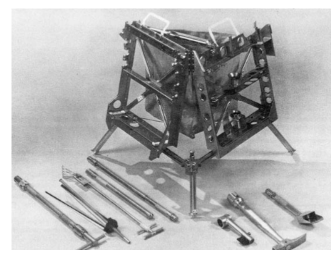
Where to position the display is an important design consideration, but there is also the question of what information to show. It is possible to show the world as it actually appears, but then why have a display at all? A display is typically designed show something humans could not otherwise see. If the display shows something completely computer-generated, that is called virtual reality. An example of virtual reality would be to use sonar, lidar, or other technology to map out an area that would be too hard to see even with powerful lights, such as a location deep underwater or surrounded by smoke. If the display combines what is normally visible with something computer-generated, then it is called augmented reality (sometimes also called mixed reality). The image to the right is an example of what an astronaut might see when using augmented reality goggles to conduct maintenance on the space station. For more information on how NASA is using augmented reality for Artemis, visit https://www.nasa.gov/feature/using-augmented-reality-to-prepare-orion-hardware-for-artemis-ii-crewed-mission. For the third activity in this guide, students will design and optionally develop a user interface that makes information available to an astronaut via a heads-up display.



What users might see in an augmented reality application that gives instructions for operating hardware.

Astro-Tools

Preparing to explore the surface of the Moon goes well beyond designing and building safe spacecraft and spacesuits. In order to do science on the surface of the Moon, NASA has to ensure that the surface vehicles and suits have the mobility required and that there are tools to collect rock and soil samples. NASA astronauts are trained in geology, spending countless hours practicing at locations on Earth that resemble regions they might see on the Moon. All of this is done in an effort to establish a long-term presence on the Moon and to help answer some outstanding science questions about the history of Earth and of the solar system.

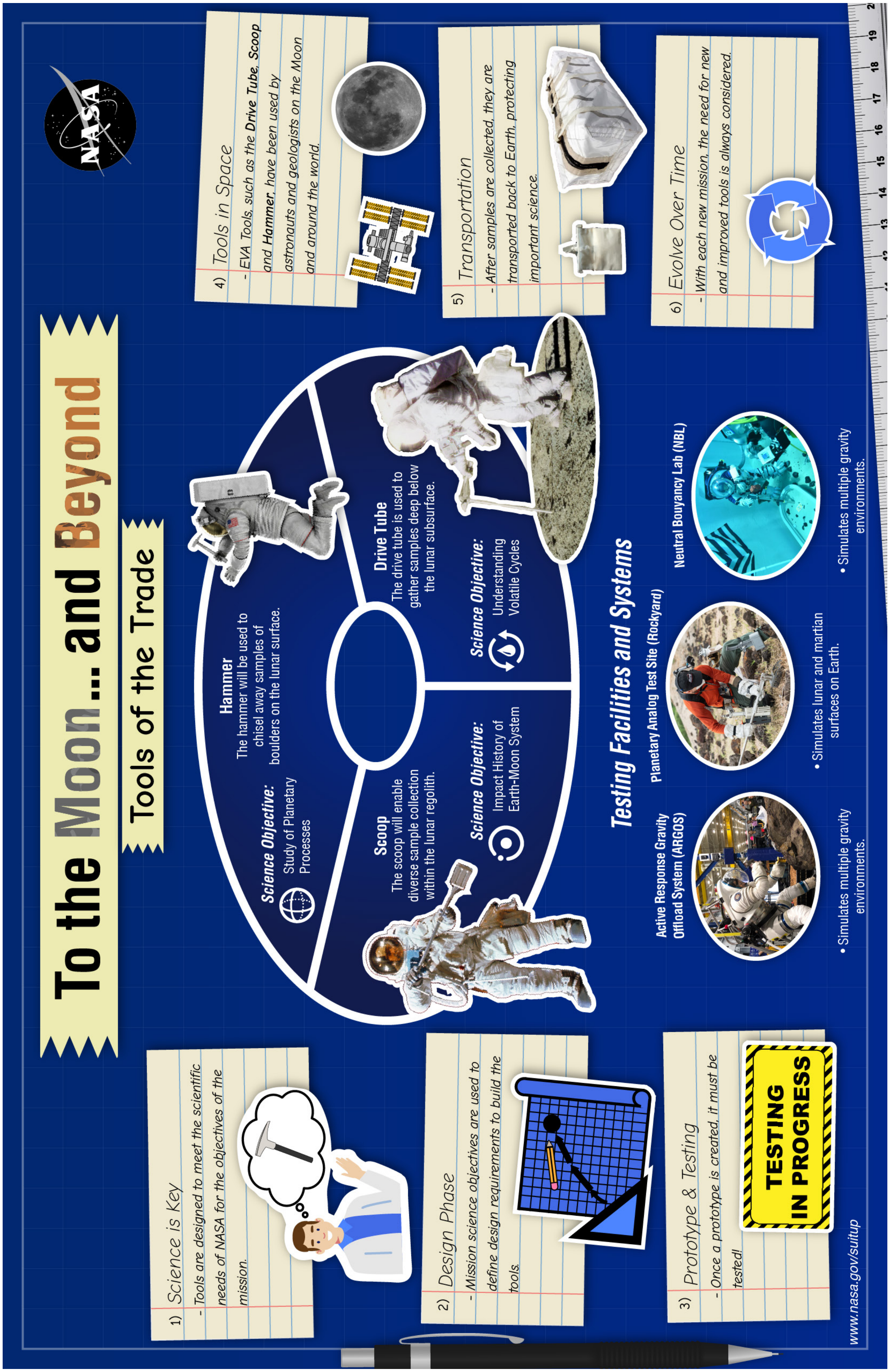


Apollo tools for extravehicular activity.

Each of NASA's six crewed missions on the lunar surface has added to our knowledge of the Moon. In the Apollo program's earliest efforts, conducting science investigations on the surface of the Moon was not a primary objective; the main goal was simply getting there. However, training and equipping astronauts to conduct science on the Moon eventually became a cornerstone of the program. Bringing back samples was a substantial part of those science objectives, so NASA scientists and engineers developed a suite of tools to do just that. Early missions used just a few simple tools, but new tools were designed as missions became more complex. These tools included shovels, scoops, and tongs that could be used to pick up rocks or move them out of the way. A tool called a *core tube* was used to get cylindrical samples of the various layers of lunar regolith. With just a few early tools, astronauts were able to bring back some great samples that are still being studied today.

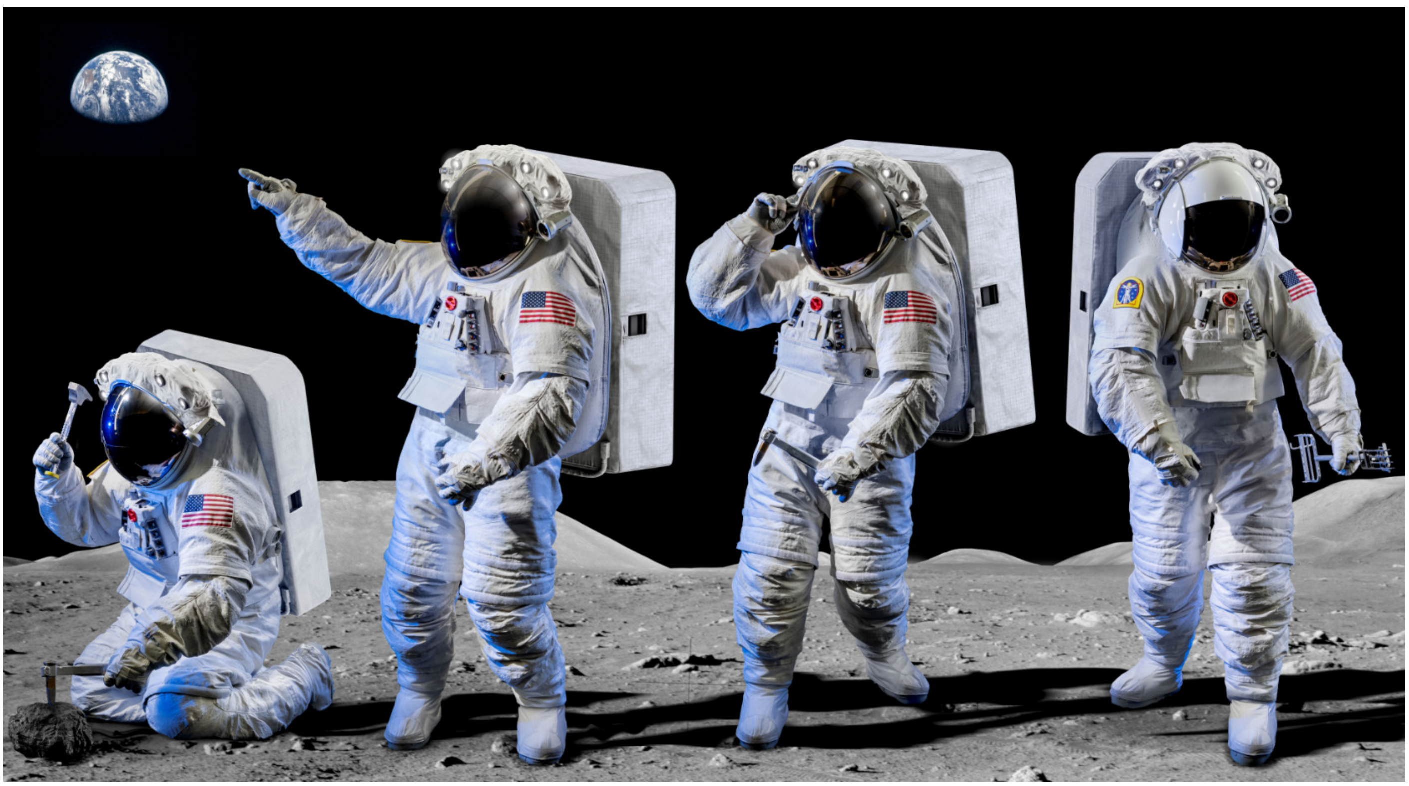
Several important factors must be considered when developing tools for use in environments other than Earth. One of those factors is environmental conditions. For example, tool designs must account for temperature extremes ranging from –300 °F to 200 °F. Another thing to consider when designing a tool to be used by an astronaut is that wearing spacesuit is essentially like wearing a balloon, and the astronaut will have to squeeze against that balloon every time they grab something. Human factor concerns include ensuring that these tools are easy to use without causing the astronaut pain or difficulty. Another factor has to do with contamination. It is a priority to bring back samples that are *pristine*—uncontaminated by anything that is not from the Moon. This is a major driver for everything that is done on the ground in terms of processing the tools and selecting the tool materials. Only certain materials can be used and approved by the scientific community. The tools go through a cleaning process to remove any contaminants prior to launch, and maintaining cleanliness throughout the mission is vital.

The infographic on the next page depicts several of the tools used to meet the science objectives of NASA missions to the Moon and beyond.


To the Moon... and Beyond
Tools of the Trade
1) Science is Key
- Tools are designed to meet the scientific needs of NASA for the objectives of the mission.
2) Design Phase
- Mission science objectives are used to define design requirements to build the tools.
3) Prototype & Testing
- Once a prototype is created, it must be tested!
TESTING IN PROGRESS
Science Objective: Study of Planetary Processes
Hammer
The hammer will be used to chisel away samples of boulders on the lunar surface.
Scoop
The scoop will enable diverse sample collection within the lunar regolith.
Science Objective: Impact History of Earth-Moon System
Drive Tube
The drive tube is used to gather samples deep below the lunar subsurface.
Science Objective: Understanding Volatile Cycles
Testing Facilities and Systems
Active Response Gravity Offload System (ARGOS)
• Simulates multiple gravity environments.
Planetary Analog Test Site (Rockyard)
• Simulates lunar and martian surfaces on Earth.
Neutral Bouyancy Lab (NBL)
• Simulates multiple gravity environments.
4) Tools in Space
- EVA Tools, such as the Drive Tube, Scoop and Hammer, have been used by astronauts and geologists on the Moon and around the world.
5) Transportation
- After samples are collected, they are transported back to Earth, protecting important science.
6) Evolve Over Time
- With each new mission, the need for new and improved tools is always considered.
www.nasa.gov/suitup

Tools for Artemis

What types of tools will be needed for the Artemis missions? Artemis astronauts will be visiting the South Pole of the Moon, a site that has never been visited by humans. NASA has learned that the site is actually very similar to the Apollo 16 highlands area, where the rocks and regolith are not as dark in color as other areas of the Moon. The terrain was created from magma that extruded onto the surface and cooled over time and contains mostly light-colored anorthosite, or calcium-rich, material. What is most challenging about the South Pole is that it is a mostly shadowed area. The Artemis astronauts' suits and tools will need to adapt to the wide swings in temperatures between sunny and shaded areas. The South Pole has permanently shadowed areas containing *volatiles*—substances that easily evaporate—and NASA wants to research and mine these volatiles. The types of compounds that are frozen into the regolith can cause chemical interactions with tools, so the tools may need a special coating to make sure those chemical reactions do not happen. Another important aspect regarding volatiles is that as they heat up, they will turn from a solid to a liquid and then to a gas. In some cases, volatiles will get to the gas phase dangerously quickly. Astronauts may need to store these samples in a freezer to protect themselves from potentially harmful compounds. These freezers must be designed to contain the volatile compounds until their return to Earth, where scientists can study them in the safety of a laboratory. The last activity in this guide will challenge students to design a modular tool with interchangeable tool heads to retrieve or process different types of regolith (e.g., powdery, rocky, or sandy). Students will also develop an instruction manual on how to use their new tool.



Graphic depiction of astronauts on the lunar surface working with tools.

Activity One: Spacesuits Are Spacecraft

Educator Notes

Learning Objectives

Students will

- Analyze pictures and resources of various spacesuits NASA has used over the years to explore their similarities.
- Identify the main components of a spacesuit along with their functions.
- Create a drawing of a prototype that uses off-the-shelf products and demonstrates the structures and functions of the spacesuit.

Investigation Overview

Students will explore the bare necessities of survival in space. Students will research must-haves for an astronaut to survive in a spacesuit and will then design a drawing of a prototype that uses off-the-shelf products and demonstrates the structures and functions of the spacesuit.

Suggested Pacing

90 to 180 minutes

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-2 Engineering Design: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • MS-ETS1-3 Engineering Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. *Crosscutting Concepts* • Cause and Effect: Phenomena may have more than one cause, and some cause-and-effect relationships in systems can only be described using probability. • Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. • Structure and Function: The way an object is shaped or structured determines many of its properties and functions.	*Science and Engineering Practices* • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system. • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. • Engaging in Argument from Evidence: Argumentation is the process by which explanations and solutions are reached. • Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.
Technology (ISTE)	
Standards for Students • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.	*Standards for Students (continued)* • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.
English Language Arts Practices (CCSS)	
• CCSS.ELA-LITERACY.RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.	

Investigation Preparation

- Read the introduction, background information, and Educator Notes.
- Print one Student Handout for each team.
- If using a vacuum chamber and pump for the Engage section demonstration, watch this video https://youtu.be/rfR7mMKtyaM for an example of the demonstration.

Materials

- ☐ Student Handout, one per team
- ☐ Computers/devices with internet access for research
- ☐ Notebook, journal, or drawing paper (optional: poster whiteboard)
- ☐ Writing/drawing utensils (optional: dry erase markers; permanent marker for adding face to balloon or marshmallow)
- ☐ If doing Option 1 demonstration: Vacuum pump, vacuum jar, and small balloon or large marshmallow
- ☐ If doing Option 2 demonstration: Large syringe and small marshmallow
- ☐ Safety eyewear
- ☐ Rubric for 5E instructional model (Appendix A)

Safety

- Students should be aware of their surroundings and move carefully throughout the room and when viewing other teams' work.
- Students should never consume any food items associated with their experiments unless instructed to do so by their educator.
- Use care if using a vacuum pump, and be sure to read and follow the manufacturer's safety precautions.
- Students should take care when handling glassware. Keep glassware away from the edges of the work surface where it could slide off or be knocked over.
- Ensure students wear eye protection when handling glass and when using a vacuum pump and glass jar.

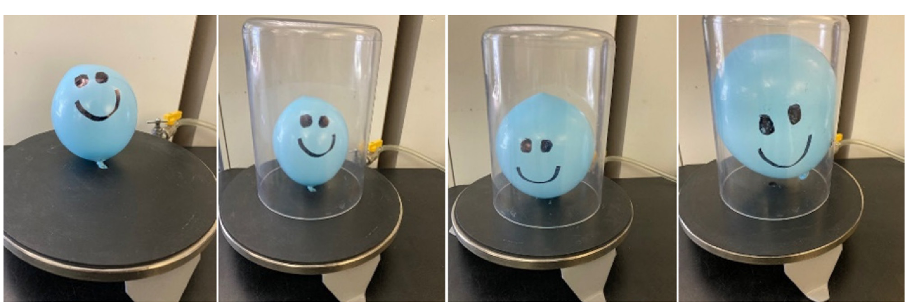
Introduce the Investigation

- Provide context for this activity using the background and introduction information in this guide. Discuss what a spacesuit is and why a spacesuit is needed at launch (ascent), on the Moon, on a *spacewalk*, or during return to Earth (descent).
- Group students into teams of three to four. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Distribute the Student Handouts and scratch paper to each team.

Facilitate the Challenge

Engage

- Ask students to predict what they think will happen to a marshmallow or balloon when it is placed in a simulated space environment (e.g., a vacuum chamber with a pump kit). Be sure to define *vacuum* (see Glossary) and explain how this vacuum chamber and pump kit represents space. Have students write down their *predictions* in their science journals and/or share their predictions with their team.
- Demonstrate the relationship of pressure on the volume of a gas using one of three options:
  - Option 1: Use a balloon with a vacuum pump and vacuum jar.
  - Option 2: Use a large syringe with a small marshmallow.
  - Option 3: Play the video demonstration "What Marshmallows Teach Us About Space—ISS Science." https://youtu.be/rfR7mMKtyaM
- The following photos of a balloon in a vacuum chamber (Option 1) and a marshmallow in a syringe (Option 2) illustrate the inverse relationship between pressure and the volume of a gas.



These four images were taken at various stages of an Option 1 demonstration, from no change in ambient pressure (far left) to decreasing pressure (next three images). As pressure decreases, the balloon expands in volume.

Share With Students

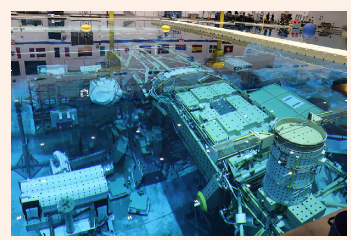
Brain Booster

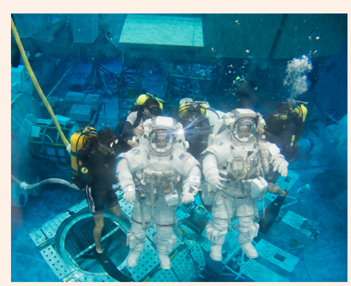
NASA's Johnson Space Center is a hub for decompression sickness research and management.

Learn more:
https://www.nasa.gov/sites/default/files/atoms/files/jsc-hhp-decompressionsicknessmitigations.pdf

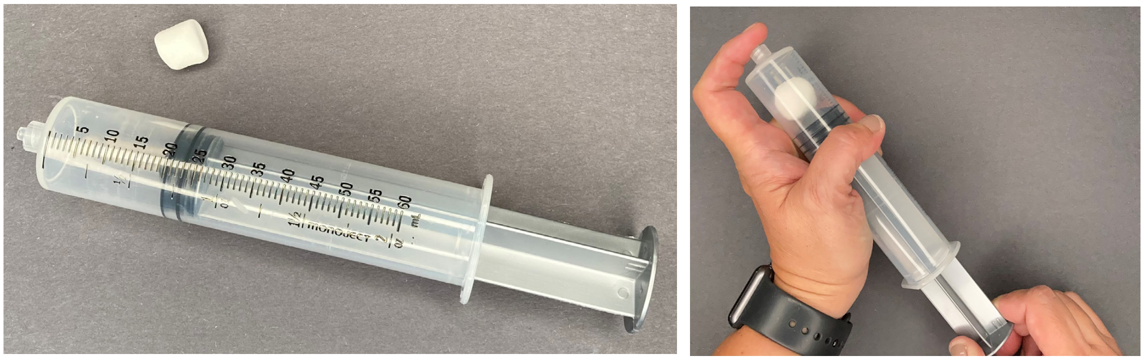
On Location

Take an immersive virtual reality (VR) tour of the facilities inside NASA's Johnson Space Center, including the Neutral Buoyancy Laboratory (pictured below) where astronauts prepare for upcoming missions to the space station.





Learn more:
https://www.youtube.com/watch?v=gk0ijHIP3hw



In the Option 2 demonstration, a marshmallow is placed inside a large syringe (left) and a low-pressure environment is created by pulling the plunger of the syringe (right). As pressure decreases, the marshmallow expands in volume.

- After the demonstration, have students share their observations/results and add to their journals their observations of what happened to the balloon or marshmallow in the vacuum and why they think that happened.
- Have students discuss the following questions:
  - Was your prediction close to what you expected?
  - Can you describe in scientific terms what this simulation was supposed to demonstrate?
    - See the background information section titled "How Does the Human Body React to the Vacuum of Space?"
  - If we were to do this demonstration again, what are some things we could do to help the balloon (or marshmallow) not be affected by the vacuum chamber and pump kit (or syringe)?
  - What are some other issues besides pressure that an astronaut must deal with in the space environment?
    - Have students think about the following: food, water, shelter, and space.
- Show these NASA videos to help introduce the concept of the Next Generation spacesuit:
  - Keeping Cool in Space: https://youtu.be/AwUvh9sluOA
  - Spacesuits for the Next Explorers: https://youtu.be/vPkamuLqwM8

Explore

- Randomly assign each team member two NASA programs from this list: Mercury, Gemini, Apollo, Skylab, Space Shuttle, International Space Station, and Artemis. Each student will research their selected program using the Research Links that follow here and become the "expert" on that spacesuit.
- Students will explore their assigned programs to identify
  - The years of the program
  - The mission objectives
  - The features of each spacesuit
  - How spacesuits (both flight suits and EVA suits) have changed over the years
- Research Links
  - Spacesuit and Spacewalk History Image Gallery. https://www.nasa.gov/audience/foreducators/spacesuits/historygallery/index.html
  - Houston, We Have a Podcast, Episode 173: Students and Spacesuits. https://www.nasa.gov/johnson/HWHAP/students-and-spacesuits
  - Houston, We Have a Podcast, Episode 16: Spacesuits. https://www.nasa.gov/johnson/HWHAP/spacesuits
  - Spacesuit Gallery. https://www.nasa.gov/suitup/spacesuit-gallery
  - #SuitUp Gallery (spacesuit infographics). https://www.nasa.gov/suitup/gallery
  - Suit Up. https://www.nasa.gov/suitup
  - Virtual Tour of the Spacesuit Collection at Space Center Houston. https://spacecenter.org/exhibits-and-experiences/spacesuitcollection/virtual

- Have teams come together and create a timeline that helps demonstrate the concepts learned. As a whole group, review the correct order of the spacesuits, the years of each program, and the mission specifics. Discuss how the spacesuits (both flight suits and EVA suits) have changed over the years.
- Finally, show "#AskNASA | What Are the Next Generation Spacesuits?" https://www.youtube.com/watch?v=F_iA2DdgMUA

Explain

- Have students select at least two of the following resources per focus question and have teams create a graphic organizer or picture to demonstrate their mastery of a spacesuit's structure and function. Students must include the following vocabulary: *spacesuit, spacewalk, mobility, extravehicular activity (EVA), intravehicular activity (IVA), layers, cooling garment, gloves, helmet*, and *torso*. Suggestion: Have students use whiteboard posters and dry erase markers for their graphic organizers and spacesuit designs.
  - Focus Question 1. What are the two main types of NASA spacesuits and what is the purpose or each?
    - What Is a Spacewalk? https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-spacewalk-58.html
    - STEMonstrations: Spacewalk, Parts 1 and 2. https://www.nasa.gov/stemonstrations-spacewalking.html
    - NASA Spacesuit Development (video). https://www.nasa.gov/feature/nasa-spacesuit-development
  - Focus Question 2. What are the basic components that flight and EVA spacesuits need for astronaut survival?
    - Spacewalk Spacesuit Basics. https://www.nasa.gov/feature/spacewalk-spacesuit-basics
    - What Is a Spacesuit? https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-spacesuit-58.html
    - Learn About Spacesuits (interactive version is only accessible with Internet Explorer). https://www.nasa.gov/audience/foreducators/spacesuits/home/clickable_suit_nf.html

Elaborate

- Teams will be asked to design an *intravehicular* (inside a spacecraft) or *extravehicular* (outside a spacecraft) spacesuit to protect and keep an astronaut safe. Teams will take on the role of the spacesuit's *prototype* designers/engineers. Student teams will consider all the basic needs of an astronaut in space.
- Have student teams start brainstorming about what *off-the-shelf* items (things available as stock items) might serve as stand-ins for the various components of a spacesuit. (For example, an off-the-shelf snorkel could represent the oxygen source.)
- After the brainstorming, have teams begin sketching their spacesuits with the items mentioned. Have students use the spacesuit in the NASA activity "How To Draw Artemis: NASA's Exploration Extravehicular Mobility Unit" (see Resources) as a reference for drawing.

Evaluate

- Student teams will present their ideas via an Engineering Fair Showcase. Educators may bring in actual community engineers, parents, school staff, and/or administrators to make up the showcase panel.
- All team members must have a speaking role during the showcase.
- Each team presentation must include
  - Brainstorm notes/journals (originals)
  - Initial sketch of the prototype
  - Final sketch of the prototype
  - Descriptions of the design structures and functions

Optional*:* Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Have teams come up with a spacesuit company name and then design a team mission patch for their company.

Resources

Why Pressure Suits? https://y4y.ed.gov/stemchallenge/nasa/why-pressure-suits3/2632

Why Do We Really Need Pressure Suits? https://www.nasa.gov/sites/default/files/atoms/files/dressing-for-altitude-nov-2017.pdf

Hazards to Deep Space Astronauts. https://www.nasa.gov/stem-ed-resources/hazards-to-deep-space-astronauts.html

How To Draw Artemis: NASA's Exploration Extravehicular Mobility Unit. https://www.nasa.gov/sites/default/files/atoms/files/ep-2020-05-002-jsc_how_to_draw_artemis_xemu_suit_5-26-20_1.pdf

Activity One: Spacesuits Are Spacecraft

Student Handout

Your Challenge

Explore the bare necessities of survival in space. Your team will research must-haves for an astronaut to survive in a *spacesuit* and create a drawing of a *prototype* that uses off-the-shelf products and demonstrates the structures and functions of the spacesuit.

Engage

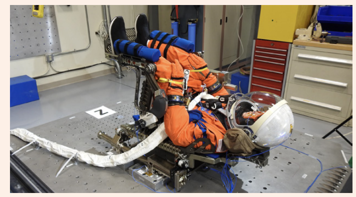
- Predict what you think will happen to a balloon or marshmallow when it is placed in a simulated space environment (e.g., a *vacuum chamber* with a pump kit). Write down your *predictions* in your science journal and/or share them with your team.
- Watch the demonstration and/or video and make observations in your science journal. After the demonstration, share your observations/results with your neighbor.
  - What happened to the balloon or marshmallow in the simulated space environment? Why do you think that happened?
  - Was your prediction close to what you expected?
  - Can you describe in scientific terms what this simulation was supposed to demonstrate?
  - If this demonstration were done again, what are some things you could do to help the balloon or marshmallow not be affected by the simulated space environment?
  - List other issues besides pressure that an astronaut must deal with in the space environment.

Explore

- You will be placed in a team and assigned a team role.
- Each team member will randomly be assigned two NASA programs from this list: Mercury, Gemini, Apollo, Skylab, Space Shuttle, International Space Station, and Artemis.
- You will research the assigned programs, identifying the following:
  - The years of the program
  - The mission objectives
  - The features of each spacesuit
- Each team member will research their selected program and become the "expert" on that particular spacesuit.
- Research Links
  - Spacesuit and Spacewalk History Image Gallery. https://www.nasa.gov/audience/foreducators/spacesuits/historygallery/index.html
  - Houston, We Have a Podcast, Episode 173: Students and Spacesuits. https://www.nasa.gov/johnson/HWHAP/students-and-spacesuits
  - Houston, We Have a Podcast, Episode 16: Spacesuits. https://www.nasa.gov/johnson/HWHAP/spacesuits
  - Spacesuit Gallery. https://www.nasa.gov/suitup/spacesuit-gallery
  - #SuitUp Gallery (spacesuit infographics). https://www.nasa.gov/suitup/gallery
  - Suit Up. https://www.nasa.gov/suitup

Fun Fact

When NASA's Orion spacecraft launched aboard the powerful Space Launch System rocket for the spacecraft's first mission around the Moon, a suited manikin named "Campos" was aboard, outfitted with sensors to provide data on what crew members may experience in flight.



Learn more: https://www.nasa.gov/feature/purposeful-passenger-artemis-i-manikin-helps-prepare-for-moon-missions-with-crew

Check out the Commander Moonikin Campos Comic Series: https://www.nasa.gov/specials/moonikin-comic/

Career Corner

Meet Marlon Cox, a spacesuit systems engineer at NASA's Johnson Space Center. Marlon is working on new technologies that would allow astronauts to suit up immediately and go straight out the spacecraft door for any kind of spacewalk.

Learn more: https://youtu.be/YfTBaX9Xv0s

   - Virtual Tour of the Spacesuit Collection at Space Center Houston. https://spacecenter.org/exhibits-and-experiences/spacesuitcollection/virtual
- After doing research, teams will come together and create a timeline that helps demonstrate the concepts learned. Your teacher will go over the correct order of the spacesuits, the years of each program, and the mission specifics.
- Finally, watch the video "#AskNASA What are the Next Generation Spacesuits?" https://youtu.be/F_iA2DdgMUA

Explain

- Select at least two of the following resources per focus question and create a graphic organizer or picture to demonstrate your team's mastery of a spacesuit's structure and function. Your team must include the following vocabulary: *spacesuit, spacewalk, mobility, extravehicular activity (EVA), intravehicular activity (IVA), Exploration Extravehicular Mobility Unit (xEMU),* layers, cooling garment, gloves, helmet, and torso.
   - Focus Question 1. What are the two main types of NASA spacesuits and what is the purpose of each?
      - What Is a Spacewalk? https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-spacewalk-58.html
      - STEMonstrations: Spacewalk, Parts 1 and 2. https://www.nasa.gov/stemonstrations-spacewalking.html
      - NASA Spacesuit Development (video). https://www.nasa.gov/feature/nasa-spacesuit-development
   - Focus Question 2. What are the basic components that flight and EVA spacesuits need for astronaut survival?
      - Spacewalk Spacesuit Basics. https://www.nasa.gov/feature/spacewalk-spacesuit-basics
      - What Is a Spacesuit? https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-spacesuit-58.html
      - Learn About Spacesuits (interactive version is only accessible with Internet Explorer). https://www.nasa.gov/audience/foreducators/spacesuits/home/clickable_suit_nf.html

Elaborate

- Your team is asked to design an *intravehicular* (inside a spacecraft) or *extravehicular* (outside a spacecraft) spacesuit to protect and keep an astronaut safe. Your team will take on the role of the spacesuit's prototype designers/engineers. Do not forget to consider all the basic needs of an astronaut in space.
- Start brainstorming about what off-the-shelf items might be a stand-in for the various components of a spacesuit. (For example, a snorkel can represent the oxygen source).
- After the brainstorming, start sketching your spacesuit with the items mentioned. As a reference for drawing, use the NASA activity "How To Draw Artemis: NASA's Exploration Extravehicular Mobility Unit." https://www.nasa.gov/sites/default/files/atoms/files/ep-2020-05-002-jsc_how_to_draw_artemis_xemu_suit_5-26-20_1.pdf

Evaluate

- Your team will present your ideas via an Engineering Fair Showcase.
- All team members must have a speaking role during the showcase.
- Each team presentation must include
   - Brainstorm notes/journals (originals)
   - Initial sketch of the prototype
   - Final sketch of the prototype
   - Descriptions of the structures and functions in your designs

Activity Two: Made To Suit

Educator Notes

Learning Objectives

Students will

- List the differences between various spacesuits NASA has used over the years.
- Design their own spacesuits for a possible future mission to a more distant location in the solar system.

Investigation Overview

In this activity, students will explore spacesuits of the past and their differences. They will then redesign an Artemis Generation spacesuit for a new extreme environment such as Mars, Mercury, or Europa, one of Jupiter's moons.

Suggested Pacing

90 to 180 minutes

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-2 Engineering Design. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • MS-ETS1-3 Engineering Design. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. *Science and Engineering Practices* • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.	*Science and Engineering Practices (continued)* • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system. *Disciplinary Core Ideas* • ETS1.B Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions. • Global Collaborator: Students use collaborative technologies to work with others, including peers, experts, or community members, to examine issues and problems from multiple viewpoints.	*Standards for Students (continued)* • Global Collaborator: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.

Investigation Preparation

- Read the introduction, background information, and Educator Notes to become familiar with the activity.
- Group students into teams of three to four per team.
- Gather materials needed to complete the spacesuit.

Materials

- One Student Handout per team
- Computers/devices with internet access OR fact sheet handout for research
- Craft items (e.g., scissors, glue, tape, paper, colored pencils, construction paper, colored duct tape, clear film)
- Items for spacesuit (e.g., felt, tinfoil, fabric)
- Plastic cups
- Astrobiology Habitability Cards (see Resources)
- Model/mannequin for students as a base on which to build their suits
- Scratch paper and writing utensils

Safety

Ensure that students

- Practice safe cutting techniques when building their spacesuits.
- Avoid moving around the room with scissors.
- Take care when using adhesives.

Introduce the Investigation

- Provide context for this activity using the background and introduction information in this guide.
- Share the video "Spacesuits for the Next Explorers." https://www.youtube.com/watch?v=vPkamuLqwM8
- Group students into teams of three to five. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Distribute the Student Handout and scratch paper to each team.
- Explain the investigation to students:
  - They will research the differences between the various spacesuits NASA has used over the years.
  - Each team will use the available materials to design their spacesuits for the extreme environments of an unexplored location such as Mars, Enceladus, or Mercury.
  - Next, teams will design their spacesuits on scratch paper and build their designs.
- Finally, the team will present their designs to other teams.

Facilitate the Investigation

Meet the Problem

- Have students imagine they are going on vacation to Alaska in winter. How would they dress once they are there? Next, have them imagine they are taking a vacation to Hawaii in summer. How would they dress differently? Have students create a chart listing the different items of clothing for each location. Below is an example chart:

Body part	Clothes for Alaska	Clothes for Hawaii
Feet	Boots	Sandals
Torso	Long-sleeve shirt	Short-sleeve shirt
Neck	Scarf	Lei
Legs	Pants	Shorts
Head	Wool hat	Sun visor
Eyes	Goggles	Sunglasses

- Ask students to discuss with their team what items they would take and why.
- Explain that different spacesuits serve different purposes, just like different kinds of clothes do. Space exploration usually includes two different kinds of spacesuits, both of which protect astronauts from the dangers of their mission. One kind is worn inside a spacecraft during launch and ascent to space and again on the way home during reentry and landing. This is called a flight suit. The other kind is designed for extravehicular activity (EVA), and it is called an EVA suit.
- Share the video "Building NASA's NEXT Generation Spacesuits." https://www.youtube.com/watch?v=ug-FHsOYP5Y

Share With Students

Brain Booster

A critical component of a spacesuit is the life support system. The Spacesuit Evaporation Rejection Flight Experiment (SERFE) is designed with thermal control technology. The thermal control loop circulates cooling water throughout the prototype to keep its electronics cool and the astronaut comfortable, like a portable air conditioner for your body.

Learn more: https://www.nasa.gov/image-feature/spacesuit-evaporation-rejection-flight-experiment-serfe

On Location

Divers at the Neutral Buoyancy Laboratory (NBL) in Houston are setting the stage for future moonwalk training by simulating lunar lighting conditions. On the Moon, the Sun will remain no more than a few degrees above the horizon. To prepare astronauts for these challenging lighting conditions, the NBL team has simulated these conditions at the bottom of a 40-foot deep pool.

Learn more: https://www.nasa.gov/image-feature/dark-mode-activated

Explore Knowns and Unknowns

- Have students break into jigsaw teams where a team member will become the "expert researcher" on one of the three following topics. Students will work with their jigsaw team to complete their research, then return to their original team and report back their findings.
  1. Material: What would a spacesuit be made of to help preserve the life of the astronaut? How has it evolved over time?
  2. Breathing: How are astronauts able to breathe in space and on other planets?
  3. Communication: How are astronauts able to communicate with each other and the space center in case of an emergency?
- Have students visit the following sites and watch the video:
  - Facts About Spacesuits and Spacewalking. https://www.nasa.gov/audience/foreducators/spacesuits/facts/index.html
  - Suit Up. https://www.nasa.gov/suitup
  - #AskNASA | What are the Next Generation Spacesuits? (Video). https://www.youtube.com/watch?v=F_iA2DdgMUA
- Allow students to view and research spacesuits used on various missions. Have students select three spacesuits from NASA's six space programs in order to compare and contrast the components of each suit.
- Optional: Listen to "Houston We Have a Podcast, Episode 120: Artemis Spacesuits." https://www.nasa.gov/johnson/HWHAP/artemis-spacesuits. Start the podcast at timestamp 4:00 and stop at timestamp 25:00 as the podcast is lengthy.
- Once the initial research phase during the jigsaw activity is complete, have "expert researchers" come back together with their initial teams to share their research with team members.

Generate Possible Solutions

- Have each team use the Astrobiology Habitability Cards to choose a distant planet or moon that could potentially be explored. https://astrobiology.nasa.gov/nai/media/medialibrary/2016/01/Astrobiology-Habitability-Cards.pdf
- Have students pick two "fast facts" hazards and brainstorm ideas with their team to equip their spacesuits with technologies to mitigate hazards to the astronauts.

Consider Consequences

- Allow teams to sketch their designs. Remind them to label the different parts of their spacesuits. If they run into issues, they may visit the Spacewalk Spacesuit Basics page. https://www.nasa.gov/feature/spacewalk-spacesuit-basics
- Have students identify the main components of their spacesuit and how those components help the astronaut to survive the conditions of the planet or moon that they have chosen.
- Have students answer the following questions as a team:
  - What are the pros and cons of the added components?
  - What are similar components you would find on Earth?
- Allow students to begin constructing their prototype.

Present Findings

After teams have completed their prototypes, they will present them to their educator and other students. To assess student learning and student presentations, educators may refer to the rubric in Appendix B (Rubric for Problem-Based Learning).

Engage students with the following discussion questions:

- Discuss the distant location you will explore and its hazards to human life.
- How will your prototype design mitigate risks to NASA's mission and the astronauts?
- How did you mitigate and/or prevent challenges your team faced during the prototype design?
- What research is being conducted for deep space travel?
- Optional*:* Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Have students imagine they are going to the Moon and have them list items they would take with them. Use the "What Would You Pack for the Moon?" activity (see Resources) to facilitate this.

References

Spacewalk Spacesuit Basics. https://www.nasa.gov/feature/spacewalk-spacesuit-basics

Spacesuits and Spacewalks. https://www.nasa.gov/audience/foreducators/spacesuits/facts/index.html

Resources

Astrobiology Habitability Cards. https://astrobiology.nasa.gov/nai/media/medialibrary/2016/01/Astrobiology-Habitability-Cards.pdf

What Would You Pack for the Moon? https://astrobiology.nasa.gov/nai/media/medialibrary/2016/01/Astrobiology-Habitability-Cards.pdf

Activity Three: Priority Packing for the Moon | NASA. https://www.nasa.gov/stem-ed-resources/activity-three-priority-packing-for-the-moon.html

Hazards to Deep Space Astronauts. https://www.nasa.gov/sites/default/files/atoms/files/ps-03383_hazards-508.pdf

Activity Two: Made To Suit

Student Handout

Your Investigation

In this activity, you will explore spacesuits of the past and their differences. You will then redesign a new generation spacesuit for an extreme environment such as Mars, Mercury, or Europa, one of Jupiter's moons.

Meet the Problem

- Imagine that you are going on vacation to Alaska in winter. How would you dress once you are there? Next, imagine you are taking a vacation to Hawaii in summer. How would you dress differently? Create a chart listing the different items of clothing you would bring for each location.
- Discuss with your team what items you would take and why.

Explore Knowns and Unknowns

- You will be placed into one of the following "expert research" groups:
  1. Material: What would a spacesuit be made of to help preserve the life of the astronaut? How has it evolved over time?
  2. Breathing: How are astronauts able to breathe in space and on other planets?
  3. Communication: How are astronauts able to communicate with each other and the space center in case of an emergency?
- You will become the "expert researcher" on one of the above topics by visiting the following sites and watching the video:
  – Facts About Spacesuits and Spacewalks. https://www.nasa.gov/audience/foreducators/spacesuits/facts/index.html
  – Suit Up. https://www.nasa.gov/suitup
  – #AskNASA: What Are the Next Generation Spacesuits? (Video) https://www.youtube.com/watch?v=F_iA2DdgMUA
- Rejoin your original team and report back your findings.
- Observe the spacesuits used on various missions, select three spacesuits, and then compare and contrast the components of each suit.

Generate Possible Solutions

- Using the Astrobiology Habitability Cards given to your team, choose a distant location that could potentially be explored. https://astrobiology.nasa.gov/nai/media/medialibrary/2016/01/Astrobiology-Habitability-Cards.pdf
- Pick two "fast facts" hazards and brainstorm ideas to equip your spacesuit with technologies to mitigate hazards to the astronauts.

Consider Consequences

- Sketch your design and label the different parts of your spacesuit. You may visit the Spacewalk Spacesuit Basics page if you run into issues. https://www.nasa.gov/feature/spacewalk-spacesuit-basics

Fun Fact

Did you know the Perseverance rover carried the first samples of spacesuit material ever sent to Mars? As NASA prepares to send humans to Mars, they are faced with a critical question: What should astronauts wear on Mars, where the thin atmosphere allows more radiation from the Sun and cosmic rays to reach the ground? To help answer this question, five samples, including a piece of helmet visor, will be tested aboard the rover.

Learn more: https://www.nasa.gov/feature/jpl/nasas-perseverance-rover-will-carry-first-spacesuit-materials-to-mars

Career Corner

Meet Amy Ross. She is an advanced spacesuit designer at NASA's Johnson Space Center in Houston. She has been designing spacesuits for years and is currently working on the Artemis Generation spacesuits.

Learn more: https://www.nasa.gov/audience/foreducators/spacesuits/careercorner/amy-ross.html?msclkid=db96f692ac4d11eca2d9c50b443e5c7d

- After identifying the main components of your spacesuit, explain how those components help the astronaut survive the conditions of the planet or moon that you have chosen.
- Answer the following questions as a team:
  - What are the pros and cons of the added components?
  - What are similar components you would find on Earth?
- Gather your materials and begin the construction of your prototype.

Present Findings

After you have completed your prototype, you will present them to the teacher and other teams.

Be prepared to discuss the following questions:

- Discuss the distant planet you will explore and its hazards to human life.
- How will your prototype design mitigate risks to NASA's mission and the astronauts?
- How did you mitigate and/or prevent challenges your team faced during the prototype design?
- What research is being conducted for deep space travel?

Activity Three: Heads-Up Display (App Design Challenge)

Educator Notes

Learning Objectives

Students will

- Identify one or more types of information an astronaut would need during an extravehicular activity (EVA, or spacewalk) in space or on a celestial body such as the Moon or Mars.
- Collaboratively design a user interface that would be mounted inside an astronaut's helmet or on a spacesuit wrist display that gives astronauts quick access to this information.
- Optional: Develop a prototype of the interface using a programmable circuit or as a desktop or smartphone application (app).

Challenge Overview

Quick access to important information can be a literal lifesaver, and that is doubly true for an astronaut doing an EVA. Just like actual programmers and engineers working on NASA's Artemis Generation spacesuits, students will design and optionally develop a user interface that makes information available to an astronaut via a heads-up display.

Suggested Pacing

60 to 90 minutes (core)
5 to 10 hours (with option)

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-1 Engineering Design. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. • MS-ETS-1-2 Engineering Design. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. **Note:** If the option to build the prototype is included, various standards from the Physical Science domain may potentially be covered, depending on the sensor students choose to incorporate in their design.	*Science and Engineering Practices* • Asking questions (for science) and defining problems (for engineering) • Developing and using models • Analyzing and interpreting data • Constructing explanations (for science) and designing solutions (for engineering) • Obtaining, evaluating, and communicating information
Technology (ISTE)	
Standards for Students • Innovative Designer: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems. Students develop, test, and refine prototypes as part of a cyclical design process. • Computational Thinker: Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem-solving and decision-making. Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving.	*Standards for Students (continued)* • Creative Communicator: Students choose the appropriate platforms and tools for meeting the desired objectives of their creation or communication. Students create original works or responsibly repurpose or remix digital resources into new creations. Students communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models, or simulations. Students publish or present content that customizes the message and medium for their intended audiences.
21st Century Skills	**English Language Arts Practices (CCSS)**
Reason Effectively • Analyze how parts of a whole interact with each other to produce overall outcomes in complex systems. *Communicate Clearly* • Articulate thoughts and ideas effectively using oral, written, and nonverbal communication skills in a variety of forms and context.	• CCSS.ELA-LITERACY.RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

Challenge Preparation

- Determine whether or not to include the optional building of the prototype. Consider the following:
  - This option is recommended primarily for upper middle school (grades 7 to 8).
  - This option requires significant extra time, materials, and potentially software that not every educator will have.
  - This option requires that the educator have some existing knowledge of at least one way to prototype (e.g., computer programming, 3D printing, or wiring circuits with a breadboard).
- Gather materials for students.
- Gather a few examples of everyday user interfaces to examine with students, such as a radio, a digital clock, a smartphone app, or screenshots from video games.

Materials

Core Challenge	Optional Challenge
Design tools, such as ☐ Paper, posterboard, etc. ☐ Writing and drawing utensils (e.g., colored pencils or markers) ☐ Measuring tools (e.g., rulers and protractors) ☐ Slideshow or photo editing software	☐ Smartphone or smartwatch and matching app development kit ☐ Programmable circuit board including appropriate buttons, screens, wires, etc. ☐ Laptop or desktop with access to a computer programming suite for the appropriate language (e.g., C++, Java, or Scratch)

Safety

Core Challenge	Optional Challenge
No special safety requirements	• The optional challenge of the activity may involve electronic components, so educators should ensure appropriate precautions are taken, such as these: – No liquids near the electronics unless the electronics are specifically designed for it (e.g., water temperature sensor) – Use rubber gloves, grounding straps, and other personal protective equipment to prevent shocks

Introduce the Challenge

- Provide students with several everyday examples of interfaces (see Challenge Preparation for examples). Ask some guiding questions to activate their prior knowledge, such as the following:
  - How is the interface used? (e.g., “What does this button do?”)
  - How might changes to the interface make it better or worse? (e.g., push-button house phones versus touch-screen smart phones)
  - Does the interface use any standard symbols used by other interfaces? (e.g., “play” button or “power” symbol)
  - What makes an interface easy to use versus hard to use?
  - What parts are *controls* and which parts are *displays*?
    - Because a spacesuit is a very specialized form of spacecraft, it might be helpful to think about controls and displays in the context of other vehicle types, such as a car, truck, or bus. What controls and displays does a car need?
      - Controls such as the steering wheel to control direction, a gas pedal for speed, or the volume dial for the radio
      - Displays such as the speedometer that indicates your current speed, the odometer that indicates the total distance you have traveled, and the screen that shows which radio station you are currently enjoying
- Show students the video “S.U.I.T.S. (Spacesuit User Interface Technologies for Students)” to demonstrate how a heads-up display can be helpful to astronauts. https://www.youtube.com/watch?v=_SNCetZitZE
- The challenge for students is to design a heads-up display for one of the two Artemis Generation spacesuits.
- Based on available time and materials, the educator may optionally extend the challenge by asking students to build and test a prototype of their display.

Criteria	Constraints
Design must be integrated into a spacesuit, typically as part of the helmet or on the wrist.	Design may not be a premade, off-the-shelf product used without additional programming or modification.
Design must be operable by an astronaut wearing a spacesuit.	
Design must display at least three important pieces of information.	
Design must include at least one form of user interaction, such as a button, toggle, command, or input.	
Design must include at least one accessibility or inclusivity feature.	

Facilitate the Challenge

Fostering an Inclusive Computing Culture

- Ask students to think about a time they were unable to answer a phone because their hands were wet, full of other objects, or covered in gunk. While this was a temporary inconvenience, it can serve as an example of how assumptions about physical ability are not always true.
- Have students identify challenges that some users may experience when using any design. Some examples to point out:
  - Many people have trouble differentiating between red and green, yet many interfaces use red for "bad" or "no" while using green for "good" or "yes." Better interfaces add options to change the colors or use shapes to differentiate options.
  - Many people have trouble reading small text, so many apps allow you to make your font size larger.
  - Television and streaming video services typically offer closed captions for people with hearing impairments.
  - Students whose first language is not English may have unique insights into how to make the design multilingual.
- Explain that each team's design must have at least one accessibility or inclusivity feature to make sure that they are fostering an inclusive computing culture.

Collaborating Around Computing

- Have students work individually to develop a list of ideas for their interface, and ask them to consider the following questions:
  - What information would an astronaut need to know right away or all the time?
  - What might an astronaut need to control on their spacesuit?
  - Where is the best place on a spacesuit to put a display?
  - Which everyday technologies might be useful as inspiration?
- Have teams discuss their individuals ideas and identify at least one idea from each team member to include in their design.

Recognizing and Defining Computational Problems

- Based on their preliminary brainstorming, have students formally define the purpose of their design in the form of a two- to three-sentence "elevator pitch." Discuss the many types of information a heads-up display could provide.
- Tip: If students need some examples, provide one or more of the following:
  - Navigation**:** Accurately guide the user in real time and navigate between multiple planned and unplanned locations during an EVA. This includes long-range (from point A to point B), short-range (obstacle avoidance), and search-and-rescue navigation.
  - Terrain Sensing: Assist crew in identifying topographical or geological features nearby.
  - EVA System State: Display suit telemetry, such as the amount of oxygen left in the tank, and astronaut vitals, such as heart rate, along with other real-time data.
  - User Interface and Controls: Allow the astronaut to adjust settings or otherwise control the spacesuit, such as toggling exterior lights on and off, adjusting the temperature controls of the suit, and sending messages to mission control.
- Next, have students create a to-do list of what needs to be designed and split up the work so that every member of the team is responsible for designing at least one thing.

Share With Students

Brain Booster

NASA is using augmented reality (AR) technologies to make useful information about all kinds of vehicles in our skies, such as drones, more widely available to those who need it.

Whether for emergency response, managing air traffic, or local governance, visualizing complex data through AR makes it easier for people on the ground to be aware of the operations of the uncrewed vehicles that will increasingly populate our skies.

Developers from the NASA Ames Research Center participated in a field evaluation of AR technology during NASA's fourth and final Technical Capability Level demonstration of the Unmanned Aircraft Systems Traffic Management project.

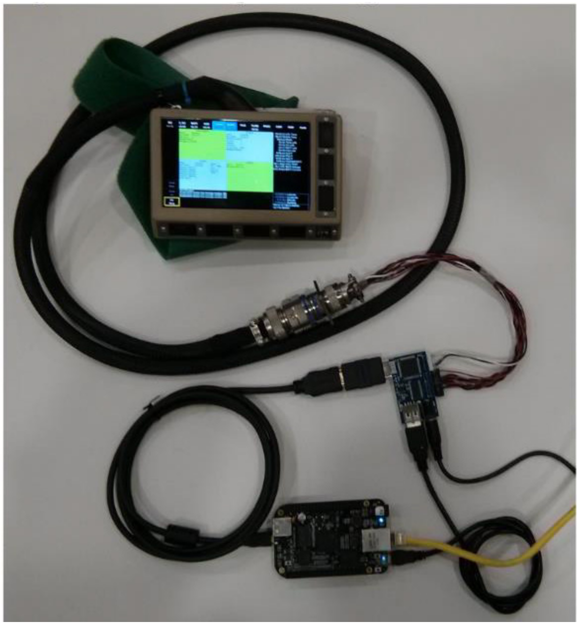
Learn more: https://www.nasa.gov/feature/ames/augmented-reality-air-traffic-management

Developing and Using Abstractions

- Direct teams to develop a template or “style guide” to ensure that each individual piece helps make a cohesive whole. This may include
  - What symbols/colors will be used to represent what features/ideas
  - Where on the display certain pieces of information should be shown
  - Key vocabulary or terms
- Tip: If students need an example of a style guide to understand this task, refer them to the example context of painting aircraft that is available as part of the Student Handout.
- Have each student design their assigned piece of the overall design. Remind them to obey their team’s style guide.
- Once the individual design pieces are completed, have students assemble them into a complete design in a jigsaw (show everything at once) or storyboard (show one thing at a time) fashion. Students should verbally walk through the completed design to make sure everything makes sense together.
- Tip: If students struggle to connect their individual pieces of the design, provide them with posterboard or a large sheet of paper (e.g., an easel pad) to draw out everything together.
- Tip: Any research notes or preliminary design sketches may be useful as formative assessment at this point.

Optional: Creating Computational Artifacts

- Depending on available resources and the educator’s expertise, optionally allow students to develop their designs. NASA frequently uses off-the-shelf programmable circuit boards to prototype its designs, as shown below.



A prototype wrist-mounted spacesuit display developed at NASA’s Glenn Research Center.

- Other options include making a smartphone app as if it were a wrist-mounted display, using web or wiki design tools to make a clickable version of the storyboard or jigsaw from the previous step, or using a full-fledged programming language to develop a working prototype.

Optional: Testing and Refining Computational Artifacts

- If students are given time to develop their designs, have them spend some of that time allowing other students to test and give constructive feedback on how to improve those designs.
- Tip: Suggest that students think of someone specific (such as a family or community member) when designing their inclusivity feature. As appropriate, encourage students to have that person try out the feature on the prototype to see if it was actually helpful.
- After they receive peer feedback, have students refine their computational artifacts.

Communicating About Computing

- Give each team a few minutes to present their final design. This can be as short as 1 minute, but up to 5 minutes per team would be appropriate. Appendix C contains an example rubric (Rubric for Computational Thinking) that may be helpful for assessing these presentations. It is important that each presentation include
  - How each design criterion was fulfilled
  - How each student contributed to the final design
  - Any important features of the design and how they changed over time
  - What students would do if they had more time to design
  - Display of the prototype or design developed
- Tip: Allow students the option to record their presentations in advance. Some students may be more comfortable recording rather than speaking in front of their peers directly. This may require students to record on their own time, or additional learning time can be allocated for recording sessions.
- Consider inviting family or community members to watch the presentations, either live or via recordings.

Extension Activities

If a basic lead-in activity is needed for students with no prior app development or coding experience, start by watching "Explore NASA's Ride to Station App and CODing Sim Activity" (https://www.youtube.com/watch?v=_QN-CWxyrQI). The video summarizes the following two activities:

- Rocket Science: Ride to Station App. https://www.nasa.gov/stem-ed-resources/rocket-science-ride-to-station.html
- Crew Orbital Docking Simulation (CODing Sim) Activity. https://www.nasa.gov/stem-ed-resources/crew-orbital-docking-simulation-coding-sim.html

For an increased focus on the electronics work, consider a Make It NASA activity (https://www.nasa.gov/centers/glenn/stem/make-it-nasa/content-modules/). The "Save Your Breath" module is particularly relevant to this activity as it could be a data source for the heads-up displays students are designing. For other, broader opportunities to go beyond app design into app development, check out the following challenges:

- NASA Spacesuit User Interface Technologies for Students (SUITS) Challenge. https://microgravityuniversity.jsc.nasa.gov/nasasuits
- NASA App Development Challenge (ADC). https://www.nasa.gov/stem/nextgenstem/moon/app_challenge.html
- NASA Space Apps Challenge. https://www.spaceappschallenge.org/

Activity Three: Heads-Up Display

Student Handout

Your Challenge

Your challenge is to design a heads-up display that could be built into one of the two Artemis Generation spacesuits.

Criteria	Constraints
Design must be integrated into a spacesuit, typically as part of the helmet or on the wrist.	Design may not be a premade, off-the-shelf product used without additional programming or modification.
Design must be operable by an astronaut wearing a spacesuit.	
Design must display at least three important pieces of information.	
Design must include at least one form of user interaction, such as a button, toggle, command, or input.	
Design must include at least one accessibility or inclusivity feature.	

Fostering an Inclusive Computing Culture

- Each member of your team should create a list of challenges that users may experience when trying to use a heads-up display.
- As a team, discuss how these challenges could be made easier with the right design.
- As a team, identify at least one accessibility or inclusivity feature that you plan to include in your design based on team members' lists.

Collaborating Around Computing

- Each member of your team should write down some initial ideas about how to design a heads-up display. Some things to think about:
  - What information would an astronaut need to know right away or all the time?
  - What might an astronaut need to control on their spacesuit?
  - Where is the best place on a spacesuit to put a display?
  - Which everyday technologies might be useful as inspiration?
- As a team, identify at least one good idea from each team member to include in the team design. Write down a list or table of all the ideas, including who came up with each.

Recognizing and Defining Computational Problems

- As a team, create a two- to three-sentence "elevator pitch" for your design, which should include the purpose of the design, the most important features, and anything else that might make it unique compared with designs from other people.
- As a team, create a to-do list of what needs to be designed. Split up the work fairly so that every member of the team is responsible for designing at least one thing.

Developing and Using Abstractions

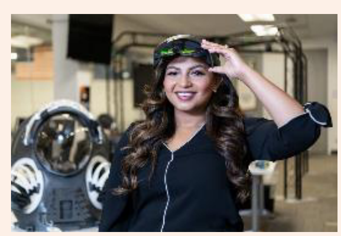
- As a team, develop a template or "style guide" to help ensure each individual piece helps make a cohesive whole. This may include
  - What symbols/colors will be used to represent what features/ideas
  - Where on the display certain pieces of information should be shown
  - Key vocabulary or terms
- A style guide for painting NASA airplanes is included at the end of the Student Handout as an example.

Fun Fact

NASA has been working on helmet-mounted displays for decades. Shown here is a system for in-flight simulation and research developed in the 1990s for the Rotorcraft Aircrew Systems Concepts Laboratory (RASCAL). The display system consisted of a programmable display generator, a display electronics unit, a head tracker, and the helmet with display optics.

Career Corner

Paromita Mitra became fascinated with astronomy and participated in a volunteer internship at Marshall Space Flight Center in the Guidance, Navigation, and Mission Analysis Branch so she could get exposure to her NASA dream for the first time. Today, Mitra is a human interface engineer at Johnson Space Center, where she continues to work through the research she began in graduate school.



Learn more: https://www.nasa.gov/feature/introduce-a-girl-to-engineering-day-meet-paromita-mitra/

- Each member of your team should then design their assigned piece of the team's overall design. Make sure to check in with each other regularly and refer back to your template or style guide often.
- As a team, assemble your individual designs into a complete team design. Two possible ways to assemble everything:
  - In a jigsaw (show everything at once)
  - In a storyboard (show one thing at a time)
- As a team, talk through the completed design to make sure everything makes sense together. Things that made sense by themselves may suddenly seem out of place when compared with all the other pieces.

Optional: Creating Computational Artifacts

- Complete this section only if directed by your teacher.
- As a team, create a working prototype of your design. Possible methods include (but are not limited to) these:
  - Smartphone or smartwatch app
  - Website or wiki
  - Desktop program
  - Programmable circuit board
  - Interactive slideshow

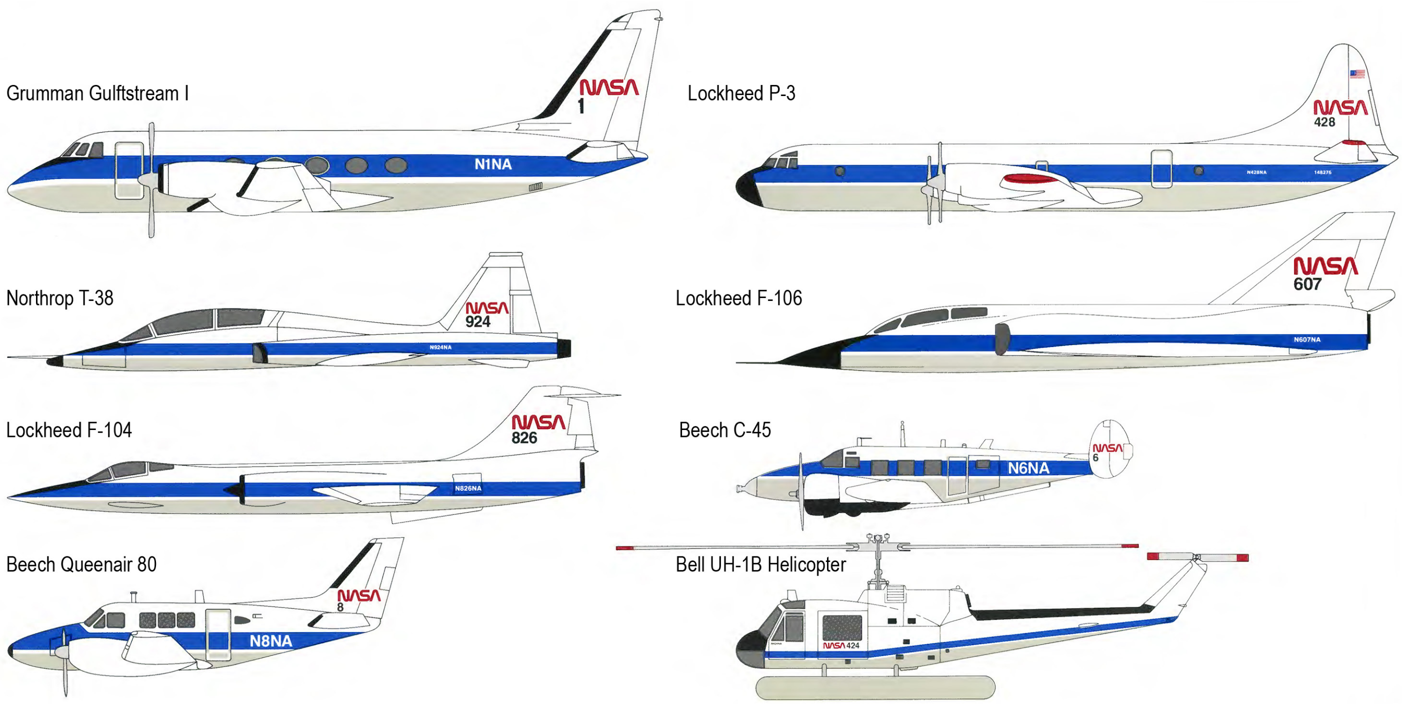
Optional: Testing and Refining Computational Artifacts

- Complete this section only if directed by your teacher.
- Swap prototypes with another team and test each other's designs.
- Provide the following constructive feedback to the other team:
  - Did the prototype work at all?
  - What is one strength of the prototype?
  - What is one specific change that could be made to improve the prototype?
- As a team, work to improve your prototype based on the feedback you got from the other team.

Communicating About Computing

- As a team, prepare a presentation, then present your design and/or prototype to everyone. Make sure to discuss
  - How you fulfilled the criteria and constraints
  - Any important features of your design and how they changed over time
  - How each member of your team contributed
  - What your team would do next if you had more time
  - Any of your designs or prototypes

Example Style Guide for Painting NASA Aircraft



- NASA red is Pantone PMS 185 (hex code #e60d2e)
- NASA blue is Pantone PMS 286 (hex code #0033ab)
- The NASA "worm" logo should always appear on the tail in NASA red, about halfway up, except on helicopters.
- An aircraft identification number should appear in black directly under the worm logo. The first digit of the number should line up with the N in NASA.
- A NASA blue stripe should go from the top of the nose of the aircraft to the bottom of the tail of the aircraft. A single bend is allowed to follow the shape of the fuselage.
- Important surfaces such as a nosecone may be painted black but do not have to be.
- For the remainder of the aircraft, the top half of the aircraft should be white, and the bottom half should be gray or silver.

Activity Four: Astro-Tools

Educator Notes

Learning Objectives

Students will

- Work in cooperative teams to engineer and build a working tool that could be useful to astronauts working on the Moon.
- Create an instruction manual or presentation on how to use the tool they have created.

Challenge Overview

In this engineering design challenge, students will work in teams to make modular tool heads, such as a rake and a hammer, for a standard tool handle (broom handle).

Suggested Pacing

75 to 90 minutes

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-2 Engineering Design: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • MS-ETS1-4 Engineering Design: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. *Crosscutting Concepts* • Influence of Science, Engineering, and Technology on Society and the Natural World: The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.	*Science and Engineering Practices* • Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables and clarifying arguments and models. • Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.	*Standards for Students (continued)* • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.
English Language Arts Practices (CCSS)	
• CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. • CCSS.ELA-LITERACY.SL.6.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly.	• CCSS.ELA-LITERACY.SL.7.5: Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points.

Challenge Preparation

- Read the introduction, background information, and Educator Notes to become familiar with the activity.
- Group students into teams of two to four. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Gather materials.
  - Create a “lunar testbed" for students to practice collecting regolith with the tools they design. This could be a small pan or plastic bowl filled with clean play sand, rice, or flour and various sizes of rocks, or it could be a tarp covered with packing peanuts and toys of various sizes.
- Print one Student Handout for each team.

Materials

☐ Zipper-seal plastic bags, gallon size (one per team) for sample collection
☐ Plastic eating utensils (forks, spoons)
☐ Assorted garden tools

- ☐ Small, lightweight paper cups
- ☐ Brass fasteners or clamps
- ☐ Crafting materials, such as
  - Scraps of cardboard
  - Ice pop sticks
  - Felt
  - Aluminum foil
  - Paper/foam plates
  - Straws
  - Polyvinyl chloride (PVC) pipe
- ☐ String or twine
- ☐ Scissors
- ☐ Safety eyewear
- ☐ Various types of gloves (plastic, garden, snow, etc.), several pairs
- ☐ Four to five 25-piece puzzles
- ☐ Tape (a variety, e.g., transparent, duct, and masking tape)
- ☐ Broom handles, dowel rods, long PVC pipe sections, or similar items
- ☐ Artificial lunar testbed materials, such as
  - Small pan, plastic bowl, or tarp
  - Clean play sand, rice, or flour
  - Rocks of various sizes
  - Packing peanuts
  - Small toys or other objects of various sizes
- ☐ Scratch paper and writing utensils
- ☐ Computer or tablet for research
- ☐ Notebooks or journals
- ☐ Posterboard for presentations

Safety

- Ensure students are practicing safe cutting techniques and scissor handling when building their tools.
- Students should avoid moving around the room with scissors.
- Ensure students use caution and wear eye protection when building and testing the tool designs.

Introduce the Challenge

- Provide context for this activity using the background and introduction information in this guide.
- Share this video with students: #AskNASA: How Will Astronauts Dig on the Moon? (5:04) https://www.youtube.com/watch?v=DpXxdSr1FWs
- Distribute the Student Handout and scratch paper to each team.
- Explain the challenge to students:
  - Each team will use the available materials to build a functioning multitool.
  - The tool must be designed to collect two different kinds of samples using interchangeable tool heads.
  - It may be helpful to provide the Rubric for Engineering Design Process (Appendix D) to teams prior to building.
  - After teams have tested and perfected their working multitool, they will develop a user manual or instruction guide for the tool. Various platforms can be used for their manual, such as a brochure, poster, or digital presentation.
- See the References and Resources at the end of the Educator Notes for further information on lunar tools if students need more ideas about the tools they will be inventing.

Facilitate the Challenge

Criteria	Constraints
Tool must be able to collect at least two different kinds of samples.	Teams may only use materials supplied by educator.
Tool must be composed of at least two different attachments that perform their own function.	
Tool must be able to be used by only one person.	
Teams must create a presentation or user manual about the use of their new tool.	

Ask

The following activity can help students understand the challenges that astronauts face with *dexterity* and hand and eye coordination while using tools on the surface of the Moon:

- Ask students what challenges astronauts might face when they are wearing bulky spacesuits and thick gloves.
- Show students the puzzles and the assortment of gloves that have been provided for a short activity to help them understand the complications that arise when wearing gloves to perform a manual task, like putting together a simple puzzle.
- Give each team an incomplete puzzle and two pairs of gloves. One pair should be tight-fitting, like children's gloves, and the other pair should be an adult-sized pair of working gloves, like garden gloves. The adult pair will be worn over the smaller pair.
- Have one student from the team put on both pairs of gloves. This student will be the "astronaut." The other students on the team will provide the astronaut with one piece of the puzzle at a time to be assembled. If enough pairs of gloves are available, all but one student can wear gloves, and the one student who is not wearing gloves can help the group as an assistant.
- Use a stopwatch or timer to determine which team completes their puzzle first. That team will be declared the winner!
- Following this activity, host a discussion and ask students:
  - What challenges did your team face?
  - What could have been done to improve your time?
  - What could you have done to make putting the puzzle together easier with the gloves?
- Optional: Have half the team wear gloves while putting the puzzle together, then have the other half complete the puzzle without gloves. Time each group and compare.
- Optional: Have teams stack pennies while wearing gloves and see which team can stack the highest tower of pennies.

Imagine

- Ask students:
  - What do you think astronauts will do while they are on the Moon?
  - What work will they be performing?
  - What are they looking for?
  - How do you think astronauts will collect and store any samples they find?
- Introduce the following terms that *geologists* use when they talk about collecting samples on the Moon. Have students include this new vocabulary in their journals or scientific notebooks:
  - *Float*: Rocks that are loosely adhered to the surface
  - *Chip*: A piece of rock forcibly removed from a larger rock

Share With Students

Brain Booster

Did you know you can explore lunar samples and meteorites through a virtual exploration platform called Astromaterials 3D Explorer? This platform allows you to access the samples as if you were actually holding them in your hands! Not only can the exterior of each sample be viewed, but slices of the rocks can be taken to see how they came to be.

Learn more: https://ares.jsc.nasa.gov/astromaterials3d/explorer/?sample=12013-11

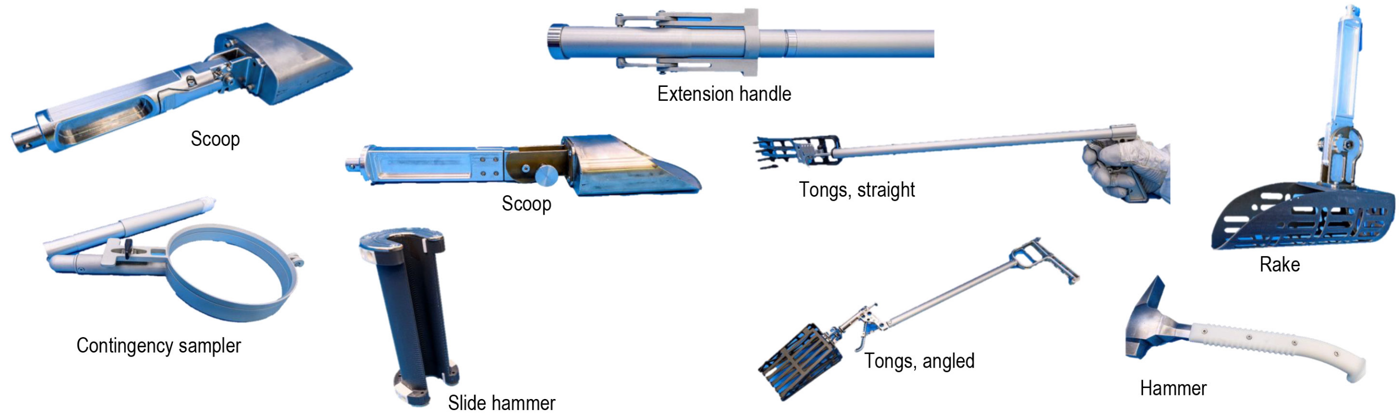
On Location

A core sample taken from the Moon during the Apollo 17 mission was finally opened almost 50 years later at the Astromaterials Research and Exploration Science division, located at NASA's Johnson Space Center in Houston, Texas. The most extensive collection of astromaterials in the world is housed here!

Learn more: https://ares.jsc.nasa.gov/

- *Soil*: Loose regolith made up of small (below pea-sized) grains
- *Soil core*: A cylindrical sample of regolith

- Have students look at the picture in their Student Handbook of various science sample acquisition tools. Have them use their new vocabulary to discuss how each tool might be used and what type of sample is being collected.



- Now that students have some ideas about the tools astronauts may use on the Moon, show them the lunar testbed. Remind them that they will be designing a new multitool for use in collecting samples. Explain that the tool
  - Must be able to collect at least two different-sized objects
  - Must have at least two different interchangeable heads that can be easily changed out while wearing gloves
- Allow students to explore the materials that they will be able to use to build their new multitool.

Plan

- Have each team member sketch a design for a tool.
- Share the following guidelines for each sketch:
  - Label each major part of the tool
  - State the purpose of the tool
  - List what materials the tool will be made from
- Explain that the final design must incorporate at least one design idea from each team member.

Create

- Allow teams at least 30 minutes to construct their new tools using the materials provided and the sketches they have created.
- Each team's new tool should be a multitool, with interchangeable tool heads on some type of handle or telescoping device.
- Ensure the teams are creating a tool that can pick up two different types of objects, such as loose sand, a core sample, small rocks, or a toy.

Test

- Now that students have created their own multitool, allow them some time to explore the lunar testbed and experiment with their new tools.
- Ensure teams can pick up two different types of objects inside the testbed.
- Once teams are sure their tool performs the way they expected, allow them time to practice using the tool while wearing gloves.

Improve

- This phase of the engineering design process is generally intuitive to students. However, some students may need a little help in troubleshooting their designs if failures occur. Be sure to visit and spend time with each team and ask probing questions:
  - Is the design working as expected? What can you do to improve your design?
  - Where are the weaknesses in the design, and what can be done to strengthen the tool?

- If the gloves are hindering your ability to use the tool, what can be done to the tool's handle to help make using it easier?

Share

- Have students discuss the following questions with their team:
  - What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
  - Were you surprised by the performance of your tool? Explain.
  - How were you able to improve your tool during the redesign phase? What design changes did you make, and how did they improve your tool's performance?
  - To share their multitool with others, teams should develop an instruction manual for the tool using their choice of a variety of platforms, such as posters, brochures, digital presentations, and notebooks.
- Optional: Have student groups share the tool they have invented with other classes or grade levels.
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Explore the Micro-g NEXT challenge to see how university students compete in this multitool challenge. https://microgravityuniversity.jsc.nasa.gov/
- Add a size constraint to the challenge. For example, give students a small box or tube that their tool and all its attachments must be packed away in for launch. Students must design their tools to be assembled, unfolded, or extended for use.
- Add a weight constraint to the challenge. For example, give students an object of a certain mass (e.g., a golf ball or a small weight) that their tool must be able to hold without failing.
- Integrate "sample bags" into the activity, where students have to bag, seal, and label their samples while wearing gloves.

References

Exploring the Moon. https://ares.jsc.nasa.gov/interaction/lmdp/documents/58199main_exploring_the_moon.pdf

NBL xEVA Lunar DAVD Test Series 1 (2020): Dive Helmet Test for DAVD Informatics and EVA Geology Tools. https://www.nasa.gov/sites/default/files/atoms/files/nbl_xeva_lunar_davd_test_series_1_2020_eva-exp-0079_0.pdf

Resources

Crew Assembly Training. https://www.nasa.gov/sites/default/files/files/Crew-Assembly-Course-508.pdf

Houston We Have a Podcast, Ep. 155: Artemis Moon Tools. https://www.nasa.gov/johnson/HWHAP/artemis-moon-tools

Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers. https://curator.jsc.nasa.gov/lunar/catalogs/other/jsc23454toolcatalog.pdf

NASA Prepares To Explore the Moon: Spacesuits and Tools (Video; 3:58). https://moon.nasa.gov/resources/410/nasa-prepares-to-explore-the-moon-spacesuits-and-tools/

Activity Four: Astro-Tools

Student Handout

Your Challenge

You will work in teams to engineer and build a working tool that could be useful to astronauts working on the Moon. You will also create an instruction manual or presentation on how to use the tool you have created.

Criteria	Constraints
Tool must be able to collect at least two different kinds of samples	Teams may only use materials supplied by educator
Tool must be composed of at least two different attachments that perform their own function.	
Tool must be able to be used by only one person.	
Teams must create a presentation or user manual about the use of their new tool.	

Ask

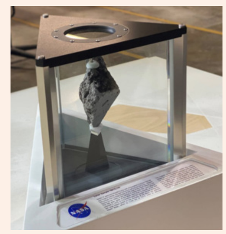
- Your teacher will show you a video called "#AskNASA: How Will Astronauts Dig on the Moon?" The video can be found here: https://www.youtube.com/watch?v=DpXxdSr1FWs
- What challenges do you think astronauts might face while wearing a bulky spacesuit? Discuss with the whole group.
- Your teacher will challenge you to complete a puzzle with your team while wearing two pairs of gloves. After this activity, think about the following questions and discuss:
  - What challenges did your team face?
  - What could have been done to improve your time?
  - What could you have done to make putting the puzzle together easier with the gloves?

Imagine

- Thinking about NASA's mission to return to the Moon:
  - What do you think astronauts will do while they are there?
  - What work will they be performing, and what samples could they be trying to find?
  - How do you think astronauts will collect and store any lunar samples that are collected?
- Take a look at the picture on the next page of lunar sample collection tools that astronauts use.
- How do you think each tool is used, and what type of sample do you think it could collect? Discuss with your team or class.
- Now that you have some ideas about the tools astronauts use to collect lunar samples, you and your team will design and construct a new multitool for sample collection. The tool
  - Must be able to collect at least two different-sized objects
  - Must have at least two different adapters that can be easily changed out while wearing gloves
- Your teacher has provided a "lunar testbed" that you can use to test your new tool when your team is ready.

Fun Fact

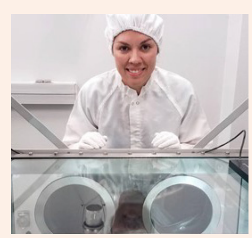
Did you know NASA loaned a Moon rock to the White House? This was done to recognize the hard work and accomplishments of earlier generations. Each lunar sample tells a story from the Moon's 3.95 billion years of history. Imagine how much more we will learn with samples collected from the Moon's South Pole!



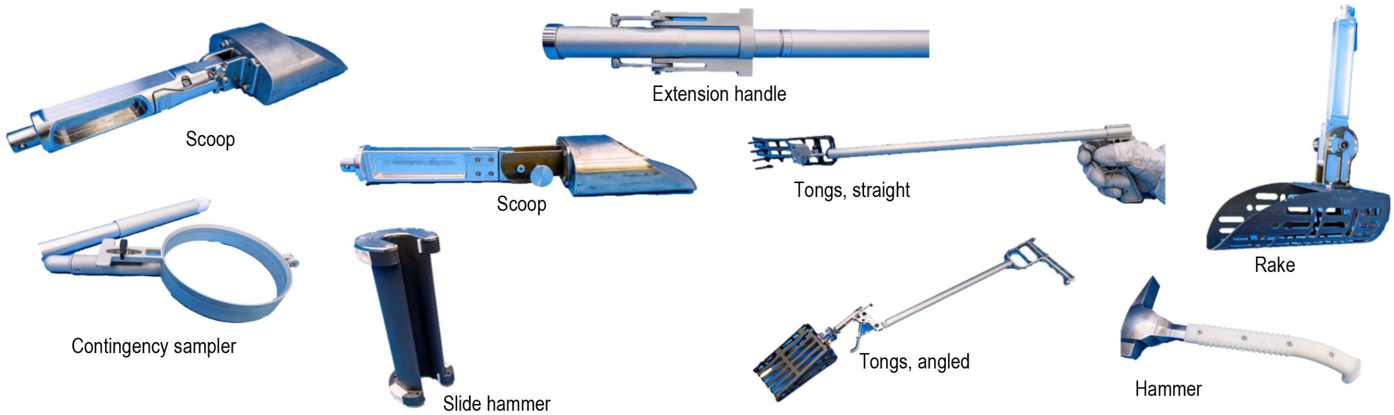
Learn more: https://www.nasa.gov/feature/top-5-things-to-know-about-nasa-s-astromaterials-research-and-science-division

Career Corner

Julie Mitchell leads the Artemis curation team in NASA's Astromaterials Research and Exploration Science Division. Mitchell works with engineers to design and build hardware to collect and store samples and teams up with astronauts to ensure safe collection and transportation of samples.



Learn more: https://www.nasa.gov/feature/i-am-artemis-julie-mitchell



- *Float*: Rocks that are loosely adhered to the surface
- *Chip*: A piece of rock forcibly removed from a larger rock
- *Soil*: Loose regolith made up of small (below pea-sized) grains
- *Soil core*: A cylindrical sample of regolith

Plan

- Each team member will create a sketch of a tool they would like to create.
- On your sketch, make sure to
  - Label each major part of the tool
  - State the purpose of the tool
  - List what materials the tool will be made from
- Once everyone on your team has created an idea, you will work together to create a team design that includes at least one design element from each team member.

Create

- Your team will now have at least 30 minutes to construct your new tool using the materials your teacher has provided and the sketches you have created.
- Keep in mind that your new tool should be a multitool, with at least two interchangeable tool heads on some type of handle or telescoping device.
- Make sure that your team is creating a tool that can pick up two different types of objects.

Test

Now that your team has created your own multitool, take some time to explore the lunar testbed and experiment with your new tool.

- Make sure your new tool can pick up two different types of objects inside the testbed.
- Once you are sure that your tool performs the way you expect, try using gloves with your tool.

Improve

- Is the design working the way your team expects? What can you do to improve your design?
- Where are the weaknesses in your design, and what can be done to strengthen the tool?
- If the gloves are hindering your ability to use the tool, what can be done to the tool's handle to help make using it easier?

Share

- Think about the following questions and discuss them with your team:
  - What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
  - Were you surprised by the performance of your tool? Explain.

- How were you able to improve your tool during the redesign phase? What design changes did you make, and how did they improve your tool's performance?
- To share your multitool with others, your team will develop an instruction manual for the tool you have created. You may choose from a variety of platforms, such as posters, brochures, digital presentations, and notebooks.

Appendix A.—Rubric for 5E Instructional Model

5E Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Engage	Student does not identify any prior knowledge or connections to previous learning experiences	Student identifies irrelevant or inaccurate prior knowledge or connections to previous learning experiences	Student identifies one example of relevant and accurate prior knowledge or connection to a previous learning experience	Student identifies two or more examples of relevant and accurate prior knowledge or connections to previous learning experiences	
Explore	Student does not participate in brainstorming discussion	Student participates in brainstorming discussion (e.g., asks questions) but does not contribute possible hypotheses, solutions, or tests	Student contributes at least one possible hypothesis, solution, or test to brainstorming	Student contributes at least one possible hypothesis, solution, or test to brainstorming and an alternative or improvement to another student's idea	
Explain	Student does not provide an explanation of observations	Student provides an explanation of observations that is inaccurate or incomplete or lacks evidence	Student provides an accurate, complete explanation of observations based on evidence	Student provides an accurate, complete explanation of observations based on evidence and supplements their reasoning with either evidence or evidence-based explanations from others	
Elaborate	Student does not draw reasonable conclusions based on evidence	Student draws reasonable conclusions but does not utilize scientific terminology or evidence	Student draws reasonable conclusions utilizing scientific terminology and evidence	Student draws reasonable conclusions utilizing scientific terminology as well as evidence and can make reasonable predictions based on those conclusions	
Evaluate	Student does not demonstrate understanding of the concept or can only repeat provided definitions	Student demonstrates an understanding of the concept by providing definitions or explanations in their own words, drawings, models, etc.	Student demonstrates an understanding of the concept by applying it to new questions or by analyzing new evidence	Student demonstrates an understanding of the concept by explaining how evidence caused their knowledge to progress over time or by proposing new ways to use their new knowledge (such as followup experiments)	
				Total	

Appendix B.—Rubric for Problem-Based Learning

PBL Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Meet the problem	Student does not identify the problem	Student incorrectly identifies the problem	Student identifies part of the problem	Student fully and correctly identifies the problem	
Explore knowns and unknowns	Student does not identify knowns and unknowns	Student incompletely identifies knowns and unknowns	Student identifies knowns and unknowns using experience but uses no resources	Student completely identifies knowns and unknowns using experience and resources	
Generate possible solutions	Student does not brainstorm	Student generates one possible solution	Student provides two solutions	Student provides three or more possible solutions	
Consider consequences	Student does not identify any consequences	Student determines inaccurate or irrelevant consequences	Student identifies consequences accurately	Student identifies consequences accurately and provides a rationale	
Present findings	Student does not communicate their results	Student shares random or irrelevant results	Student shares organized results, but the results are incomplete	Student shares detailed, organized results with others	
				Total	

Appendix C.—Rubric for Computational Thinking

Category	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Fostering an inclusive computing culture	Student does not consider accessibility or inclusivity features	Student participates in discussion regarding possible accessibility or inclusivity features	Student identifies at least one accessibility or inclusivity feature for the design	Student meets Journeyperson requirements AND the accessibility or inclusivity is a major focus of the design	
Collaborating around computing	Student does not consider the criteria and constraints of the challenge	Student participates in discussion regarding how to meet some of the criteria and constraints of the challenge	Student identifies how all of the criteria and constraints are planned to be fulfilled by the design	Student meets Journeyperson requirements AND the team has documented how each member has contributed at least one idea that will be used in the design	
Recognizing and defining computational problems	Student does not create an elevator pitch or to-do list	Student creates either an elevator pitch or a to-do list, but not both	Student creates both an elevator pitch and a to-do list	Student meets Journeyperson requirements AND the team has documented how each team member will contribute to the final design	
Developing and using abstractions	Student does not create style guide	Student creates a style guide, but there is not evidence of its use	Student creates a style guide, and there is evidence of its use	Student meets Journeyperson requirements AND the individual designs form a cohesive team design	
OPTIONAL: Creating computational artifacts	Student does not create computational artifacts (score as N/A instead if not assigned)	Student creates a computational artifact, but it has limited or no functionality	Student creates a computational artifact that is functional	Student meets Journeyperson requirements AND the artifact fulfills all the criteria and constraints of the challenge	
OPTIONAL: Testing and refining computational artifacts	Student does not test computational artifacts (score as N/A instead if not assigned)	Student has provided constructive feedback to another team OR received constructive feedback from another team, but not both	Student has provided constructive feedback to another team AND received constructive feedback from another team	Student meets Journeyperson requirements AND the team has documented how it has improved the artifact in response to feedback	
Communicating about computing	Student does not present final design/artifact	Student has presented the final design, but only some of the four presentation requirements were fulfilled	Student has presented the final design, and all four presentation requirements were fulfilled	Student meets Journeyperson requirements AND the presentation is given in an enthusiastic, persuasive, and/or entertaining manner	
				Total	

Appendix D.—Rubric for Engineering Design Process

EDP Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Identify the problem (Ask)	Student does not identify the problem	Student incorrectly identifies the problem	Student identifies part of the problem	Student fully and correctly identifies the problem	
Brainstorm a solution (Imagine)	Student does not brainstorm	Student generates one possible solution	Student provides two solutions	Student provides three or more possible solutions	
Develop a solution (Plan)	Student does not select or present a solution, or the solution is off-task	Student presents a solution that is incomplete or lacks details	Student selects a solution but does not consider all criteria and constraints	Student selects a solution that considers all criteria and constraints	
Create a prototype (Create)	Student does not directly contribute to the creation of a prototype	Student creates a prototype that does not meet the problem criteria and constraints	Student's prototype meets most problem criteria and constraints	Student creates a prototype that meets all problem criteria and constraints	
Test a prototype (Test)	Student does not contribute to the testing of the prototype	Student conducts tests that are irrelevant to the problem or do not accurately assess the strengths and weaknesses of the prototype	Student conducts carefully performed tests that consider one to two strengths and weaknesses of the prototype	Student conducts relevant and carefully performed tests that consider three or more strengths and weaknesses of the prototype	
Redesign based on data and testing (Improve)	Student does not contribute to the redesign	Student does not improve the design or address concerns	Student addresses one concern to improve the design	Student addresses two or more test-based concerns to improve the design	
Communicate results from testing (Share)	Student does not communicate the results	Student shares random results	Student shares organized results, but the results are incomplete	Student shares detailed, organized results with the group	
				Total	

Appendix F.—Glossary of Key Terms

Air pressure. The weight of the atmosphere over a particular point, also called barometric pressure. Average air exerts approximately 14.7 pounds (6.8 kilograms) of force on every square inch (or 101,325 newtons on every square meter) at sea level.

Atmospheric pressure. The external pressure of the atmosphere.

Chip. A piece of rock forcibly removed from a larger rock.

Constraints. Limits placed on a design or project due to available resources and the environment.

Core. A cylindrical sample of regolith at depth or drilled into the surface.

Criteria. Standards by which something may be judged or decided.

Dexterity. Skill and ease in performing tasks, especially with the hands.

Extravehicular activity (EVA). Activity performed outside a spacecraft by an astronaut in space.

Float. Rocks that are loosely adhered to the surface.

Geologist. An expert in (or student of) geology, which is the study of Earth's processes and structures.

Informatics. The study of how to effectively communicate information via computers.

Interface. The means by which a human interacts with a computer, such as a keyboard or a clickable button on the screen.

Intravehicular activity (IVA). Activity performed by an astronaut within a spacecraft.

Mobility. The ability to move or be moved freely and easily.

Prediction. The act of attempting to tell beforehand what will happen.

Prototype. An engineering unit that is built to address all critical scaling issues and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).

Regolith. A layer of loose, unconsolidated rock, mineral, and glass fragments covering solid rock (e.g., on the lunar surface).

Spacesuit. A self-contained living environment for pilots and astronauts that consists of everything needed for short-term survival, including breathing oxygen, the pressure exerted on the body, and a heating and cooling system.

Spacewalk. Any human activity in space that takes place outside a vehicle. A spacewalk is also called an extravehicular activity (EVA).

Vacuum. The nearly total absence of gas molecules, or the absence of air.

Vacuum chamber. A rigid enclosure from which air and other gases are removed, resulting in a low-pressure, space-like environment.

Vacuum pump. A mechanical device used to draw air out of a chamber, creating a low-pressure environment.

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