National Aeronautics and Space Administration

Build, Launch, Recover

Educator Guide

ENGINEERING DESIGN
SPACE VEHICLES

Next Gen STEM – Moon

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

Education Product	
Educators and Students	Grades 5-8

Contents

Preface

Build, Launch, Recover 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 May 2022.

STEM Education Standards

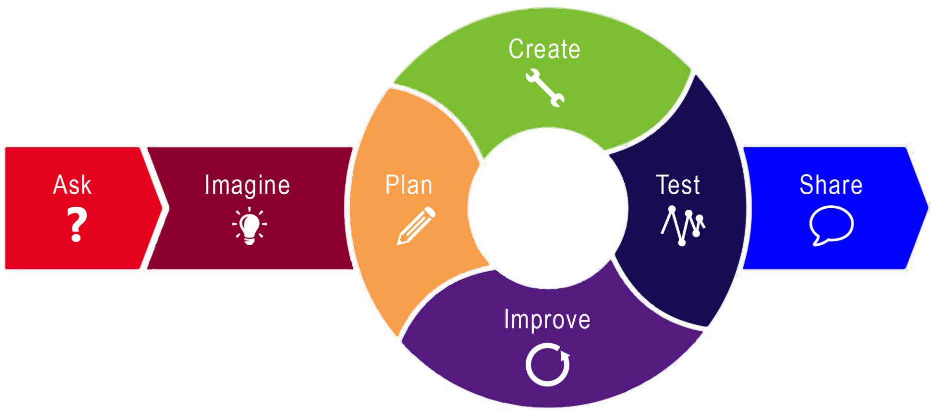
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) middle school disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) 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	Equations and Expressions	Geometry
Build It	✓			✓	✓	✓		✓	✓		✓	✓			✓	
Move It				✓		✓		✓	✓	✓	✓	✓				
Launch It	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓			
Recover It	✓			✓	✓	✓		✓	✓	✓	✓					✓

Engineering Design Process

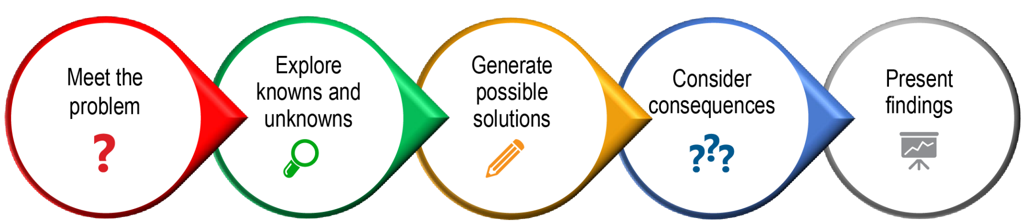
The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. Students can use the seven steps outlined below for many of the activities in this guide. Learn more about the 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.



Problem-Based Learning

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



Teamwork

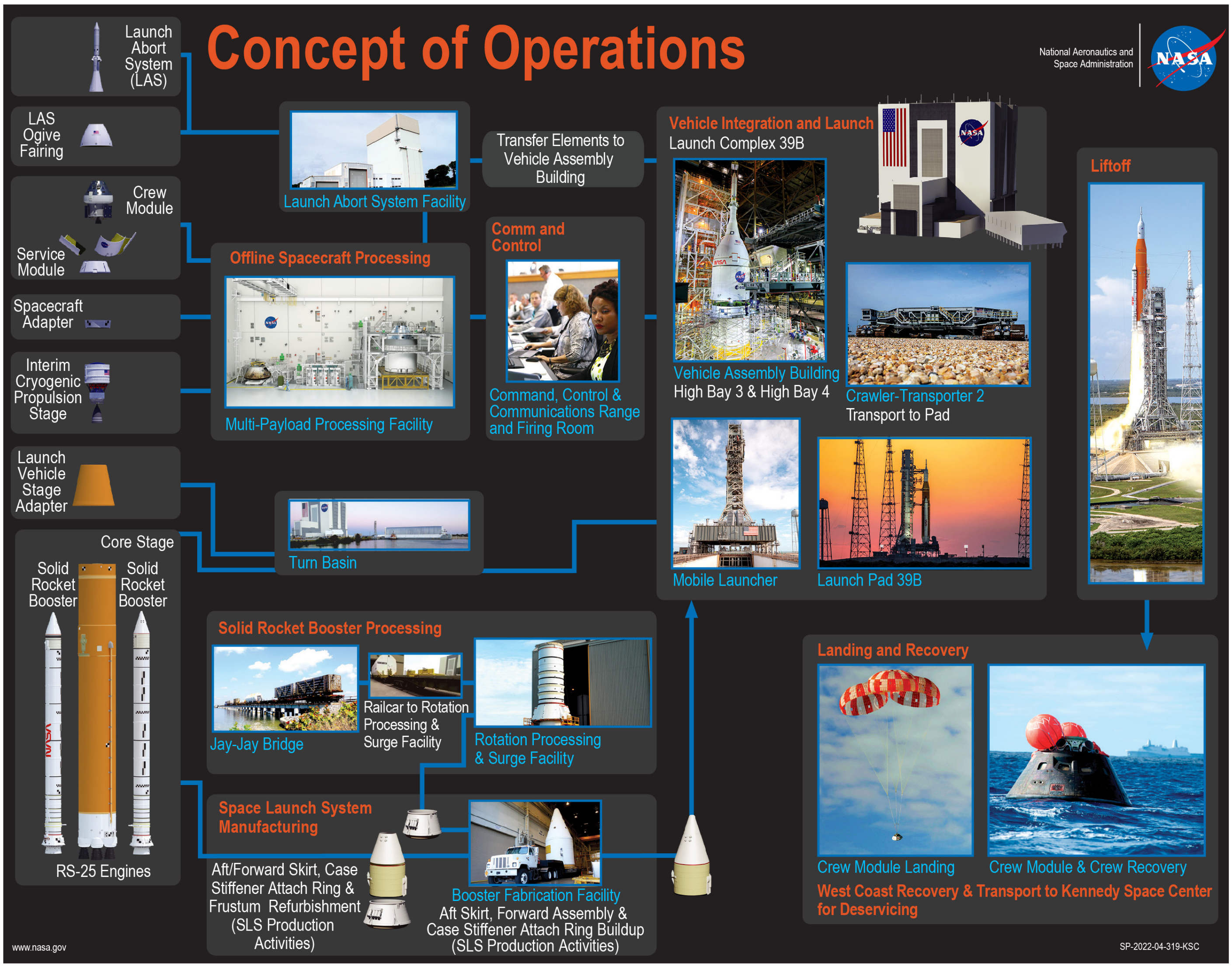
Everyone is a scientist and an engineer! It is important that everyone on the team be able to participate and contribute throughout these activities. If one student does all the building, the other students may be very bored during the building process. If one student is the leader, other students may 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 the roles of scientists and engineers from NASA's Exploration Ground Systems (EGS) team and the Orion Recovery Team. EGS was established to develop and operate the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, and launch. The EGS motto is "Build, Launch, Recover," so it was only natural to use these words as the title for this module. Each activity encourages collaborative teamwork to apply the engineering design process or problem-based learning techniques to Build, Launch, Move, and Recover. Each activity suggests a variety of additional resources—videos, articles, extension activities, websites, and more—to help encourage the educator and students to immerse themselves in being a part of the EGS teams and facilities.

Concept of Operations



This Exploration Ground Systems Concept of Operations lithograph is a visual overview of the intricate processes required to build, move, launch, and recover Artemis mission components. (NASA; https://www.nasa.gov/sites/default/files/atoms/files/lg-2022-04-319-ksc_egs_concept_of_operations_lithograph.pdf)

NASA Partners

Since the Artemis program's inception, every state in America has made a contribution to its success, with companies hard at work on innovations that will help establish a sustainable human presence on the Moon. Men and women across America and Europe are building the systems to support missions to the Moon, Mars, and beyond. These missions are critical to the space economy, fueling new industries and technologies, supporting job growth, and furthering the demand for a highly skilled workforce. The following map shows some of the locations of NASA's many Artemis partners. Link: www.nasa.gov/content/artemis-partners

Map generated using Google My Maps.

Key:

- Red-Human Landing Systems (HLS)
- Purple-Exploration Ground Systems (EGS)
- Yellow-Space Launch System (SLS)
- Blue-Orion
- Green-Miscellaneous

NASA SPINOFF

NASA “spinoffs” are NASA technologies that benefit life on Earth in the form of commercial products. NASA technology has resulted in more than 2,000 spinoff products since 1976. There is more space in our lives than we could ever imagine! The following examples illustrate how NASA works with companies to develop problem-solving technologies.

Ultrasonic Detectors Safely Identify Dangerous, Costly Leaks

In 1990, NASA grounded its space shuttle fleet when leaks were detected in the hydrogen fuel systems of Atlantis and Columbia. The leaks had to be identified and fixed before the shuttles could be considered safe to fly. To help locate the existing leaks and check for others, Kennedy Space Center engineers used portable ultrasonic detectors to scan the fuel systems. NASA engineers employed UE Systems Inc. detectors to examine the shuttle fuel tanks and solid rocket boosters, but they encountered difficulty with the devices’ limited range—certain areas of the shuttle proved difficult or unsafe to scan up close. To remedy the problem, the NASA engineers created a long-range attachment for the detectors. Read more about this spinoff at https://spinoff.nasa.gov/Spinoff2012/ps_1.html.

UE Systems Inc. detectors use licensed NASA technology to safely scan for electrical and compressed air leaks.

Lubricants Protect NASA Crawler-Transporters

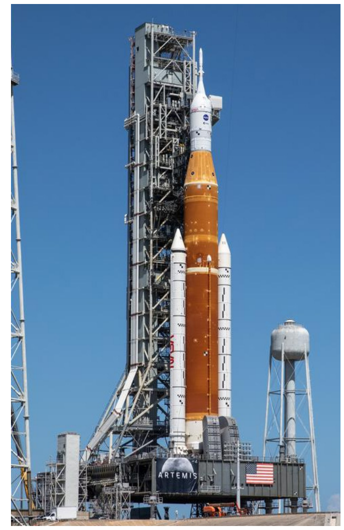
In 1994, NASA sought a new type of lubricant that would be safe for the environment and would help “grease the wheels” for the meticulous 1-mph, 4.2-mile trek of the shuttle-bearing launcher platform to the launch pad aboard one of NASA’s massive crawler-transporters. To develop a special lubricant that could meet the stringent requirements for shuttle transport, NASA and Lockheed Martin Space Operations looked to Sun Coast Chemicals of Daytona Inc. (now known as the X–1R Corporation). In a matter of weeks, Sun Coast Chemicals produced the solution. This new biodegradable, high-performance lubricant, dubbed the “X–1R Crawler Track Lube,” was a success—first in trial tests and then when applied directly to the crawler-transporter. Read more about this spinoff at https://spinoff.nasa.gov/Spinoff2007/ch_5.html.

A crawler-transporter enters the Vehicle Assembly Building at NASA's Kennedy Space Center in Florida. (NASA/Kim Shiflett)

Introduction and Background

What Is Exploration Ground Systems?

Exploration Ground Systems (EGS) is based at NASA's Kennedy Space Center in Florida. EGS was established to develop and operate the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, and launch. EGS's mission is to transform the center from a historically Government-only launch complex to a spaceport that can handle several different kinds of spacecraft and rockets—both Government and commercial.



NASA's Space Launch System rocket stands atop the mobile launcher at NASA's Kennedy Space Center. (NASA)

What Is Artemis?

With Artemis missions, NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. NASA will collaborate with commercial and international partners and establish the first long-term presence on the Moon. NASA's scientists and engineers will use what they learn on and around the Moon to take the next giant leap: sending the first astronauts to Mars.

Vehicle Assembly Building

NASA's Space Launch System rocket rolls out of the Vehicle Assembly Building on its journey to the launch pad. (NASA/Kim Shiflett)

The Vehicle Assembly Building (VAB) is one of NASA's most iconic structures and is recognized across the world. It has served as the final assembly point for the Apollo/Saturn V Moon rocket, the space shuttle, and, most recently, the Space Launch System (SLS) rocket. The VAB also serves as the central hub of NASA's multi-user spaceport, located at the Kennedy Space Center. No matter the destination of the rockets and spacecraft, whether it be low Earth orbit or deep space, the VAB has the infrastructure to prepare them for their missions.

The VAB was originally constructed for the assembly of the Apollo/Saturn V rocket, the largest rocket at the time. Construction was completed in 1966. The VAB is located 3.5 miles from launch pad 39A and 4.2 miles from launch pad 39B.

The tallest areas of the VAB are called high bays. There are four high bays in the VAB, two on the east side of the building and two on the west. Each high bay has a 456-foot-high door, enabling components of a rocket to be stacked vertically inside the high bay and then rolled out to the launch pad. These doors are the highest in the world, taking 45 minutes to completely open or close. Each high bay is connected in the middle by a transfer aisle, which allows massive components and equipment to be rolled into the building and lifted by cranes into position within the high bays. There are a total of five overhead cranes inside the building, two of which are capable of lifting 325 tons—the weight of 47 full-grown African elephants! Controlled by operators in cabs located near the VAB ceiling, the cranes are precise enough to lower an object onto an egg without cracking it!

The building itself is one of the largest in the world by area, covering 8 acres. It is 525 feet tall, which means the 305-foot Statue of Liberty could easily stand inside. The 209-foot-long American flag on the side of the building, originally painted in 1976 in celebration of the nation's bicentennial, is the largest painted American flag in the world.

The VAB was upgraded after the retirement of the shuttle program to increase its capability to house various types and sizes of rockets in order to support a truly modern 21st-century launch complex. The first activity in this guide uses the VAB as its inspiration, specifically the giant cranes housed within its walls that lift the heavy rockets into their places inside the high bays. Students will be challenged to modify a crane system to lift and stack sections of rocket fuselages, just like engineers who work inside the VAB.

The Crawler-Transporter

View of Artemis I rocket as seen from the foot of the crawler that carried it from the Vehicle Assembly Building. (NASA)

One of NASA's two massive crawler-transporters will play a pivotal role in helping the Agency achieve its goal of going back to the Moon. NASA recently used one of the crawler-transporters to transport the SLS from the VAB to the launch pad for a wet dress rehearsal. The wet dress rehearsal is very important because it is the last major test of the SLS.

Each crawler can carry more than 18 million pounds and is large enough to fit a baseball diamond on top of its platform. The crawlers move at various speeds based on load, environment, and other factors. The crawler carrying the SLS to the launch pad will travel slower than 1 mph.

The crawlers have been in use since 1965 but have undergone numerous upgrades in preparation for NASA's new missions. Each crawler's four continuous tracks—the parts that allow the crawlers to move—have been modified and strengthened with structural reinforcements. Alternating-current (AC) power generators have been replaced on both crawlers to increase available power. Other modifications include redesigned roller bearings; jacking, equalization, and leveling (JEL) cylinders to increase load-carrying capacity and reliability; a redesigned braking system; rebuilt gearboxes; replacement of electronics, cables, tubing, and hydraulic components; and cleaning of fuel tanks and hydraulic systems.

How does this massive vehicle work? Each crawler is able to raise and lower its sides and corners independently and is designed to roll underneath the mobile launcher in the VAB, pick it up, and steadily carry it 4.2 miles to launch pad 39B. The crawler uses its JEL system to keep the mobile launcher level all the way to the top of the pyramid-sloped launch pad, where it sets the platform in place so the SLS can lift off safely.

Rocco A. Petrone Launch Control Center

The Artemis I launch team participates in a countdown simulation inside the Launch Control Center's Firing Room 1 at NASA's Kennedy Space Center. (NASA/Kim Shiflett)

The Rocco A. Petrone Launch Control Center (RAP LCC) was built in 1967 in support of NASA's Apollo Program. It subsequently supported NASA's Space Shuttle Program and has now been updated and renovated to support NASA's Artemis missions. The RAP LCC comprises several control rooms, known as firing rooms, where countdown and launch operations are supervised and commanded.

The RAP LCC uses complex software that links launch team operators inside the main firing room to the SLS rocket and Orion spacecraft—either in processing areas such as the VAB and the mobile launcher or at Launch Complex 39B. The software allows controllers to communicate with astronauts inside Orion and with the Air Force Eastern Range and other NASA control centers.

The RAP LCC will use new processing and launch software called the Launch Control System (LCS). The LCS software is the first new software to be developed for NASA since the Space Shuttle Program was retired in 2011. It represents a suite of advanced software tailored to the unique needs of both the SLS rocket and the Orion spacecraft. The new software is designed to take advantage of modern computers, servers, and information technology to provide a faster, safer, and more reliable network than as used in the past. The software is also designed to be upgradable and adaptable to the launcher and spacecraft as they are flown in different configurations and in increasingly advanced versions.

Before any NASA program or project begins, there is a common systems engineering process in place. The NASA Systems Engineering Handbook (https://www.nasa.gov/seh/2-fundamentals) describes systems engineering best practices that are incorporated in the development and implementation of large and small NASA programs and projects. This is NASA's "go-to" document before, during, and after NASA missions and projects. The engineering of NASA systems requires a systematic and disciplined set of processes that are applied recursively and iteratively for the design, development, operation, maintenance, and closeout of systems throughout the life cycle of the programs and projects.

Launch System Review Process

In Activity Three, Launch It, students will gain insight into the "ins and outs" of launch protocols and become the personnel involved in various aspects of a rocket launch. They will work as a team to go through an actual launch simulation and make sure their protocol is accurate and reliable. The following review processes are part of a typical launch design and can serve as a helpful protocol example for students. This list has been adapted from NASA's Student Launch challenge (https://www.nasa.gov/stem/studentlaunch/home/index.html).

Preliminary Design Review (PDR). The purpose of this review is to convince the NASA Review Panel that the preliminary design will meet all requirements, has a high probability of meeting the mission objectives, and can be safely constructed, tested, launched, and recovered.

Critical Design Review (CDR). The CDR is a review of the final design of the launch vehicle and payload system. It demonstrates that the maturity of the design is appropriate to support proceeding to full-scale fabrication, assembly, and integration. The CDR shows that the technical effort is on track to complete mission operations in order to meet overall performance requirements within the identified cost, schedule, and technical performance constraints.

Flight Readiness Review (FRR). The FRR examines tests, demonstrations, analyses, and audits that determine readiness of the overall system (all projects working together) for a safe and successful launch and for subsequent flight operations of the as-built rocket and payload system. It also ensures that all flight hardware, software, personnel, and procedures are operationally ready.

Launch Readiness Review (LRR). All rockets and payloads undergo a detailed, deconstructive, hands-on inspection. Rockets are assessed for structural and electrical integrity as well as safety concerns.

Post-Launch Assessment Review (PLAR). The PLAR is an assessment of system in-flight performance.

Safety and Mission Success Review (SMSR). After several iterations of PDR, LRR, and PLAR, the SMSR provides the knowledge, visibility, and understanding necessary for senior safety, engineering, and health and medical management to either concur or non-concur in upcoming program decisions to proceed with a launch or significant flight activity. This is the final step to certify their design before testing with a real rocket.

Debrief. A debrief is a data-gathering process that should be done at the end of a launch. The data give insight into what worked and what did not work and what was learned from the process, along with any recommendations for additional testing or improvements to design.

Documenting Algorithms

Figuring out the best method or set of methods for accomplishing a task is only half the battle. The procedure, or *algorithm*, must be written down for future use so that steps do not get skipped or performed in the wrong order. In Activity Three (Launch It) and Activity Four (Recover It), students will use a variety of methods to document algorithms.

The simplest way to document algorithms is to write the procedure as a list of steps. For example:

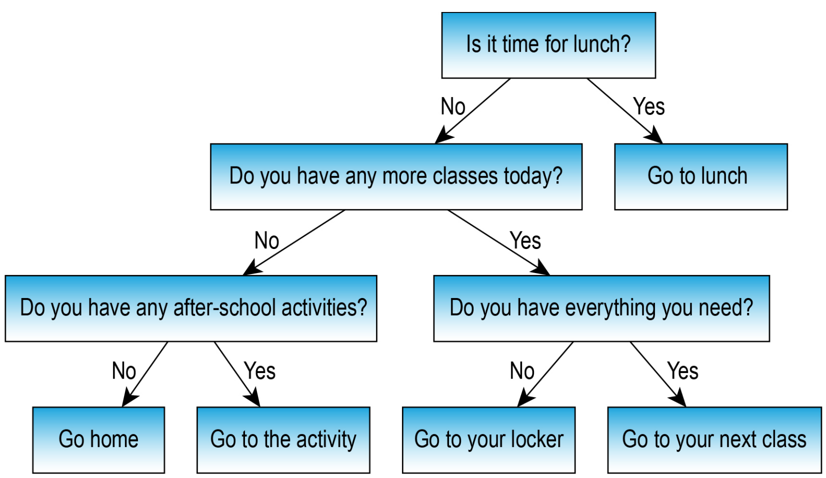
1. Put on socks.
2. Put on shoes.
3. Tie shoes.

However, simple lists like these often run into problems when exceptions occur. What if the shoes have hook-and-loop straps or zippers instead of laces? Once such possibilities are taken into consideration, step 3 might look like this:

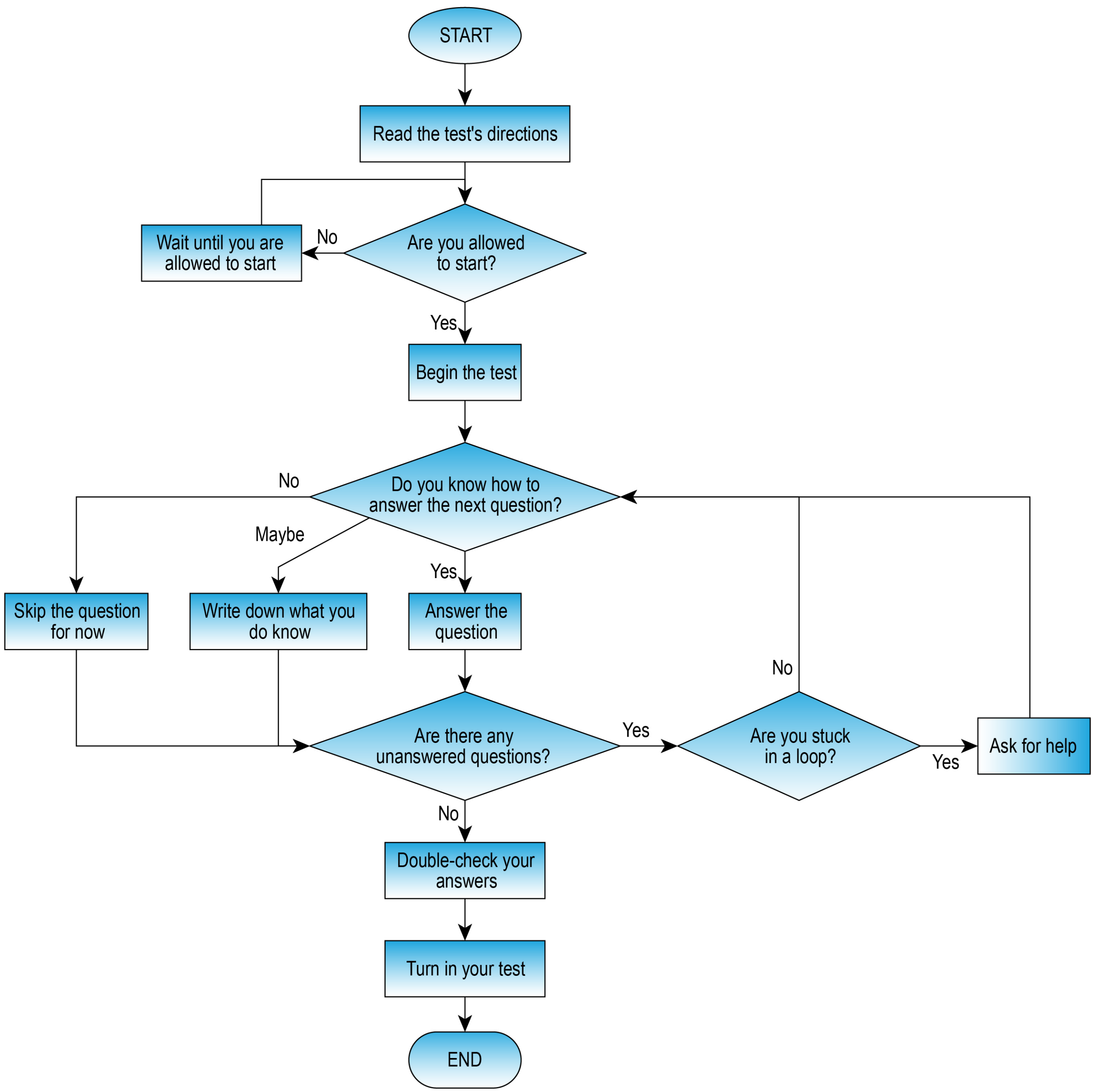
3. Pick one of the options below, depending on what kind of shoes you have:
   a. Laces: Tie the shoes.
   b. Zippers: Zip up the shoes.
   c. Hook-and-loop: Fasten the hook straps to the loop straps.
   d. Slip-ons: No action needed; you are done.

To better illustrate complex algorithms, two kinds of graphic organizers are commonly used: *decision trees* and *flowcharts*. A decision tree is structured so that one "branch" or the other is followed depending on how each yes-or-no question is answered. Decision trees are easy to draw because they are just rectangles and lines, but they can get very big for complex situations, and they do not "backtrack" very well. In the following example, a decision tree shows where a student needs to go next, depending on how the questions are answered.

Flowcharts are similar to decision trees, but they allow for "loops," or answers beyond yes and no. Flowcharts can include many shapes, but the most important three are (1) ovals to represent start or end, (2) diamonds to represent choices or questions, and (3) rectangles to represent actions. In the following example, a flowchart is used to convey test-taking instructions.



Example of a decision tree that shows where a student needs to go next after a class ends.


START
Read the test's directions
Are you allowed to start?
No
Wait until you are allowed to start
Yes
Begin the test
Do you know how to answer the next question?
No
Maybe
Yes
Skip the question for now
Write down what you do know
Answer the question
Are there any unanswered questions?
Yes
Are you stuck in a loop?
No
Yes
Ask for help
No
Double-check your answers
Turn in your test
END

If the algorithm will eventually be turned into a computer program, sometimes *pseudocode* is used. The prefix "pseudo-" means "kind of like but not really," so pseudocode is "kind of like code but not really code." In other words, pseudocode consists of words arranged to look like the code that makes a computer program work, but pseudocode is not actually written in a computer programming language. Here is an example of pseudocode for deciding what tools and materials you might need for class, though the syntax color coding is entirely optional.

```
If (class.type = "gym"){
        bring(gymClothes);
} else {
        bring(pencil);
        bring(notebook);
        bring(textbook);
        switch (class.type) {
                case "math":
                        bring(calculator);
                        if (class.name = "geometry"){
                                bring(protractor);
                                bring(compass);
                        }
                        break;
                case "science":
                        bring(labCoat);
                        bring(safetyGoggles);
                        break;
                case "art":
                        bring(artSupplies);
                        break;
        }
}
```

Recovery Team

A test version of the Orion capsule is pulled into the flooded well deck of the USS John P. Murtha. (NASA/Tony Gray)

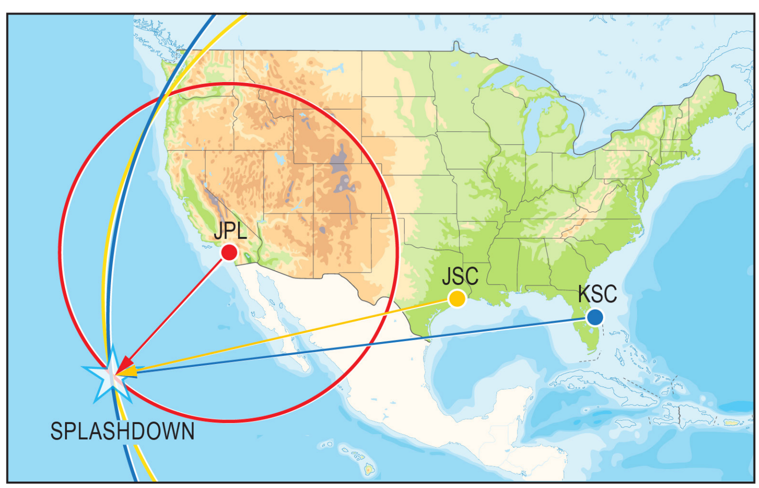
When the Orion spacecraft returns its Artemis I crew to Earth, it will enter the atmosphere traveling at 25,000 mph. During reentry, Orion will slow to 300 mph; then, parachutes will deploy to slow the spacecraft to approximately 20 mph before splashing down in the Pacific Ocean an anticipated 60 miles off the coast of California. The Landing and Recovery Team, led by Exploration Ground Systems (EGS) from Kennedy Space Center, will be responsible for safely recovering the capsule after splashdown and returning it (and, on future missions, the crew) to land. Before splashdown, the recovery team will head out to sea in a Navy amphibious ship that has a well deck at the waterline to allow boats to dock with the ship. At the direction of the NASA recovery director, Navy divers and other team members will be cleared to approach Orion's location in inflatable boats. When Orion is ready to be pulled into the well deck, the divers will attach a cable called the winch line. Up to four additional tending lines will be connected to attachment points. The winch will pull Orion into a specially designed cradle inside the ship's well deck, and the other lines will control the lateral motion of the spacecraft.

Finding Orion

U.S. Air Force Senior Airman Kyle Boyes releases a weather balloon during an underway recovery test in the Pacific Ocean. (NASA/Amanda Griffin)

The safety of the flight crew is NASA's top priority, so NASA uses multiple technologies to help accurately track the location of a spacecraft returning to Earth, including the long-established Global Positioning System (GPS). NASA is constantly developing new technology to improve this process. New software called Sasquatch (https://www.nasa.gov/feature/searching-with-sasquatch-recovering-orion) will help NASA track the various pieces of debris the Orion crew module will release as it reenters the atmosphere. That debris might include the capsule's forward bay cover—a protective ring that covers the back shell of the capsule and protects the parachutes during most of the mission—as well as the three main parachutes themselves. Despite advances in technology, malfunctions can still happen, but NASA can use a variety of surprisingly low-tech methods to ensure the rescue of astronauts and the recovery of the Orion crew module. For example, because wind can influence where a spacecraft might splash down, NASA routinely uses weather balloons just before a splashdown to examine the current wind conditions (see photo). This section discusses three low-tech methods NASA can use to locate spacecraft: triangulation, trilateration, and search patterns.

The first two methods, triangulation and trilateration, are closely related. As the prefix "tri" suggests, both methods involve three known locations. The examples illustrated in this map use three NASA locations: the Jet Propulsion Laboratory (JPL), the Johnson Space Center (JSC), and the Kennedy Space Center (KSC). Triangulation uses three angles from these known locations to find the unknown location of the capsule. The splashdown is south-by-southwest of JPL, southwest of JSC, and west-by-southwest of KSC. Similarly, trilateration uses three distances. This splashdown would be about 600 miles from JPL, 1,700 miles from JSC, and 2,500 miles from KSC. Together, these two methods uniquely identify a single splashdown area.

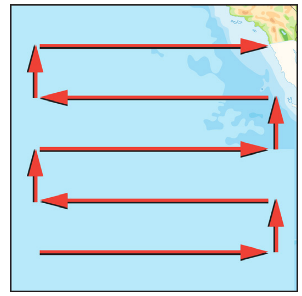


An example of triangulation and trilateration.

Although triangulation and trilateration identify the area where the capsule may have splashed down, they may not do so with pinpoint accuracy. Even a few square kilometers of ocean are a lot of area to search for a module that is just big enough to hold a few people. Randomly searching the ocean might cause the module to be missed, which is unacceptable when lives are at stake. Consequently, NASA uses a third low-tech method: the search pattern. There are numerous types of search patterns, each with strengths and weaknesses. Five examples are provided here.

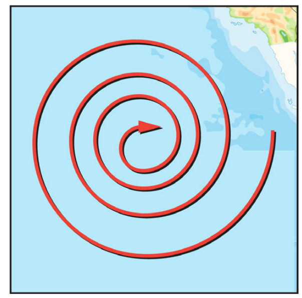
1. Back-and-forth pattern:

   Start at one corner, then move in alternating horizontal and vertical lines until you reach the opposite corner.
   - Strength: It is a simple way for one ship to check everywhere.
   - Weakness: It takes a long time and may cover a lot of unnecessary area.



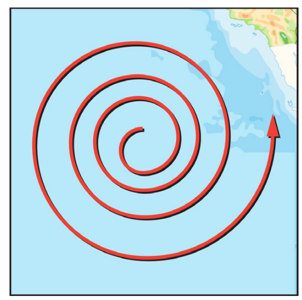
2. Inward spiral pattern:

   Start at a corner, then circle inward tighter and tighter until you reach the center.
   - Strength: It is a simple way for one ship to check everywhere.
   - Weakness: It looks in the least likely places first.



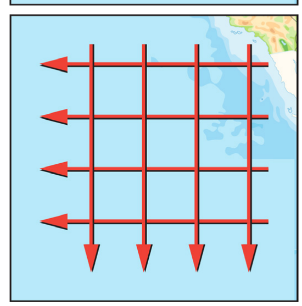
3. Outward spiral pattern:

   Start at the expected splashdown, then circle outward larger and larger until you reach a corner.
   - Strength: It is a simple way for one ship to check everywhere, starting with the most likely place first.
   - Weakness: If the module drifted far from the predicted splashdown, it would take a long time to find.



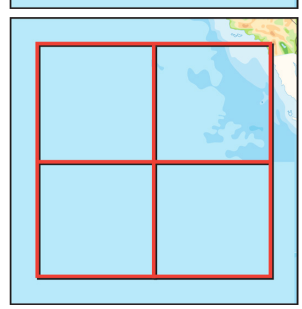
4. Grid pattern:

   Start along two of the edges, then move in a straight line towards the opposite edge from where you started.
   - Strength: It is simpler and faster than a back-and-forth pattern.
   - Weakness: It requires multiple ships.



5. Subsection pattern:

   Divide the search area into smaller subsections, then use any of the other search patterns in each of the subsections.
   - Strength: Smaller subsections can be searched more quickly than the full area.
   - Weakness: It is more complicated and requires multiple ships than other options.



Activity One: Build It

Educator Notes

Learning Objectives

Students will

- Use the engineering design process to design and build a crane out of cardboard.
- Design ways to reinforce the arms to withstand heavy loads.
- Design and build a crank handle. (Optional)
- Test and improve their cranes.

Challenge Overview

This activity provides students an opportunity to explore engineering design as if they were engineers working inside the Vehicle Assembly Building (VAB) with the cranes that are used to lift and stack the spacecraft and rockets. In this challenge, students will construct a crane and improve their design after testing in order to stack the heaviest and tallest "model rocket" possible.

Suggested Pacing

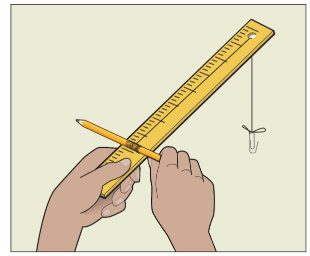
60 to 100 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-1 Motion and Stability: Forces and Interactions: Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. • 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-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. *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. • Systems and System Models: Models can be used to represent systems and their interactions —such as inputs, processes, and outputs—and energy and matter flows within systems.	*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. • Engaging in Argument From Evidence: Argumentation is the process by which explanations and solutions are reached. • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system. • Developing and Using Models: Developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Analyzing and Interpreting Data: Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.
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.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.CONTENT.7.EE.B.3: Solve multistep real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.	*Mathematical Practices (continued)* • CCSS.MATH.PRACTICE.MP2: Reason abstractly and quantitatively • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically • CCSS.MATH.PRACTICE.MP6: Attend to precision

Challenge Preparation

- Read the introduction and background information and the Educator Notes to become familiar with the activity.
- Gather materials.
- Print one Student Handout for each team.
- Build a simple crane out of a ruler, a string, and a pencil to be used as a take-up reel (see illustration).



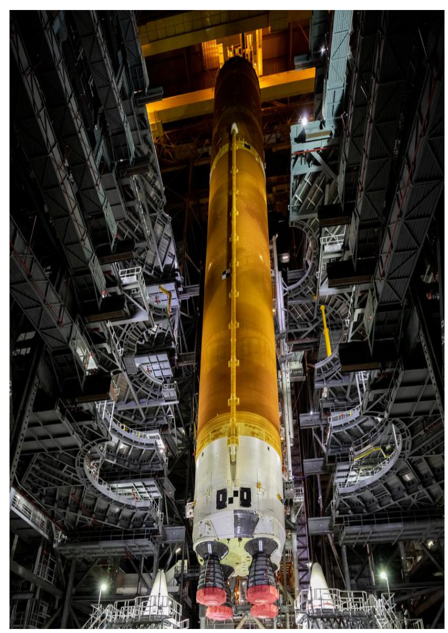
Materials (per crane)

- ☐ Cardboard box (shoebox size or bigger)
- ☐ 3 strips of cardboard, about 5 by 28 cm each
- ☐ Paper clip
- ☐ Small, lightweight cups
- ☐ Index cards or cardstock
- ☐ 3 writing utensils
- ☐ Wooden craft sticks
- ☐ Scissors
- ☐ Safety eyewear
- ☐ Smooth string (e.g., fishing line, dental floss, or kite string, but not twine or yarn)
- ☐ Variety of tape (duct, masking, scotch)
- ☐ Weights (e.g., coins, marbles, steel washers, gravel)
- ☐ Sketch paper

Safety

Ensure students

- Practice safe cutting techniques and scissor handling when building their cranes.
- Use caution and wear eye protection when building and testing the crane designs.


NASA teams prepare to lower the Space Launch System core stage inside the Vehicle Assembly Building at NASA's Kennedy Space Center. (NASA/Cory Huston)

Introduce the Challenge

- Provide context for this activity using the introduction and background information in this guide. Discuss the cranes in the VAB and their purpose.
- Share the "SLS Complete Stacking Compilation" with students, pointing out the bright yellow cranes lifting the Space Launch System rocket into place within the high bay of the VAB. https://images.nasa.gov/details-KSC-20220209-MH-FMX01-0001-SLS_Complete_Stack_TIMELAPSE-3270416
- 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 sketch paper to each team.
- Explain the challenge to students:
  - Each team will use the available materials to build a crane. The crane needs to be stationary, such as on the edge of a counter or desk.
  - Next, the team will design a take-up reel.
  - Finally, the team will add the string and hook.
  - Using the crane, students will be challenged to stack as many cups as possible before the stack collapses or falls over.

- Each cup represents one “stage,” or section, of a rocket.
- Each cup will have a standard weight inside. Example: Twenty coins or marbles.
- Place an index card between the stages of the rocket to help with balancing.

– Final weight and height are determined when the model rocket falls over or collapses.

Criteria	Constraints
Crane arm must be attached to a base (not handheld as in the educator’s example) that will allow students to pivot the crane on the surface of the table.	Students must only use materials supplied by the educator.
Crane must include an arm, a take-up reel, a string, and a hook.	Students must stop working when the model rocket falls over or collapses.

Facilitate the Challenge

Ask

- Show students the simple crane arm built with a ruler, string, and pencil and show them how the different parts work together. Explain that they could use a cardboard strip for the arm instead of a ruler and that they may need to use two or three. Ask students for their ideas on what they could do to strengthen this simple model.
- Explain that cranes on construction sites have a long arm that holds a cable with a hook on the end, very similar to the cranes in the VAB. Cranes must be strong to lift heavy loads without bending or breaking. Ask students how they can take the simple crane example to build a stronger crane in order to stack the tallest and heaviest “model rocket.”
- If students are unfamiliar with the concept of simple machines and pulleys, consider sharing the video “Our World: Simple Machines—Here and In Space.” https://nasaeclips.arc.nasa.gov/video/nasa360/our-world-simple-machines-here-and-in-space
- Ask students where the point of failure could occur on the crane. What can be done to reinforce the crane and make it stronger?

Imagine

- Prior to distributing the supplies, allow student teams some time to brainstorm on sketch paper.
- Ensure all students in each group are involved in the brainstorming process. It may help to have students create their own individual sketches first, and then the group, as a whole, will incorporate the strengths of each design into one final idea.

Plan

- Each team will now create one sketch of their crane idea, complete with labels and descriptions of materials being used. Have students keep in mind the following questions:
  – How will you keep the crane’s arm from breaking off as it lifts a heavy load?
  – How will you stop a heavy load from pulling the arm to the right or left?
  – How will you wind and unwind the cable so the hook can move up and down?
- After reviewing each group’s drawing, allow students to retrieve the needed materials to construct their crane.

Share With Students

Brain Booster

The Vehicle Assembly Building (VAB) is home to the enormous Space Launch System (SLS) rocket. NASA is preparing the SLS for the Artemis missions to take us back to the Moon. Visit NASA’s Kennedy Space Center blog to watch videos of VAB cranes stacking the SLS and to see some amazing pictures.

Closeup view of the SLS rocket inside the Vehicle Assembly Building with platforms retracted. (NASA/Frank Michaux)

Learn more: https://blogs.nasa.gov/kennedy/tag/vehicle-assembly-building/

On Location

Connect with NASA live in 360° from the Vehicle Assembly Building (VAB). Learn about Artemis I, the Mobile Launcher, and more from Senior Field Manager Krista Shaffer.

Watch here: https://www.youtube.com/watch?v=6fFPdyffLYA

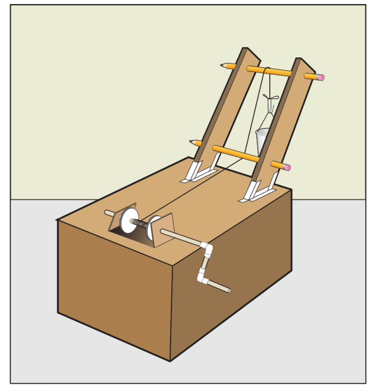
Create

- Have teams construct their cranes.
- Each crane should incorporate a take-up reel, cable, and hook. Students can also incorporate a handle as an extension to this activity.

Test

Help students with any of the following issues as they test their cranes:

- **The heavy cup rips the arm off the crane.** Have students attach the base of the arm securely to the box (or whatever they use for their base). Have them consider cutting slits in the box for the arm to slide into and then securing it with tape on both sides.
- **The arm falls when lifting the heavy cup.** Have students start over with new cardboard. Have them consider using multiple strips of cardboard for the arm, taped all together or spread apart.
- **The arm sways under a heavy load.** Have students make sure the cable is in the center of the arm. Have them ensure the arm is supported by strips of cardboard or string. The arm will tend to tilt if the strips are not all the same length.
- **It is difficult to secure the take-up reel.** Have students build something that holds the pencil (or whatever material the group used to create their reel). They could poke holes in the box or cut flaps out of the top of the box and poke the pencil through the flaps.



Example of a crane design with the optional handle.

Consider having students create a data table like the one shown here to track their test results:

Trial	Final Height of Rocket, cm	Final Mass of Rocket, g
Trial 1		
Trial 2		
Trial 3		

Improve

- Now that students have built and tested their cranes, it is time to begin the challenge. Teams will use their cranes to stack the paper cups, increasing the weight as they stack. The bottom cup should have 10 coins or marbles, the second should have 15, the third should have 20, and so on. Students can move and pivot their cranes on the tabletop to move the cable around to pick up the cups from the floor and stack them.
- As students work, encourage them to improve their crane design. Remind them that “improve” is one of the steps in the engineering design process.

Share

- Have student teams present their cranes to the class. Have them discuss any challenges that arose and how they overcame those challenges. Emphasize the key ideas in today’s challenge by asking the following questions:
  - Engineers’ ideas rarely work out perfectly the first time. How does testing them improve a design?
  - What force was affecting your crane, and how did the design of your crane deal with it?
  - How does the way you use a cardboard strip affect how much it can hold?
- Optional*:* Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Add a crank handle to the basic design to make turning the pencil easier.

- Have a “Most Efficient Design” contest. To determine the winner, divide the mass of the heaviest cup the crane was able to lift by the mass of the crane. For example, if the crane lifted a load of 50 grams and the crane itself weighs 10 grams, divide 50 by 10 to get 5. This means that the crane lifted 5 times its own weight. The contest winner will be the crane with the highest number.
- Add a cost constraint to the challenge and create a budget for students to “purchase” materials. Assign costs to all materials based on mass, area, or type of material.

Reference

Heavy Lifting Design Challenge.
https://www.nasa.gov/pdf/418000main_OTM_Heavy_Lifting.pdf

Resources

Draw NASA’s Vehicle Assembly Building (VAB)
https://www.nasa.gov/sites/default/files/atoms/files/draw_vab.pdf

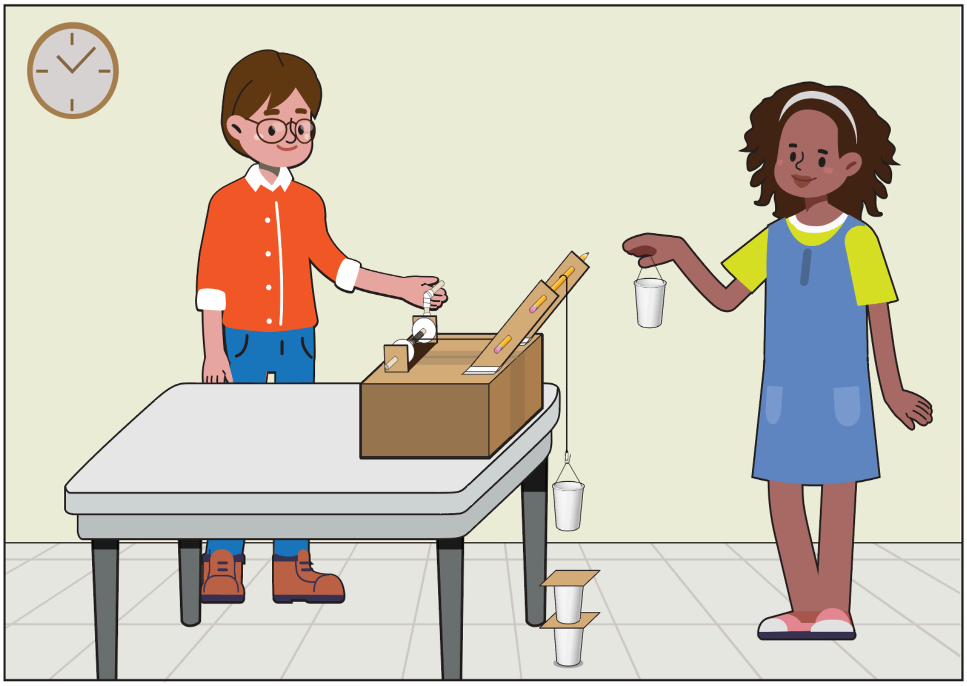
Activities about Simple Machines and Pulleys
https://www.grc.nasa.gov/www/k-12/Summer_Training/KaeAvenueES/SIMPLE_MACHINES.html

Activity One: Build It

Student Handout

Your Challenge

In this challenge, you will be working in teams to construct a crane and test and improve on your design in order to stack the heaviest and tallest rocket possible.



Criteria	Constraints
Crane arm must be attached to a stationary base.	Students must only use materials supplied by the teacher.
Crane must include an arm, a take-up reel, a string, and a hook.	Students must stop working when the model rocket falls over or collapses.

Ask

- Study the simple crane arm your teacher built and notice how the different parts work together. What could your team do to strengthen this simple model?
- Cranes on construction sites have a long arm that holds a cable with a hook on the end, very similar to the cranes in NASA's Vehicle Assembly Building. Cranes must be strong to lift heavy loads without bending or breaking. How can you take your teacher's simple crane example to build a stronger crane to stack the tallest and heaviest "model rocket"?
- Where do you think the weakest part of your crane might be? What can be done to reinforce the crane and make it stronger?

Imagine

- As a team, take some time to discuss how you want to construct your crane, then sketch your ideas on paper.
- Your goal is to stack cups, with increasing weight, on top of each other, with an index card placed between each cup.

Fun Fact

Have you ever seen the Statue of Liberty? At 305 feet tall, it is 17 feet shorter than NASA's Space Launch System (SLS) rocket. The SLS is 322 feet tall, which is a little shorter than the Apollo/Saturn V rocket.

Learn more: https://www.nasa.gov/sls/multimedia/gallery/sls-infographic3.html

Career Corner

NASA STEM Stars invites students to learn about careers at NASA. Check out this episode that features three engineers who are working on different parts of the Artemis program to launch our newest rocket to the Moon!

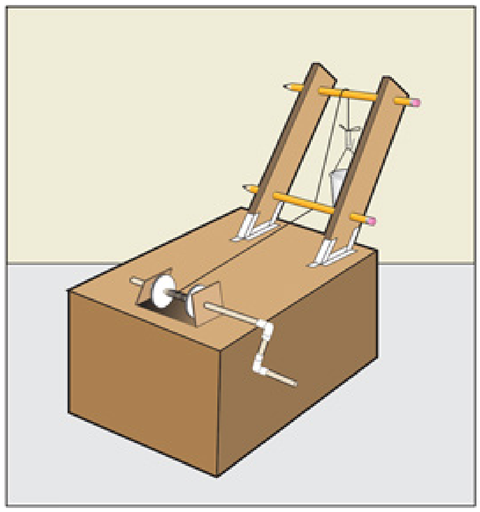
Artemis panel members from NASA STEM Stars.

Learn more: https://www.youtube.com/watch?v=7viDWd82y_w

- Allow everyone on the team to contribute their ideas and try to incorporate everyone's ideas. Make sure to look at all the materials your teacher has laid out.

Plan

- Your team will now create at least one sketch of your crane idea, complete with labels and descriptions of the materials being used. If you need help getting started, begin by studying the picture shown below, but make sure your team improves this original design. Keep in mind the following questions:
  - How will you keep the crane's arm from breaking off as it lifts a heavy load?
  - How will you stop a heavy load from pulling the arm to the right or left?
  - How will you wind and unwind the cable so the hook can move up and down?
- After getting your teacher's approval of your sketch, retrieve the needed materials to construct your crane.



Example of a crane design with an optional handle.

Create

- Construct your crane and make sure that everyone on your team can help.
- Each crane should also have a take-up reel, cable, and hook.
- Make sure that you can wind the hook up and down and that it moves smoothly.

Test

Now it is time to test your crane.

- Take a paper cup and add a handle made of tape for the hook to grab.
- Add 10 coins or marbles to the cup and try to pick up the cup.
- You can move or pivot your crane as needed on top of the table to reach the cups down on the floor with your cable.
- Do not let the stack fall over or collapse.

Improve

Now that you have built and tested your crane, it is time to begin the challenge.

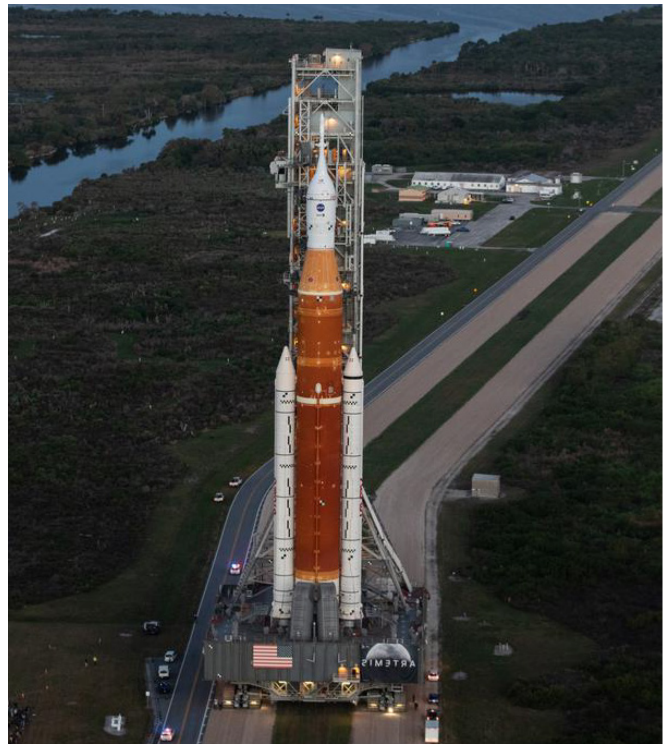
- Your team will use the crane to stack the paper cups, increasing the weight with each cup stacked. The bottom cup should have 10 coins or marbles. The second cup should have 15; the third should have 20, and so on.
- As your team works, you may need to improve your crane design. That is okay! "Improve" is an important step in the engineering design process.

Share

Present your crane to the class and discuss any challenges your team had and how you overcame those challenges. Think about the following questions:

- Engineers' ideas rarely work out perfectly the first time. How does testing improve a design?
- What force was affecting your crane, and how did the design of your crane deal with it?
- How did the way you used the cardboard strips affect how much it can hold?

Activity Two: Move It



NASA's crawler-transporter carries the Space Launch System rocket with the Orion spacecraft to the launch pad. (NASA/Joel Kowsky)

Educator Notes

Learning Objectives

Students will

- Use the engineering design process to design, build, and improve a rubberband-powered crawler that can move the heaviest payload possible at least 1 meter.
- Test and improve the design of their crawler.

Challenge Overview

In this challenge, students become engineers and NASA crawler operators while working in teams to design and build a rubberband-powered model of NASA's crawler-transporter that will be able to carry the most mass possible the farthest distance without failure.

Suggested Pacing

60 to 100 minutes

National STEM Standards

<table>
<tr><th colspan="2">Science and Engineering (NGSS)</th></tr>
<tr><td>Disciplinary Core Ideas
• MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
• MS-PS3-1 Energy: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
• 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.
• MS-PS3-1: Reason abstractly and quantitatively.</td><td>Crosscutting Concepts
• Cause and Effect: Cause-and-effect relationships may be used to predict phenomena in natural or designed systems.
• Scale, Proportion, and Quantity: Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.
Science and Engineering Practices
• Planning and Carrying Out Investigations: Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.</td></tr>
<tr><th colspan="2">Technology (ISTE)</th></tr>
<tr><td colspan="2">Standards for Students
• 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.</td></tr>
<tr><th colspan="2">Mathematics (CCSS)</th></tr>
<tr><td colspan="2">Mathematical Content
• CCSS.MATH.CONTENT.6.NS.C.8: Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.</td></tr>
</table>

Challenge Preparation

- Read the introduction, background information, and Educator Notes to become familiar with the activity.
- Group students into teams of three to five.
- Gather materials needed to complete the crawler.
- Print one Student Handout for each team.
- Build a crawler from the materials provided. This example will be used in the Ask phase of the design challenge.

Materials (Per Crawler)

- ☐ Cardboard box (e.g., shoebox or cereal box)
- ☐ Rubberbands, #33 (3 1/2 x 1/8 in.) (2 to 3 per group)
- ☐ Wooden dowels or skewers (2 per group, long enough to span the width of the box being used)
- ☐ Glue
- ☐ Small round objects for wheels (e.g., bottle caps) in sets of 4
- ☐ Ruler
- ☐ Metric tape measure or meterstick
- ☐ Safety eyewear
- ☐ Straws (optional, 2 per group)
- ☐ Tape (optional)
- ☐ Various payloads of up to 1 kg (e.g., book, plastic bottle)
- ☐ Scissors

Safety

Ensure that

- Students are practicing safe cutting and handling techniques when building their crawlers.
- Students' model crawlers do not contain sharp or pointed surfaces that could present a hazard.
- The test zone is clear of students and items that may be in the path of moving crawlers.
- Students use caution and wear eye protection when handling and releasing the crawlers during the distance test.

Introduce the Challenge

- Provide context for this activity using the background and introduction information in this guide. Discuss the crawlers and their purpose.
- Share the video "Artemis Path to the Pad: Crawler-Transporter 2." https://www.youtube.com/watch?app=desktop&v=pjGB2zGjJpY
- 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 challenge to students:
  - Each team will be designing and building a crawler that is able to carry a payload without breaking.
  - Teams will design their crawlers on scratch paper.
  - Next, teams will use available materials to build the crawler.
  - Finally, teams will test their crawlers with and without the payload and measure the distance traveled.

Criteria	Constraints
Crawler must have at least two axles, with at least two wheels per axle.	Crawler must not fail under the weight of the payload.
Crawler must be capable of traveling 1 meter while carrying a payload of at least 1 kilogram.	Students must only use materials provided by the educator.
Crawler must be rubberband powered.	Students must not use their hands to move the model crawler.

Facilitate the Challenge

Ask

Assess prior knowledge by asking students the following questions:

- Can you list four vehicles that are designed to carry heavy loads?
- What do these vehicles have in common?
- What is a crawler-transporter? (Refer to background information.)

Show students the simple prebuilt crawler and demonstrate how the different parts work together. Explain that the crawler is very important to NASA's mission and is used to move the SLS rocket to the launch pad. A crawler must be able to support a lot of weight and stabilize its load.

Ask students:

- What could your team do to strengthen this model so that it supports a heavy payload?
- What problems do you anticipate encountering while building your crawler? Student answers may vary, but here are some possible answers:
  - Building the crawler strong enough to handle a heavy payload
  - Being accurate enough with the meterstick to collect good data
  - Making sure the holes are properly positioned for the axles and making sure the crawler is level
- Does your team have any other questions about the challenge before you begin?

Imagine

- Allow students to observe the building materials that are available for their team to use and brainstorm to determine how they can be used to build their crawler.
- Ensure that all students in each group are involved in the brainstorming process. It may help to have students create their own individual sketches and then group the students together to incorporate the strengths of each design into one final idea.

Plan

- Have each team sketch their own design of a crawler and label the different parts. (Make sure to approve their design before they begin building their model.)
- Each team should now have one completed sketch of their crawler with parts labeled and descriptions of materials they plan to use. They should keep in mind the following questions:
  - How will you keep the crawler from breaking as it carries a heavy load?
  - How will you stop a heavy load from falling off the crawler as it moves?
- After reviewing each group's drawing, allow students to retrieve the needed materials to construct their crawler.

Create

- Have teams construct their crawlers. Remind students that each crawler should have two axles, with two wheels per axle, and be powered by rubberbands.
- The crawler will be required to move on its own without any help. The crawler must also be able to move as far as possible.
- Help students if they have difficulty making holes in their box for the axles of the crawler, gluing the straws to the bottom of the box, or gluing the wheels to the axles. Have students

Share With Students

Brain Booster

Housed at Kennedy Space Center, the crawler-transporter plays a vital role in moving rockets to the launch pad. The crawler is over 50 years old but has been upgraded to keep it in operation for years to come.

NASA's crawler-transporter. (NASA)

Learn more:
https://www.nasa.gov/sites/default/files/atoms/files/combined_crawler-transporters_fact_sheet_final.pdf

On Location

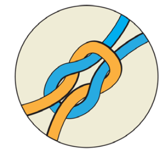
The crawlerway is the path used by the crawlers to carry a payload to the launch pad and is very important to the success of the Artemis I mission. The crawlerway must support the weight of the crawler and its payload of more than 20 million pounds. The weight can cause liquefaction, where the soil acts as a liquid and not a solid, so the crawlerway must be conditioned to provide stability for the crawler and its payload.

Crawlerway. (NASA/Ben Smegelsky)

Learn more:
https://blogs.nasa.gov/kennedy/2020/12/02/nasa-to-rock-and-roll-on-crawlerway-ahead-of-artemis-i-mission/

consider cutting slits in the box for the rubberbands to slide into. Students may also tape the rubberbands to the box after attaching them to the axles.

- If students have difficulty tying the rubberbands together to make the string or attaching the wheels to the axles, they can refer to the diagram in the following activities (also listed in the References section):
  - Make A Cardboard Rover. https://www.jpl.nasa.gov/edu/learn/project/make-a-cardboard-rover/
  - Roving on the Moon. https://ds-tc.prod.pbskids.org/designsquad/diy/DS_NASA_05Roving_CS_1.pdf



Test

- Students should test their crawlers by placing a payload on the crawler and allowing the crawler to move without the crawler breaking.
- If the crawler should fail under the weight of the payload, have the students consider attaching the wheels or axles another way. Also, have the students consider using multiple strips of tape to stabilize the payload.
- Here are examples of some problems the students may encounter and some solutions to suggest:
  - **The crawler does not move when they release the wheels.**
    - Make sure the axles are level and the holes are large enough for the axles to spin.
    - Make sure the rubberbands are not getting stuck under the box. If they are, try to cut small holes where the rubberbands are getting stuck.
    - Try using a different type of material for the wheels, or try the crawler on a different surface.
  - **The wheels do not stay on when they add a payload.**
    - Try attaching them in a different way.
  - **The rubberbands break when they apply tension.**
    - Try using slightly thicker rubberbands to power the axles.

Improve

- Now that students have built and tested their crawlers, it is time to begin the challenge. Teams will use their crawlers to carry a payload of up to a kilogram and measure the distance it travels. Make sure students are consistently measuring from the front wheel of their crawlers to get a more accurate result.
- As students work, encourage them to improve their crawler design. Help students understand that this is the “Improve” part of the engineering design process. More information on the engineering design process is provided at the beginning of this guide.

Share

Have student teams present their crawlers to the class. Have them discuss any challenges that arose and how they overcame those challenges. Emphasize the key ideas in today’s challenge by asking the following questions:

- Engineers’ ideas rarely work out perfectly the first time. How does testing them improve a design?
- What force was affecting your crawler, and how was the design of your crawler able to deal with it?
- How do changes to your rubberbands affect the distance your crawler is able to travel?

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

Extensions

- Have students add a device to stabilize the payload on their crawlers. Having a stabilized load will make it easier for the crawler to travel and avoid vibrations that could possibly cause failure.
- Have a “Most Efficient Design” contest. To determine the winner, measure the distance the crawler was able to travel with a sequence of increasing payloads. Have students graph the mass of the different payloads versus the distance traveled. Show them the formula KE = 1/2 mv^2. Explain that kinetic energy (KE) is related to mass (m), so as the mass of the payload increases, so does the kinetic energy of the crawler. The velocity (v) decreases, however, and the crawler moves slower with the payload.

- Have students calculate the velocity of the crawler by dividing the distance the crawler traveled versus the time it took to travel. This will require a timer or a stopwatch.
- Modify the mass and then graph the distance, rate, and time versus the mass.
- Provide a budget for the materials.
- Try attaching different rubberband sizes to see how it affects the distance the crawler travels.

References

Roving on the Moon. ds-tc.prod.pbskids.org/designsquad/diy/DS_NASA_05Roving_CS_1.pdf

Make a Cardboard Rover. jpl.nasa.gov/edu/learn/project/make-a-cardboard-rover/

Resources

"Build to Launch" With LEGO Education and Artemis I. education.lego.com/en-us/build-to-launch#meet-the-lego-space-team

Gaining Traction on Mars. nasa.gov/centers/glenn/stem/glenn-engineering-design-challenges/gaining-traction-on-mars

Activity Two: Move It

Student Handout

Your Challenge

In this challenge, you will be working in teams to construct a crawler and improve upon the design in order to carry the heaviest payload possible without your crawler breaking.

Criteria	Constraints
Crawler must have two axles, each with two wheels.	Crawler must not fail under the weight of the payload.
Crawler must be capable of traveling 1 meter while carrying a payload of at least 1 kilogram.	You must only use materials provided by your teacher.
Crawler must be rubberband powered.	You must not use your hands to move the model crawler.

Ask

- Can you list four vehicles that are designed to carry heavy loads?
- What do these vehicles have in common?
- What is a crawler-transporter, and how does it work?
- The crawler is very important to NASA's mission and is used to move rockets to the launch pad. The crawler must be able to support a lot of weight and stabilize its load while moving to prevent the rocket from falling. Study the crawler your teacher built and observe how the different parts work together. What could your team do to strengthen the model so that it supports a heavy payload?
- What problems do you anticipate encountering while building your crawler?

Imagine

- Observe the building materials that are available for your team to use. Brainstorm with your group to determine how they can be used to build your crawler.
- Allow everyone in your group to contribute their ideas, and try to incorporate everyone's ideas.

Plan

- Sketch your own design of a crawler and label the different parts. (Make sure your teacher approves your design before you begin building your model.)
- You should now have one completed sketch of your crawler with parts labeled and descriptions of materials your group plans to use. Keep in mind the following questions:
  - How will you keep the crawler from breaking as it carries a heavy load?
  - How will you stop a heavy load from falling off the crawler as it moves?
- After receiving approval of your group's sketch, retrieve the needed materials to construct your crawler.

Create

- Construct your crawler, making sure each group member participates in the building process.

Fun Fact

Did you know NASA's crawler weighs approximately 6.6 million pounds? That's the weight of about 15 Statues of Liberty or 1,000 pickup trucks. The crawler is able to transport 18 million pounds, which is the weight of more than 20 fully loaded Boeing 777 airplanes. Because of the heavy payload, the crawler is only able to move 1 mph.

Learn more: https://www.nasa.gov/content/the-crawlers

Career Corner

Breanne Rohloff is a mechanical engineer and one of the crawler drivers at NASA's Kennedy Space Center. Through a NASA internship, Breanne had the opportunity to work on multiple projects, and it was there that she was first introduced to the crawler.

Learn more: https://www.nasa.gov/feature/in-the-driver-s-seat-of-artemis-i

Learn more about NASA internships: intern.nasa.gov.

- Your crawler must have two axles, with two wheels per axle. It must be powered by rubberbands and move as far as possible.
- Your crawler will be required to move on its own without any help.
- After you have constructed your crawler, the payload should be placed on the crawler and moved without the crawler breaking.

Test

It is time to test your finished crawler.

- Apply tension to the rubberbands by turning the wheels to wind up the rubberbands. Place the crawler on the floor, release the wheels, and watch it GO!
- Add your payload on top of your crawler and repeat the previous step.

Improve

- Now that you have built and tested your crawlers, it is time to begin the challenge. Teams will use their crawlers to carry a payload and measure the distance that it travels. Measure and record the distance from the crawler's starting point to where the crawler stops. Make sure you are consistently measuring from the front wheel of your crawler to get a more accurate result.
- As your team works, you may need to improve your crawler design. Fear not! That is part of the engineering design process.

Share

Present your crawler to the class and discuss any challenges your team had and how you overcame those challenges. Think about the following questions:

- Engineers' ideas rarely work out perfectly the first time. How does testing improve a design?
- What force was affecting your crawler, and how was the design of your crawler able to deal with it?
- How does your rubberband's thickness or length affect the distance your crawler is able to travel?

Activity Three: Launch It

Illustration of Space Launch System rocket launch. (NASA)

Educator Notes

Learning Objectives

Students will

- Develop and test a procedure to launch a rocket consistently.
- Analyze various protocols, operations, and reviews used in NASA rocket launches. Evaluate the procedure by sharing it with another team who will follow the directions and provide feedback.

Investigation Overview

Students will take on the role of a NASA launch team by creating a launch protocol to consistently launch a rocket and hit a target. Prior to starting this challenge, educators must select a rocket design for students to build or find a prefabricated rocket to use for testing the launch protocol.

Suggested Pacing

160 to 180 minutes

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-3: 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* • Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them. • Systems and System Models: Models can be used to represent systems and their interactions —such as inputs, processes, and outputs—and energy and matter flows within systems. *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)* • Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system. • Engaging in Arguments 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.
English Language Arts (CCSS)	
• CCSS.ELA-LITERACY.W.6.3: Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences. • 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.L.6-8.6: Acquire and use accurately grade-appropriate general academic domain-specific words and phrases; gather vocabulary knowledge when considering a word or phrase important to comprehensions or expression.	• 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). • CCSS.ELA-LITERACY.L.7.3A: Choose language that expresses ideas precisely and concisely, recognizing and eliminating wordiness and redundancy.
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.	*Standards for Students (continued)* • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.
Mathematics (CCSS)	
Mathematical Content • CCSS.MATH.CONTENT.7.SP.C.8: Find probabilities of compound events using organized lists, tables, tree diagrams, and simulation.	

Investigation Preparation

- Read the introduction and background information and the Educator Notes.
- Optional*:* Print out the decision tree and flowchart from the Documenting Algorithms section (one copy per team).
- Print out the student section, including the Launch Console Roles and Responsibilities page (one copy per team).
- Select a rocket design for students to build from one of the NASA activities below, or find a prefabricated rocket to use for testing the launch protocol (each team will need one rocket).
  - Design a Foam Rocket with Stabilizing Fins. https://www.nasa.gov/stem-ed-resources/activity-one-design-a-foam-rocket-with-stabilizing-fins.html. (This is a training video from NASA's Build and Launch a Foam Rocket activity, found at https://www.jpl.nasa.gov/edu/teach/activity/foam-rocket/)
  - Rockets Educator Guide. https://www.nasa.gov/stem-ed-resources/rockets.html
  - Stomp Rockets. https://www.jpl.nasa.gov/edu/teach/activity/stomp-rockets/
  - Straw Rockets. https://www.nasa.gov/stem-ed-resources/3-2-1-puff.html
- Prepare any needed materials or assembly instructions for the selected rocket. For consistency, all teams should use the same type of rocket. Rocket building may take a full class period.
- Set up the launch area and a target for testing the launch protocols. Remember: The smaller the target, the more challenging it is to successfully hit the target.
- Differentiate and accommodate as needed by providing recorded instructions for auditory learners and/or pictorial instructions for visual learners.

Materials

- ☐ Preconstructed rocket (1 per team) (see Investigation Preparation)
- ☐ Target (e.g., garbage can, "x" marked with tape on the floor, hula hoop)
- ☐ Student Handout (1 per team)
- ☐ Decision tree and flowchart printouts (optional, 1 of each per team)
- ☐ Writing utensils
- ☐ Materials for a common household task, such as making a sandwich or tying shoes

Safety

- Follow safety guidelines for rocket building and launching activity.
- Students should be aware of their surroundings and move carefully throughout the room and launch area when viewing other teams' work.

Introduce the Investigation

- Provide context for this activity using the introduction and background information in this guide.
- To activate students' prior knowledge, ask students to define "Protocol" in their own words. Have students list some examples of protocols in their lives. Compare and contrast the various protocols on the student-generated list.
- Divide the students into teams (three to four students per team is ideal) and distribute the Student Handout to each team. Explain the details of the challenge, including the design criteria and constraints and the expectations for teamwork and classroom management.

Criteria	Constraints
Launched rocket must land 3 times or more on a specified target.	Teams must meet key milestones to receive certification from educator and proceed to the next step.
Protocol must have at least 5 steps/instructions.	Students must not make adjustments to the rocket design once the protocol testing has begun.
Launch team must read and follow the protocol exactly as written.	Teams must use only the materials that have been provided by the educator.
Protocol must contain a contingency plan for a rocket that does not launch successfully.	

Facilitate the Investigation

Meet the Problem

- In this demonstration, students will practice using descriptive vocabulary, communicating ideas to others, recognizing steps in a process, and recognizing the importance of using clear language.
- Ask students to write down a protocol for doing a simple daily task, such as making a sandwich or putting on and tying their shoes. Give them 5 to 10 minutes to write their protocols.
- Ask for a volunteer to read their protocol out loud. Tell the student to read the instructions EXACTLY as they are written. As the student reads, the educator will model the protocol by following the instructions EXACTLY. This could produce interesting results. For example, if an instruction is to "Spread butter on a sandwich" but does not mention using a knife, the educator would use fingers to spread the (imaginary) butter. If the instructions are not detailed and leave room for interpretation, have fun with it!
- Once the student has read the entire protocol, ask the group, "What was this demonstration showing?" Protocols and communication need to be clear and concise. Giving clear, concise instructions to others is an important skill.
- If time permits, allow students to improve their protocols and pair up to try the simple task instructions with each other.
- Ask students what could happen if the proper steps are not communicated and followed for a NASA rocket launch. Safety is NASA's number one priority, so be sure directions demonstrate that safety is the top priority.
- Share the following videos to encourage excitement and demonstrate launch sequences:
  - 3, 2, 1…Lift-Off of the Artemis I Mission to the Moon. (Artemis I Launch Sequence) youtube.com/watch?app=desktop&v=ewnrAmjLakQ&feature=youtu.be
  - Watch NASA's Perseverance Rover Launch to Mars! (42:20 to 48:55) youtube.com/watch?app=desktop&t=2540&v=JIB3JbIIbPU&feature=youtu.be
  - Crew–3 Astronauts Launch to the Space Station. (4:10:15 to 4:16:47) youtube.com/watch?app=desktop&t=15015&v=zekfpIRlVyY&feature=youtu.be
  - Hot Fire Engine Test for the Artemis Moon Rocket. (1:56:10 to 2:07:45) youtube.com/watch?app=desktop&v=ELHOXi2t3lk
- Ask students to compare the various launches to find similarities and differences.

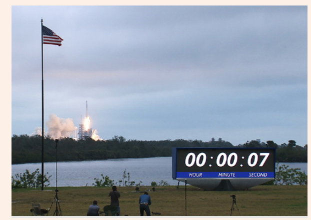
Explore Knowns and Unknowns

- After they have listened to several NASA launch sequences and protocols, students will individually research various roles and responsibilities of a general launch team. Have each student research roles and responsibilities for at least two of the general launch team members from the Launch It: Launch Console Roles and Responsibilities page.
- Student teams will create a visual graphic organizer that identifies the roles and responsibilities of a general launch team during the launch process.
- Review with students the sequence of a launch and various launch criteria, including the Launch System Review Process in the background information.
  - Artemis I Wet Dress Rehearsal Preparations Underway (NASA Artemis Blog). https://blogs.nasa.gov/artemis/2022/03/

Share With Students

Brain Booster

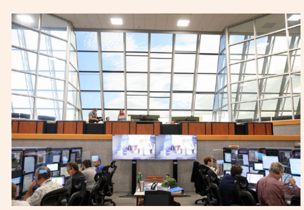
NASA's launch countdown clock at the Kennedy Space Center is one of the most-watched timepieces in the world. Before launch, the launch director performs the traditional roll call and the countdown clock is activated, counting down in hours, minutes, and seconds to reach T-zero.



Learn more: nasa.gov/content/new-display-counts-down-for-new-generation

On Location

NASA's Exploration Ground Systems team in the Rocco A. Petrone Launch Control Center conducts a variety of tests and simulations in the control center and at the launch pad to ensure they are ready for the first Artemis launch. Learn about the launch team and a major test NASA will use to make sure Artemis ground equipment is "go" for launch.



Learn more: nasa.gov/content/launch-control-center

360° virtual reality experience: youtu.be/k8MxCQJ9dy0

- Falcon 9 Crew Dragon Launch Weather Criteria. https://www.nasa.gov/pdf/649911main_051612_falcon9_weather_criteria.pdf

Generate Possible Solutions

- Provide the Criteria and Constraints table to students prior to the development of their launch protocol.
- Using information gathered from students' individual research, each team will create a protocol for launching the rocket the educator has selected for this activity.
- The protocol should
  - Identify consoles (roles and responsibilities of the launch team).
  - Include a checklist of the steps for launching the rocket, starting 5 minutes prior to launch (T–5 minutes).
  - Include a flowchart or other diagram for the steps of the protocol (see background section for examples).
  - Start at T–5 minutes (including the exact countdown and language for the launch).
- After teams have completed all the steps, they will submit their protocols to the Launch Director (educator) for a Safety and Mission Success Review (SMSR). The educator will verify there are no safety concerns before the teams exchange their rocket and protocol with another team for testing.

Consider Consequences

- After teams have passed SMSR and developed all needed documentation for the protocol, assign teams to pair up and exchange their rocket and protocol.
- Prior to launch, have each team create a data table with categories that align with their launch protocol. Data categories might include the following: name of team or rocket, number of trials, angle of release, weather, distance (m) from the target, height (m), and other observations. During testing, each team will launch the other team's rocket using the exact protocol provided and determine if the protocol allows for the rocket to hit the target three times consistently. Launching more than three times is acceptable with the goal of having 3 consistent launches land on the target 3 times in a row.
- While observing the launch, they will record their observations for the Post-Launch Assessment Review (PLAR).
- The team that developed the protocol will observe the launch team and record observations in a data table for the PLAR. The observing team may not intervene or communicate with the launch team during the launch. The PLAR is a summary of recommendations for improving the launch protocol, including missing steps or other key elements.
- If time allows, teams can cycle through more iterations of developing and testing the launch protocol to make improvements.

Present Findings

- Debriefing: Teams will submit a final presentation to the Launch Director (educator), including
  - An overview of the investigation
  - The PLAR
  - What they learned from the process
  - One thing they would do if there were more time
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Make the target smaller or more difficult to hit.
- Add contingencies for weather (e.g., add a fan for wind if indoors), broken parts, or unforeseen delays.

Resources

Artemis I Simulations. nasa.gov/feature/artemis-i-simulations-ramp-up-for-the-countdown

Launch Control Center History: NASA's LCC: Building the Brains of Launch Operations. youtu.be/R8aByl2fK5I

Build, Launch, Recover

Artemis I Rocket, Spacecraft Prepare for Return to Launch Pad. blogs.nasa.gov/artemis/tag/exploration-ground-systems/

NASAfacts: Launch Control Center. nasa.gov/sites/default/files/atoms/files/launch_control_center_final.pdf

Video: 3…2…1 Lift-Off of the Artemis 1 Mission to the Moon. youtu.be/ewnrAmjLakQ

Activity Three: Launch It

Student Handout

Your Investigation

You will take on the role of a NASA launch team by creating a launch protocol to consistently launch a rocket and hit a target.

Criteria	Constraints
Launched rocket must land 3 times or more on a specified target.	Teams must meet key milestones to receive certification from educator and proceed to the next step
Must have at least 5 steps/instructions in the protocol.	Students must not make adjustments to the rocket design once the protocol testing has begun.
Launch team must read and follow the protocol exactly as written.	Teams must use only the materials that have been provided by the teacher.
Protocol must contain a contingency plan for a rocket that did not launch successfully.	

Meet the Problem

- Individually write down a protocol for doing a simple daily task, such as making a sandwich or putting on and tying your shoes.
- When time has expired, volunteer to read your protocol out loud. If selected, read the protocol EXACTLY as it is written. Continue until you have read the entire protocol. Your teacher will be following your EXACT instructions.
- What was this demonstration portraying?
- What could happen if the proper steps are not communicated and followed for a NASA rocket launch?
- View videos of various launch sequences, NASA launches, and preparations for Artemis missions.
  - 3, 2, 1…Lift-Off of the Artemis I Mission to the Moon. (Artemis I Launch Sequence) youtube.com/watch?app=desktop&v=ewnrAmjLakQ&feature=youtu.be
  - Watch NASA's Perseverance Rover Launch to Mars! (42:20 to 48:55) youtube.com/watch?app=desktop&t=2540&v=JIB3JbIIbPU&feature=youtu.be
  - Crew–3 Astronauts Launch to the Space Station. (4:10:15 to 4:16:47) youtube.com/watch?app=desktop&t=15015&v=zekfpIRIVyY&feature=youtu.be
  - Hot Fire Engine Test for the Artemis Moon Rocket. (1:56:10 to 2:07:45) youtube.com/watch?app=desktop&v=ELHOXi2t3lk
- Compare the various launches. How are they similar, and how are they different?

Explore Knowns and Unknowns

- After your team has listened to a variety of NASA launch sequences and protocols, each team member will research the roles and responsibilities of at least two of the general launch team members from the Launch It: Launch Console Roles and Responsibilities page.
- Your team will now create some type of visual (flowchart or decision tree) that identifies the roles and responsibilities of a general launch team during the launch process.

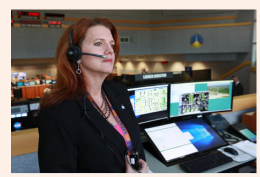
Fun Fact

NASA's Kennedy Space Center is unofficially known as the "Lightning Capital of the United States!" Lightning is an important factor when determining launch safety.

Learn more: https://www.nasa.gov/feature/all-clear-smooth-simulation-ahead-of-nasa-s-artemis-i-launch

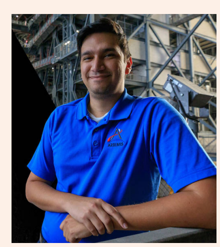
Career Corner

Exploration Ground Systems (EGS) Launch Director Charlie Blackwell-Thompson is NASA's first female launch director.



Learn more: https://www.nasa.gov/centers/kennedy/about/biographies/blackwell-thompson.html

Abdiel Santos-Galindo's journey to becoming a ground systems integration engineer for EGS was fueled by inspiration and hard work.



Learn more: https://www.nasa.gov/feature/i-am-artemis-abdiel-santos-galindo

- Explore the sequence of a launch and different launch criteria.
  - Artemis I Wet Dress Rehearsal Preparations Underway (NASA Artemis Blog). https://blogs.nasa.gov/artemis/2022/03/
  - Falcon 9 Crew Dragon Launch Weather Criteria. https://www.nasa.gov/pdf/649911main_051612_falcon9_weather_criteria.pdf

Generate Possible Solutions

- Using all the information gathered about NASA's launches, create a protocol for launching the rocket your teacher selected for this activity.
- Be sure to reference the criteria and constraints table prior to the development of the protocol.
- The protocol should
  - Identify consoles (roles and responsibilities of the launch team).
  - Include a checklist of the steps for launching the rocket, starting 5 minutes prior to launch (T–5 minutes).
  - Include a flowchart or other diagram for the steps of the protocol (see example flowchart and decision tree from your teacher).
  - Start at T–5 minutes (including the exact countdown and language for the launch).
- After your team has completed all the steps, submit your protocol to the Launch Director (teacher) for a Safety and Mission Success Review (SMSR) to verify there are no safety concerns.

Consider Consequences

- After your team has passed SMSR and developed all needed documentation for the protocol, the Launch Director (teacher) will assign teams to pair up and exchange their rocket and protocol with your teams.
- Prior to launch, each team will create a data table with categories that align with their launch protocol. Data categories might include the following: name of team or rocket, number of trials, angle of release, weather, distance (m) from the target, height (m), and other observations. During testing, your team will launch the other team's rocket using the exact protocol provided and determine if the protocol allows for the rocket to hit the target three times consistently. Launching more than three times is acceptable with the goal of having three consistent launches land on the target three times in a row.
- While observing the launch, you will record observations for the Post-Launch Assessment Review (PLAR).
- The team that developed the protocol will observe the launch team and record observations in a data table for the PLAR. The observing team may not intervene or communicate with the launch team during the launch. The PLAR is a summary of recommendations for improving the launch protocol, including missing steps or other key elements.
- If time allows, teams can cycle through more iterations of developing and testing the launch protocol to make improvements.

Present Findings

- Debriefing: Your team will submit a final presentation to the Launch Director (educator), including
  - An overview of the investigation
  - The PLAR
  - What you learned from the process
  - One thing you would do if there were more time

Launch It: Launch Console Roles and Responsibilities

Name of Console	Examples of People and Expertise for This Role	Description of Launch Team Role
Launch Director	Charlie Blackwell-Thompson https://www.nasa.gov/centers/kennedy/about/biographies/blackwell-thompson.html	The launch director leads the launch control team at NASA's Kennedy Space Center in Florida and is responsible for overseeing the countdown and liftoff of the Space Launch System (SLS) rocket and Orion spacecraft for NASA's Artemis I mission. On launch day, the launch director and launch team will review the launch commit criteria—about 490 different items—to ensure all ground and flight systems are in a safe configuration for launch. Next, the team will monitor the health of the rocket while it is being loaded with propellant—a combination of super-cold liquid hydrogen and liquid oxygen. Once fueling is complete, the launch director will oversee the terminal countdown, culminating with the "go" for launch. After the command is given to fire the solid rocket boosters and SLS blasts off from Kennedy's Launch Pad 39B, control of the mission transfers from the launch control team to the mission control team at NASA's Johnson Space Center in Houston.
Assistant Launch Director	Jeremy Graeber https://www.nasa.gov/centers/kennedy/about/biographies/graeber.html	The assistant launch director is responsible for assisting the launch director in the execution of the launch countdown. They are also responsible for planning and executing test operations to validate the ground systems at Kennedy. This includes overseeing testing of flight and ground systems for SLS and Orion and monitoring launch and recovery operations.
Technical Assistant to Launch Director	Wes Mosedale https://www.nasa.gov/centers/kennedy/about/biographies/mosedale.html	The technical assistant to the launch director helps the launch director with the technical coordination of launch-related content for the SLS rocket and Orion spacecraft and the integration of launch-related requirements.
Weather	Meteorologists, Launch Weather Officer, and Weather Technicians	These weather specialists monitor weather conditions to ensure safe launch using Kennedy's Meteorological Interactive Data Display System (MIDDS). MIDDS integrates diverse weather data on a single display, including weather radar and lightning strikes. This data helps forecasters determine if weather and lightning avoidance criteria are met and helps the team make decisions about launch.
NASA Test Director	Jeff Spaulding and Danny Zeno https://www.nasa.gov/feature/nasa-test-directors-eagerly-await-artemis-launch	NASA test directors (NTDs) oversee flight and ground hardware testing at Kennedy's Launch Control Center (LCC) from Firing Rooms 1 and 2, where activities involved with preparing SLS and Orion for flight can be controlled from computer terminals. They are responsible for emergency management actions, helping lead the launch team during all facets of testing, launch, and recovery. Some specific tasks include verifying that the flight and ground systems are working as expected when SLS is in a launch configuration; ensuring the mobile launcher's umbilicals—giant swing arms that provide power, communications, and propellants to the rocket—are operational; and rehearsing launch countdown operations with the integrated rocket and spacecraft inside the Vehicle Assembly Building and at the launch pad. At the end of the mission, part of the NTD team will lead recovery efforts aboard a Navy vessel after Orion splashdown.

Name of Console	Examples of People and Expertise for This Role	Description of Launch Team Role
Orion Test Conductor	Medical Doctors, Surgeons, Biomedical Engineers, and Emergency Medical Staff	The Orion test conductor oversees testing of the Orion spacecraft and those operations involved with powering up and powering down the capsule. When there is crew in the capsule: Kennedy's physician, crew surgeon, and biomedical engineer maintain current medical data on each crew member in the event baseline data is needed in an emergency. This team is responsible for medical advice for such a contingency. In addition to monitoring the astronauts' vital signs, they are also responsible for emergency procedures for astronauts exiting the Orion spacecraft and emergency crews responding onsite. The Operational Bioinstrumentation System console displays an electrocardiograph, or heart monitor, of two designated flight crewmembers. It also shows each astronaut's pulse, respiration, oxygen level, blood pressure, and temperature.
SLS Test Conductor	Tracy Parks and Roberta Wyrick https://www.nasa.gov/feature/woman-power-equals-rocket-power-for-artemis-moon-missions	The SLS test conductor oversees all tests involving the SLS core stage, interim cryogenic propulsion stage, and twin solid rocket boosters. Essentially, the test conductor acts as the interface between the flight systems and the launch vehicle by directing system engineers to start a command, such as the call to begin cryogenic loading, or fueling the SLS rocket with super-cold propellants. The test conductor is responsible for writing the procedures for directing those commands, as well as monitoring whether the command given results in an error. Because Artemis I is an uncrewed flight, the SLS test conductor is the prime test conductor. Once crew is onboard, the Orion test conductor becomes the prime.
Ground Test Conductor	https://www.flickr.com/photos/nasakennedy/52352706351/in/album-72157649473620280/	The ground test conductor oversees testing of the ground systems and launch infrastructure in place for Artemis I. This includes tests involving the mobile launcher and its umbilicals, as well as the crew access arm—a walkway connected to the mobile launcher that provides access to Orion's crew module. The ground test conductor also oversees simulations in the LCC to verify that the software linking launch team operators and system engineers to the rocket and spacecraft performs accurately.
Launch Project Engineer	Philip Weber https://www.nasa.gov/centers/kennedy/about/biographies/weber.html	Launch project engineers are the senior-most technical people sitting on console in the firing room. For the Artemis I launch, there will be a primary and backup launch project engineer—a model carried over from the Space Shuttle Program. If an anomaly were to occur during the launch countdown, such as a measurement showing an unsafe range to launch, it is the lead launch project engineer's responsibility to work with the system engineers to troubleshoot and provide a go/no-go launch recommendation to the NTD and launch director for the final call.

Activity Four: Recover It

Navy divers attach lines to a mock Orion capsule during a recovery test. (NASA/Frank Michaux)

Educator Notes

Learning Objectives

Students will

- Develop a list of questions to find a "crew module" on a gridded "ocean."
- Refine their questions through testing.
- Convert their refined questions into a flowchart, decision tree, or pseudocode.

Investigation Overview

Acting in the role of NASA's recovery team, students will work in small teams to find the crew module on the opposing team's 10 x 10 grid, using the fewest number of yes-or-no questions possible. After exploring different sets of questions on various grids, teams will develop an algorithm for finding a capsule on any given grid.

Suggested Pacing

60 to 120 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-ETS 1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • MS-ETS1-3: 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(s) works and which can be empirically tested. • Constructing Explanations and Designing Solutions: The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints. • 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.	*Science and Engineering Practices* (*continued*) • Engaging in Argument From Evidence: Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. • Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. • Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. • Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. *Nature of Science* • Scientific knowledge is open to revision in light of new evidence.

Technology (ISTE and CSTA)	
ISTE Standards for Students • Computational Thinker (1.5a): Students formulate problem definitions suited for technology-assisted methods such as data analysis, abstract models, and algorithmic thinking in exploring and finding solutions.	Computer Science Teachers Association (CSTA) Standards • 2-AP-10: Use flowcharts and/or pseudocode to address complex problems as algorithms.

Mathematics (CCSS)
Mathematical Content • 5.G.A.1: Graph points on the coordinate plane to solve real-world and mathematical problems. • 6.NS.C.8: Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.

Investigation Preparation

- Read the introduction, background information, and the Educator Notes.
- Print out at least one copy per team of the Ocean Map Handout, Search Pattern Handout, and Yes/No Game Handout.
  - Optionally, laminate the Ocean Map Handout so that it can be reused multiple times with a dry erase marker.
  - Optionally, cut out or make the Search Pattern Handout tokens in advance to save instructional time.
- Optional: Print out or otherwise share with students the examples of a decision tree, flowchart, and pseudocode from the background section (Documenting Algorithms).
- Put students into teams of two to three. This activity includes significant teamwork components. Consider allowing students with social challenges to work individually.

Materials

- ☐ Student Handouts
- ☐ Ocean Map Handout
- ☐ Search Pattern Handout with tokens (alternatively, two-color counters, bottle caps, or other physical tokens)
- ☐ Writing utensils for marking the ocean map
- ☐ Scissors for cutting out tokens
- ☐ Blank paper for flowcharts, decision trees, and pseudocode
- ☐ Flowchart handouts (optional)
- ☐ Trifold poster board or another way to separate an algorithm reader from the algorithm follower (optional)

Safety

No special safety preparations are needed beyond typical crafting safety, such as safe scissor use.

Introduce the Investigation

- Pretend to have lost something important, such as a house key. Ask students for ideas on how best to find it. Try to elicit answers about narrowing down the possible areas, organizing your search, eliminating possibilities, and so forth.
- After the initial discussion, explain that NASA must sometimes find important things as well.

Facilitate the Investigation

Meet the Problem

- Have students watch the Orion Recovery Team video. https://www.youtube.com/watch?v=kJDwlC2PrAw
- Pass out the Ocean Map Handout as well as tokens or counters. Explain that while technology makes it possible for NASA to predict the location where Orion will splash down with great accuracy, this activity is based on an imaginary scenario where those systems have malfunctioned. Orion has splashed down somewhere in a 10- by 10-km area of the Pacific Ocean, and NASA is racing against time to rescue the crew and recover the capsule. (Keep in mind that distances in the real world would be much larger.)

Explore Knowns and Unknowns

- Have students work individually to complete the Search Pattern activity.
  - As appropriate, provide students with additional details on search patterns from the background information at the beginning of this module (Recovery Team section) to help guide their thinking.
  - Discuss the strengths and weaknesses of searching this way. Try to guide students to realize that it would be helpful to be able to eliminate more than one square at a time.
  - If the idea of developing a method for searching the ocean is too abstract for some students, they may benefit from considering how to find a lost household item (such as keys) in a room.
  - If time is limited, students can test patterns only once instead of three times.

Generate Possible Solutions

- Based on the exploratory activity, each individual should develop a decision tree, flowchart, or pseudocode to efficiently find the capsule in a patch of ocean. Some students, particularly younger ones, may struggle with a flowchart, decision tree, or pseudocode. Consider using one of the following options:
  - As a lead-in activity, have students practice making a flowchart, decision tree, or pseudocode for a common everyday activity, such as making a sandwich, tying shoes, or getting ready for school in the morning.
  - Instead of using a flowchart, decision tree, or pseudocode, allow students to depict their patterns visually, with arrows drawn directly on the Ocean Map. It is important to emphasize that students need to develop a structured, reusable pattern rather than a haphazard or random pattern.
  - As appropriate, provide students with additional details on documenting algorithms from the background information at the beginning of this module (Documenting Algorithms section) to help guide their work.

Consider Consequences

- Once all students have created their own decision tree, flowchart, or pseudocode, have them swap algorithms with one of their team members. Explain that they will attempt to follow the algorithm and then provide feedback to the original author.
  - Consider preapproving algorithms before the swap to ensure the directions are safe.
  - Provide some examples of constructive feedback versus unhelpful feedback.
- After they have followed the algorithm, have students provide feedback by answering these questions:
  - Were you able to find the capsule by following the algorithm?
  - What was one strength of the algorithm?
  - What is one way to improve the algorithm?
  - How is your algorithm similar to or different than your teammate's?
- Optionally, after reviewing individual algorithms, have students take the best elements of each to collaboratively make an algorithm for the team.

Present Findings

- Have each team briefly present their algorithm to the other teams.
- Have the whole group discuss common features, strengths, and weaknesses across all team algorithms.
- As an alternative, students can individually write a self-reflection recognizing their own successes and areas for improvement.
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Define a scale for the grid on the Ocean Map Handout, such as 1 cm on paper representing 1 km in real life. Have students use a ruler and a protractor to perform triangulation and trilateration from three corners of the map to find the position of the module.

Share With Students

Brain Booster

Decision trees, flowcharts, and pseudocode are often used as a starting point to do computer programming. NASA has lots of coding activities for beginners to take your algorithm design skills to the next level.

Learn more: https://www.jpl.nasa.gov/edu/learn/tag/search/Coding

On Location

NASA partners with the U.S. Navy to practice recovering Orion and its crew after splashdown. Shown here is the USS Anchorage leaving its home port at the Naval Base San Diego on its way to practice recovering an Orion crew module. The USS Anchorage is equipped with an amphibious transport dock that can carry Orion and is crewed with specially trained divers who will secure Orion for recovery.

Learn more: https://www.defense.gov/News/News-Stories/Article/Article/1418131/uss-anchorage-participates-in-nasas-orion-mission-test/

- The NASA Tournament Lab (NTL) regularly posts challenges and competitions. These sometimes include designing algorithms, especially in the Information Technology category.
  - Find the latest open challenges: https://www.nasa.gov/offices/coeci/challenges/open
  - Watch a video on how NASA crowdsources algorithms: https://www.youtube.com/watch?v=ZRd4PExbkB4
- NASA's 2020 App Development Challenge involved programming a pathfinding algorithm to explore the Moon's surface.
  - Kickoff video: https://www.youtube.com/watch?v=PZ1F7QAcheQ
  - Activity website: https://www.nasa.gov/stem/nextgenstem/moon/adc_guide_and_coding_components_fy20.html

References

Orion Recovery Operations. https://www.nasa.gov/sites/default/files/files/orion-recovery.pdf

Searching With Sasquatch: Recovering Orion. https://www.nasa.gov/feature/searching-with-sasquatch-recovering-orion

Resources

NASA Tests Crew Recovery for Orion. https://www.youtube.com/watch?v=ZbApD6niDiA

NASA Rescue and Recovery. https://www.nasa.gov/subject/5338/rescue-and-recovery/

Navy Divers Recover NASA Orion Crew Module. https://www.youtube.com/watch?v=GHZmi256dJc

Houston We Have a Podcast, Episode 210: Artemis I Recovery Director Melissa Jones. https://www.nasa.gov/johnson/HWHAP/artemis-recovery

Activity Four: Recover It

Student Handout

Your Investigation

While technology makes it possible for NASA to predict the location where Orion will splash down with great accuracy, any system can malfunction. For this activity, you will take on the role of someone on NASA's recovery team. You are racing against time to rescue the crew of the Orion spacecraft, who have splashed down somewhere in the Pacific Ocean.

Meet the Problem

- NASA has narrowed down the possible locations of the Orion spacecraft to a 10- by 10-km area, represented by the grid on the Ocean Map Handout.
- Tokens represent the Orion spacecraft, the rescue vessel, and (for some activities) islands or other obstacles.
- Unless stated otherwise, the rescue vessel can only search the square that it is in and can only search one square at a time.

Explore Knowns and Unknowns

- Follow the instructions on the Search Patterns Handout. These instructions will guide you through the process of developing and testing a search pattern

Generate Possible Solutions

- ***By yourself***, develop a decision tree, flowchart, or pseudocode to efficiently find the Orion capsule in a patch of ocean.

Consider Consequences

- ***With your team***, swap search pattern algorithms. Follow them as safely and exactly as possible. Then provide the following feedback:
  - Were you able to find the capsule by following the algorithm?
  - What was one strength of the algorithm?
  - What is one way to improve the algorithm?
  - How is your algorithm similar to or different than your teammate's?

Present Findings

- ***With everyone***, share team algorithms.
  - What do most of the algorithms have in common?
  - What is unique or unusual?
  - What other activities might a flowchart, decision tree, or pseudocode help you do more efficiently?

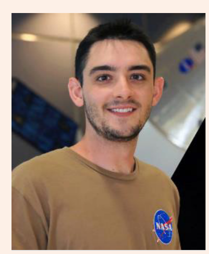
Fun Fact

One piece of software NASA uses to predict where Orion will splash down is called Sasquatch because the "footprint" of possible locations is so big.

Learn more: https://www.nasa.gov/feature/searching-with-sasquatch-recovering-orion

Career Corner

Taylor Hose, a flight vehicle processing technician, is one of just three people on the ground systems team who are certified as Orion hatch operators. He has been assigned to NASA's Exploration Ground Systems Landing and Recovery Team, which will recover the Orion spacecraft (and crew, in later missions) from the Pacific Ocean after splashdown. Taylor holds two degrees: a bachelor of science in multidisciplinary studies from West Virginia University and a master of science in space studies with a concentration in astronomy from American Public University.



Learn more: https://www.nasa.gov/feature/i-am-artemis-taylor-hose

Search Patterns Handout

- If you had exactly one ship that could only search the square it is in, describe a path your rescue vessel could take to ensure it visits every square. Make sure to include a starting point and an explanation of how the ship would move.
- Describe a second, different path your rescue vessel could take to ensure it visits every square.
- Place the spaceship capsule token at a random place on the ocean. Record its row and column in a table, such as the example provided below. Then, follow each of the two search patterns you described. For each of the two search patterns, count the number of squares the ship travels before it finds the capsule, then record those numbers in a table.

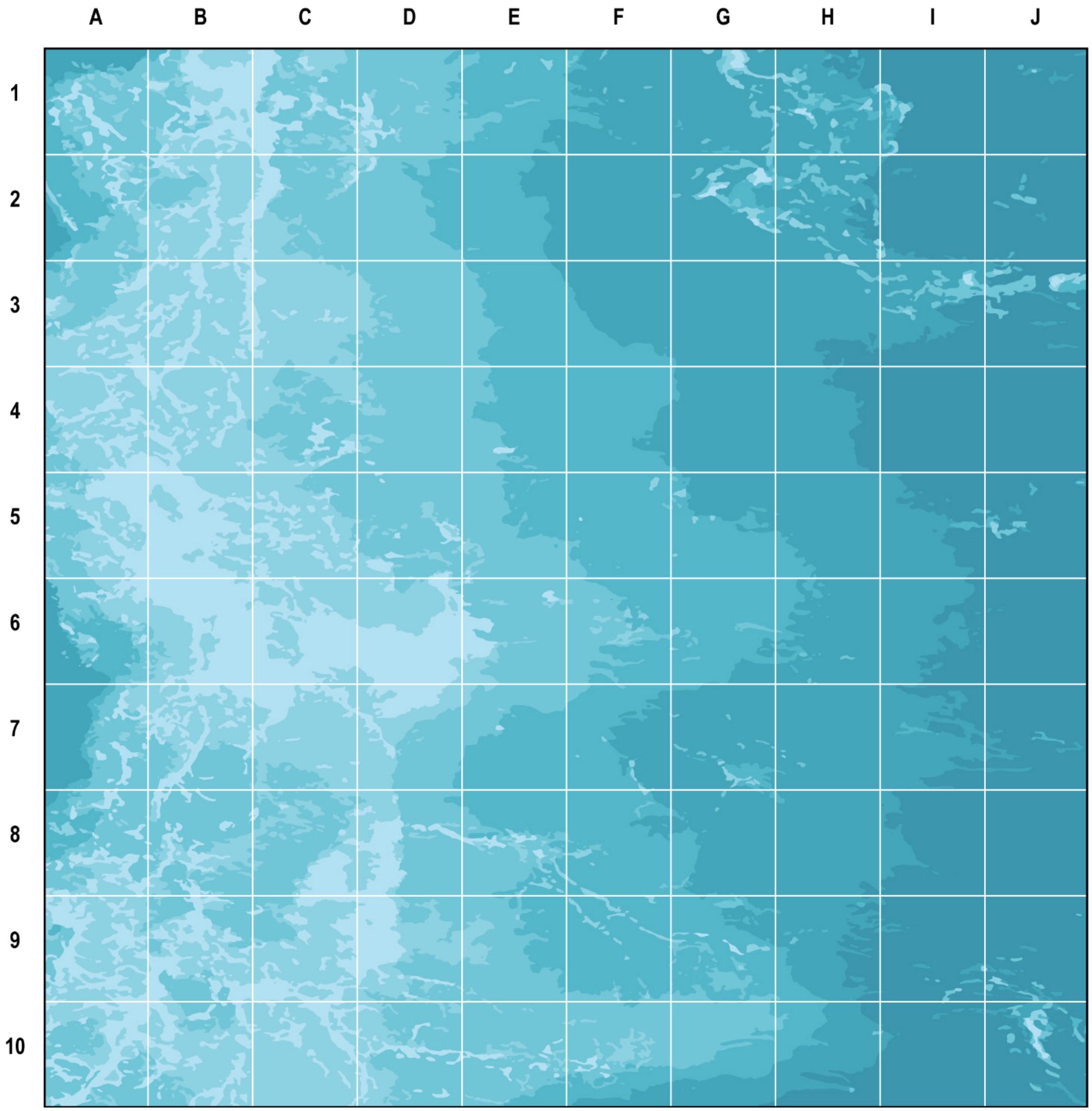
Row of capsule	Column of capsule	How many squares did it take for Search Pattern 1 to find the capsule?	How many squares did it take for Search Pattern 2 to find the capsule?

- Which search pattern seems to be more efficient? Why? Does the location of a capsule make a difference? If so, how?
- ***With your team***, discuss each person's search patterns, specifically:
  - What is one strength of the pattern?
  - What is one specific change that could be made to improve the pattern?
- Randomly place three island tokens on the ocean map. Pick one of your existing search patterns to try out. Test it three times in the same way as before. Then, compare the results of the new scenario (three islands) with the results of the original scenario (no islands). Now that you have seen what happens with islands in the way, revise your search pattern to better handle the islands. Test the revised pattern three times.

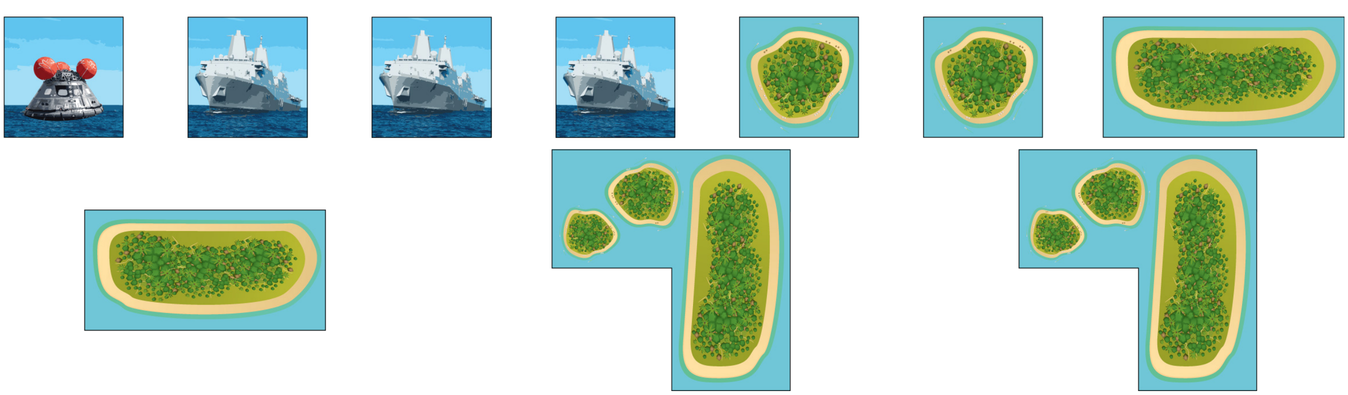
Row of capsule	Column of capsule	How many squares did it take for the original Search Pattern to find the capsule?	How many squares did it take for the revised Search Pattern to find the capsule?

- Did the revised search pattern work better than the original? Why?
- If you still have time, consider these other situations:
  - What if searchers on your rescue ship had binoculars so they could see more than one square at a time?
  - What if the area of ocean to be searched was a much larger size (such as 100 x 100 km)?
  - What if you had three rescue ships instead of one?

Ocean Map Handout With Tokens



Tokens



Appendix A.—Rubric for Engineering Design Process

Engineering Design Process 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 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 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 results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with the group	
				Total	

Appendix B.—Rubric for Problem-Based Learning

Problem Based Learning 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 results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with others	
				Total	

Appendix C.—Glossary of Key Terms

Algorithm. A series of steps or directions meant to be followed exactly, often repeatedly.

Decision tree. A way of illustrating an algorithm using boxes and arrows, where each box represents a yes-or-no question, and each arrow represents an answer.

Flowchart. A way of illustrating an algorithm using a variety of shapes and arrows. Each shape represents something different, such as boxes representing actions and diamonds representing questions or decisions.

Payload. The things carried by a vehicle to a destination (e.g., cargo, a satellite, or extra oxygen for the ISS).

Protocol. A plan for a scientific experiment or a set of instructions. Protocols establish clear rules or steps that attempt to meet a goal. Protocols can be either straightforward (e.g., step 1, step 2, step 3) or complex (e.g., if this happens, do A; otherwise, do B).

Pseudocode. A way of illustrating an algorithm using words meant to closely resemble computer code without using a computer language.

Rocket Stage. One of two or more sections of a rocket that is designed to separate midflight, with each section having its own fuel and engine.

Triangulation. A way of finding something by determining its direction from three known locations.

Trilateration. A way of finding something by determining its distance from three known locations.

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