National Aeronautics and
Space Administration

Engineering Design Challenge

Facilitation Guide

Grades 6–8

Powered and Pumped Up

Above: NASA's Glenn Research Center in Cleveland, Ohio, is 1 of 10 NASA centers. Serving as an essential component of NASA and an integral contributor to the region, Glenn Research Center investigates, designs, develops, and tests innovative technology for aeronautics and space flight.

"The most important thing we can do *is* ***inspire young minds*** *and to advance the kind of science, math and technology education that will help youngsters take us to the next phase of space travel."*

John H. Glenn, Jr., 1921–2016
NASA Astronaut and United States Senator

NASA: Why We Explore

Humanity's interest in the heavens has been universal and enduring. Humans are driven to explore the unknown, discover new worlds, push the boundaries of our scientific and technical limits, and then push further.

Human space exploration helps address fundamental questions about our place in the universe and the history of our solar system. Through addressing the challenges related to human space exploration, we expand technology, create new industries, and help foster peaceful connections with other nations. Curiosity and exploration are vital to the human spirit. Accepting the challenge of going deeper into space will invite the citizens of the world today and the generations of tomorrow to join NASA on this exciting journey.

The United States is a world leader in the pursuit of new frontiers, discoveries, and knowledge. The National Aeronautics and Space Administration, more commonly known as NASA, performs a unique role in America's leadership in space. NASA has landed people on the Moon, sent spacecraft to the Sun and every planet in the solar system, and launched robotic explorers to travel beyond the solar system. NASA's vision is to reach for new heights and reveal the unknown for the benefit of humankind.

NASA was formed in 1958 and has amassed a rich history of unique scientific and technological achievements in human space flight. From John Glenn's 1962 orbit around the Earth in Mercury Friendship 7, through the Apollo missions and the space shuttle years, to today's orbiting International Space Station (ISS), NASA is on the forefront of manned space flight.

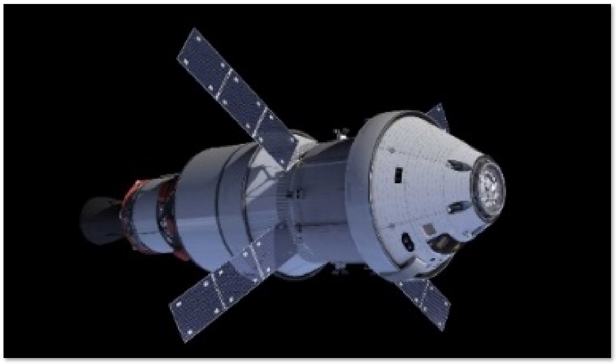

Figure 1. Illustration of the Orion Spacecraft, a multi-purpose crew vehicle designed to carry astronauts into deep space. (NASA)

NASA is leading the next steps into deep space near the Moon, where astronauts will build and begin testing the systems needed for challenging missions to deep space destinations, including Mars. This area of space near the Moon offers a true deep space environment to gain experience for human missions that push farther into the solar system, yet astronauts will be close enough to access the lunar surface for robotic missions and, if needed, return to Earth in days rather than weeks or months.

NASA's future success and global leadership will be determined largely by the investments and innovations we make today in scientific research, technology, and our workforce. NASA's focus has always been, and always will be, to discover, invent, and demonstrate new technologies, tools, and techniques that will allow our Nation to explore space while improving life on Earth.

Career Connection

What is an engineer? An **engineer** is a person who works on a team to solve a problem that humans want to solve or make better. Engineers are at the heart of every engineering challenge. Engineers design and build things we use every day. The NASA for Kids video "Intro to Engineering" explains the role of an engineer and can be shared with your students: http://youtu.be/wE-z_TJyzil. After viewing the video, have students discuss what they learned about what an engineer does.

Figure 2. Aerospace Engineer Chris Randall tests rocket parts and life support systems to ensure they work as planned. (NASA)

Some examples of NASA-engineered products include the following:

Figure 3. Simulation System Engineer Debbie Martinez works on developing general aviation flight simulation software. (NASA)

- Portable x-ray machines: NASA engineers worked to create a small, low-radiation x-ray machine so medical professionals can examine people's injuries at accident scenes.
- Infrared ear thermometers: NASA engineers developed infrared temperature sensors for space missions, and these sensors were adapted to create a faster and easier way to take someone's body temperature.
- Food processing control: NASA engineers worked with food production companies to create a process to identify the critical points where food could be contaminated.
- Airplanes: NASA engineers work with private companies to design and develop aircraft that are safer, quieter, lighter, more fuel efficient, and more reliable.

Engineers help to improve society. Women and men of all races, ethnicities, and walks of life can become engineers. Encourage students to explore NASA engineer career profiles at https://www.nasa.gov/audience/forstudents/careers/profiles/index.html

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Introduction to the Engineering Design Challenge

Figure 4. Artist's rendering of the Space Launch System. (NASA)

Facilitator's Overview

NASA has created an **engineering design challenge (EDC)** that involves students in using the **engineering design process (EDP)** to develop solutions to authentic NASA mission-centered challenges.

The EDC serves as an authentic, standards-driven investigation that allows students to engage in the process of answering questions and solving problems like today's scientists and engineers do. This EDC provides students with opportunities to gain tangible skills that are essential in science, technology, engineering, and mathematics (STEM) careers. This guide is organized into three sections:

1. **Introductory Materials** establish a basic level of understanding about the EDP and the EDC and provide tools to support students through the challenge.
2. **Facilitator Instructions** provide instructions for facilitators to use throughout the design challenge and include tools to assess student understanding throughout each step.
3. **Student Team Challenge Journal** contains prompts and tools to guide students through the cycle of steps in the EDP while documenting their work for each step. It is suggested that each student have a copy of this journal.

For more information, visit the NASA Glenn Research Center EDC website at https://www.nasa.gov/glenn-engineering-design-challenges

What is the Engineering Design Process?

The EDP is a systematic practice for solving problems. Engineers work through the process to solve problems and create new technologies and systems that enhance our lives. All EDP models begin by identifying a need or problem, but there is no defined or fixed path toward the end goal. The EDP model allows problem solvers the flexibility to move between steps as appropriate for the challenge faced.

What is an Engineering Design Challenge?

The EDC is a learner-centered instructional approach that organizes learning around a shared goal or challenge. Students are presented with a challenge or problem and, using the EDP, work in teams to complete activities and experiments to develop solutions toward solving that problem. These challenges facilitate teamwork and engage students in problem-solving practices used by real-world engineers.

Engineering Design Process

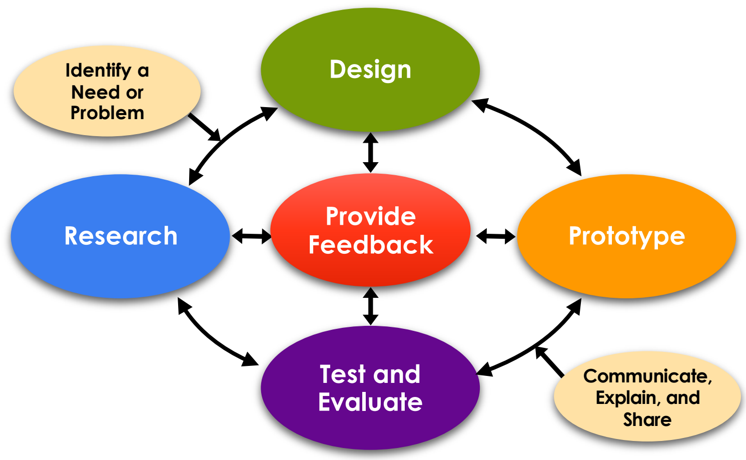


Figure 5. Engineering design process model (model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf).

Identify a Need or Problem. Engineering design begins by identifying a need or problem to be solved, improved, and/or fixed. This typically includes articulation of criteria and constraints that will define a successful solution.

Research. Constructive investigation is performed to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and it can be an ongoing part of design.

Design. All gathered information is used to inform the creation of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. A prototype is constructed based on the design model(s) and is used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

Test and Evaluate. The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype's performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, redesigning, and refining the need or problem.

Provide Feedback. Oral or written feedback provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to convey how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Communication of explanations must be clear and analytical.

Engineering Design Challenge: Powered and Pumped Up

NASA is currently working on systems to land crewed missions far from Earth. For these missions to be successful, in situ (in-place) resources will need to be collected and used wherever possible. By using natural resources that are already at the destination, spacecraft could carry less weight, use less fuel, and be more cost effective.

Figure 6. Technicians work on NASA's InSight lander during a solar array deployment test. The lander will use solar power to operate its science equipment on the surface of Mars. (NASA/JPL-Caltech/Lockheed Martin)

Since past space missions have sent back data confirming that water is present in Martian soil, NASA plans to send a robotic system to Mars ahead of humans. Astronauts will need enough water for drinking, washing, and growing food to eat for long periods of time. Research is currently being conducted to create a reliable and efficient system to harvest these resources so they are ready for when humans arrive. Such a system could use solar power to collect water and other resources from the soil or atmosphere and store them until humans arrive some time later.

The Challenge

Teams of students will design, build, and improve a stand-alone, solar-powered pumping system to move water as quickly as possible between two containers. Students will use light-concentrating materials, shapes, and structures to maximize the collection of simulated solar energy. The energy will then be directed toward solar cells that will power the system to move the water.

Criteria and Constraints

1. The solar cells must be at least 20 cm from the light source.
2. The entire system (not including the light source and the water) cannot have a mass of more than 750 g.
3. The system must move 200 mL of water from a storage tank to a habitat tank.
4. The water must be moved through a minimum of 50 cm of tubing.
5. The system must NOT use siphoning as a means to accelerate the movement of water.

Suggested Pacing

The following pacing guide serves to assist facilitators in planning each session. Facilitators should feel free to condense or expand the structure of these activities or add additional engineering design process (EDP) iterations to fit their specific needs. It is estimated that the entire EDP for this challenge will take between 12 and 20 hours.

Activity	Approximate Time
Facilitator Preparatory Work	2 hours
Engagement: • Access prior knowledge • Watch the introductory video • Present background information	1 hour
Exploration and Explanation:	
• Supporting Science Investigation 1: How Intense Are You?	30 minutes
• Supporting Science Investigation 2: What's the Point?	30 minutes
• Supporting Science Investigation 3: Shed Some Light	60 minutes
Elaboration:	
• Introduction to the Engineering Design Process (EDP) *The following activities represent the steps of the EDP. They may be completed in any logical order and should be repeated as often as necessary to complete the challenge.*	30 minutes
• Identify a Need or Problem	30 minutes
• Research	1 hour
• Design	1 hour
• Prototype	1 hour
• Test, Evaluate, and Redesign	2 hours
• Communicate, Explain, and Share	30 minutes
Evaluation: • Creating solution presentations • Student debriefing questions	1.5 hours

Learning Outcomes

Education Standards

The engineering standards addressed here are tailored for 6th–8th grade students based on Next Generation Science Standards. Even if your state has not adopted these standards, similar core ideas are likely found in other terms in your state's standards.

Standards Addressed

Next Generation Science Standards
Engineering Design • **MS–ETS1–1** 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** 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. • **MS–ETS1–4** 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–PS4–2** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

Connected Concepts

Common Core State Standards	
Mathematics	***English Language Arts***
• **MP.2** Reason abstractly and quantitatively. • **MP.4** Model with mathematics. • **6.RP.1** Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. • **6.RP.3** Use ratio and rate reasoning to solve real-world and mathematical problems. • **7.RP.2** Recognize and represent proportional relationships between quantities. • **7.EE.3** Solve multi-step 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.	• **RST.6–8.2** Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. • **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). • **WHST.6–8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. • **WHST.6–8.8** Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. • **WHST.6–8.9** Draw evidence from informational texts to support analysis, reflection, and research. • **SL.6–8.5** Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

Evidence of Learning

This guide uses a number of tools to indicate student progress, including the following:

- Accessing of existing knowledge and assessment of level of understanding
- Supporting Science Investigations, Data Collection Sheets, and post-investigation discussions
- Sample guiding questions to assist in facilitating discussions
- A final assessment, including creation of a video or slide presentation explaining the iterative design process, challenges encountered, and how decisions were made based upon the concepts learned

Student Team Challenge Journal

The engineering design process (EDP) that each team uses will vary from team to team. Prior to starting the engineering design challenge, print and assemble enough copies of the Student Team Challenge Journal into three-ring or loose-leaf binders so that each student receives a complete journal. Included in the journal are the EDP practices students will use to record their progress. Print extra copies of these EDP sheets and make them available for students. Students will select the appropriate sheets as they move through the process. Instruct students to work page-by-page through their journals, documenting the challenges they faced and the steps they took. This documentation will help students prepare their final presentations.

Solution Presentation Criteria

Student teams should use the Student Presentation Rubric to guide them as they work through the challenge. The Student Presentation Organizer and the Team Progress Chart are tools students can use to help them create a final product that clearly communicates the team progress through the engineering design challenge.

Once the video or slide presentation is complete, submit according to the guidelines on the Glenn engineering design challenge website: https://www.nasa.gov/glenn-engineering-design-challenges

Student Presentation Rubric

This rubric can be used to review and assess the quality of each final presentation. Each category will be scored from 0 to 3 points. Totals for each column will be added for a final score.

Team name: ______________________________ **Total score:** ______________________________

Engineering Design Process	Exemplary = 3	Proficient = 2	Novice = 1	Not Included = 0
We can **identify** the challenge and the criteria.	Challenge was restated and all criteria and constraints were described.	Challenge was restated with only the challenge criteria.	Only the challenge story was stated.	Team did not include a description of the challenge or the criteria.
We can discuss the results of our **research,** the Supporting Science Investigations, and connections with a NASA scientist or engineer.	Three or more facts relating to the challenge were discussed.	Two facts relating to the challenge were discussed.	One fact relating to the challenge was discussed.	No facts relating to the challenge were discussed.
Each of our team members sketched an original **design** that demonstrated the challenge criteria and constraints.	All criteria and constraints were represented (sketches and photos) in each team member's design.	Two criteria were represented (sketches and photos) in each team member's design.	One criterion was represented (sketches and photos) in each team member's design.	No criteria were represented.
Our final team **design** represented elements from each team member's original design.	Team design included the best from each member's design to represent the challenge and the criteria.	Team design included ideas from two team members' designs to represent the challenge and the criteria.	Team design included ideas from one team member's design to represent the challenge and the criteria.	Team was not able to provide a design to represent the challenge and the criteria.
Our team constructed a **prototype** to represent the challenge criteria and constraints.	A prototype was completed that met all of the challenge criteria and constraints.	A prototype was completed that met only two of the challenge criteria and constraints.	A prototype was completed that met only one of the challenge criteria and constraints.	A prototype was completed that did not meet the challenge criteria or constraints.
Our team collected and recorded data to **test and evaluate** our model's solutions.	Data were collected by testing to represent all of the criteria and constraints.	Data were collected by testing to represent only two criteria.	Data were collected by testing to represent only one criterion.	No data were collected and/or no testing was completed.
Our team was able to explain our design, gather **feedback,** and explain how we solved the challenge.	Difficult issues were explained and their solutions described.	Difficult issues were explained with no solutions offered.	Discussion of difficult issues was unclear and no solutions were presented.	No discussion of difficult issues was included.
Our team made **design** improvements after testing the prototype.	All improvements to the prototype were described.	Two improvements to the prototype were described.	One improvement to the prototype was described.	No improvements to the prototype were described.
Our team followed the **presentation process** to communicate our team **design.**	All the presentation requirements and procedures were met.	Three or more of the presentation requirements and procedures were met.	One or two of the presentation requirements and procedures were met.	The presentation requirements and procedures were not met.

Facilitator Instructions

Recommended Materials

The following materials are required to complete this challenge. The quantity will depend on the number of students participating. Alternatives and additional materials can be used if desired, but be mindful of safety when allowing students to bring in or handle materials that could potentially be dangerous.

Each team will require the following items:

Figure 7. Household supplies that could be used as construction materials for the challenge.

- 2 solar cells (3 V, 70 mA) with wires
- Small submersible water pump with tubing
- Electrical tape
- 75 cm of aquarium tubing (sized to match outlet of pump)
- 2 containers that hold 400 mL (e.g., 16-oz plastic cups)
- At least 300 mL tap water
- Buckets, sponges, and other items to hold water and clean up spills
- Stopwatch
- Writing utensils
- Ruler or measuring tape
- Astronaut figure, approximately 3 cm tall
- Light source (100-W clear bulb and clamping socket, at least 1 per class)
- Scale for weighing (minimum capacity 1,000 g)
- Flashlights
- Mirrors, 6 x 6 cm (3 x 3 in.)
- Cardboard, 55 x 25 cm (22 x 10 in.)
- Foam insulator conduit
- 4-oz paper cups
- Box lid, tray, or similar item to hold the design structure (a copier-paper box lid or cafeteria tray will work well)
- Folder or three-ring binder for holding documentation
- Other general building supplies (see below)

Examples of additional materials that may be used:

- 16-oz clear drinking cups
- Cardstock
- Craft sticks, lollipop sticks, or tongue depressors
- Dowel rods (various sizes)
- Glue
- Heavy-duty aluminum foil
- Magnifying lenses
- Mirrors (various sizes)
- Manila folders
- Paper (copier, construction, and waxed)
- Paper bags
- Plastic wrap (clear and colored)
- Polystyrene cups
- Poster board
- Rubber bands
- Skewers
- Staplers and staples
- Tape (packing, duct, masking, and transparent)

Safety

Safety, an important issue for all curricular areas of education, is of special concern for STEM-based activities and courses. Many national and state academic standards address the need for schools and subject areas to promote development of student knowledge and abilities in a safe learning environment.

School administrators, teachers, and facilitators are responsible for providing a learning environment that is safe, suitable, and supportive. Facilitators are also responsible for their students' welfare in the classroom and laboratory.

Facilitators should

- Approve all drawings before students start building their designs.
- Look for flimsy structure designs and potentially hazardous combinations of materials.
- Ensure that resources are clean and dry, with no sharp edges exposed.
- Make sure all materials are undamaged and in good repair.
- Prohibit students from bringing in or using additional materials for their designs without prior approval.

Students should

- Make safety a priority during all activities.
- Wear safety goggles when conducting all investigations and the challenge.
- Demonstrate courtesy and respect for ideas expressed by others in the group.
- Use tools and equipment in a safe manner.
- Assume responsibility for their own safety and the safety of others.

Team Building

Begin by dividing students into teams of no more than four to give all students an opportunity to contribute. By working as members of a team, students develop skills such as trust, cooperation, and decision making. Working as a team member, however, can be challenging for some students. The following exercises are recommended to help teams begin to work together effectively.

Figure 8. This Apollo 11 patch depicts an eagle landing on the Moon with a view of the Earth in the background. (NASA)

Establish a team name. Many NASA teams are named based on the work they do.

Design a mission patch. Teams that work on NASA missions and spacecraft are unified under a mission patch designed with symbols and artwork to identify the group's mission.

Create a vision statement. This is a short inspirational sentence or phrase that describes the core goal of the team's work. NASA's current vision statement is "*To reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind.*"

As students begin to work together, their individual strengths will become apparent. Students can volunteer or be assigned tasks or responsibilities that are vital to completing the challenge. Team jobs can also be rotated throughout the team members to give all students an opportunity to improve their team skills. The following list includes examples of jobs that student teams will need to complete. Feel free to come up with others, and remember that all team members should serve as builders and engineers for the team.

Design engineer. Sketches, outlines, patterns, or plans the ideas the team generates

Technical engineer. Assembles, maintains, repairs, and modifies the structural components of the design

Operations engineer. Sets up and operates the prototype to complete a test

Technical writer/videographer. Records and organizes data and prepares documentation (text, pictures, and/or video) to be reported and published

NASA Mission Background

Why Solar Power?

The ability to produce power while in space is an ongoing challenge. Energy sources commonly found on Earth, such as fossil fuels and hydroelectric power, are not available on other planets or in space. One-time use batteries, such as those used in flashlights and electronic toys, have limited lifetimes and are heavy. This makes it impractical to use them as primary power sources for space missions. Another viable alternative comes from nuclear energy sources, but this engineering design challenge will focus on solar power.

The Sun emits a tremendous amount of energy, or **electromagnetic radiation**, every second of every day. The Sun emits enough energy in a single second to power every home, business, and vehicle in the world for 700 million years. Of course, only a very small fraction of the Sun's energy ever makes it to the Earth, and even less travels to the planets farther from the Sun. A lot of that energy is already used on Earth in the form of heat, or by plants using the light for photosynthesis, but a large portion remains unused and ready for capture.

How Does NASA Use Solar Power?

NASA has used solar power extensively throughout its missions. Solar power is a primary source of power for many NASA satellites, landers, and rovers as well as for the International Space Station. The constraints of space flight, primarily weight and size, demand that solar energy systems be as efficient and lightweight as possible. To achieve this, researchers at NASA are pushing the current capabilities of solar energy efficiency here on Earth by creating new materials that enhance solar energy system performance.

Twin robot geologists named "Spirit" and "Opportunity" landed on Mars in January 2004 to help us learn about the history of water on Mars. These Mars Exploration Rovers were designed to take panoramic images of the Martian landscape. Scientists look at those images and select promising geological targets that may reveal the role of water in Mars' past. Through remote control and robotic programming, the rovers drive to the selected locations to perform mechanized scientific investigations. The rovers have tools that can study a diverse collection of rocks and soils that may hold clues to past water activity on Mars. The rovers are solar powered. Energy is absorbed through solar arrays on panels that sit atop what look like the rovers' "wings." These panels were designed to maximize the area of

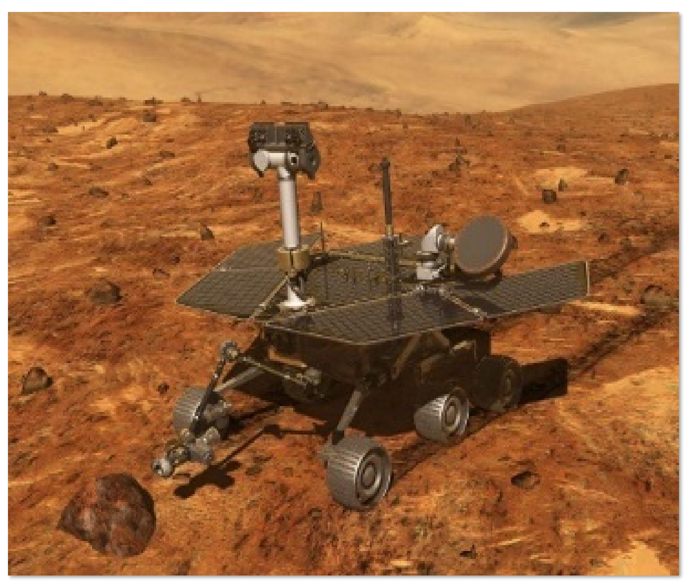


Figure 9. Artist's concept of one of the Mars Exploration Rovers conducting experiments on Mars. (NASA)

solar cells that collect the Sun's energy. The original life expectancy of these rovers was 90 days. Spirit stopped operating after 6 years, but Opportunity continues its journey and has exceeded all expectations by functioning for well over a decade.

Technologies designed by NASA for space-based applications also provide Earth-based benefits. In the last 20 years alone, solar arrays have become 50 percent more efficient, helping drive down the cost of solar energy and making it more practical to use in solar farms, on building rooftops, and in other commercial and residential applications.

How Does Solar Power Work?

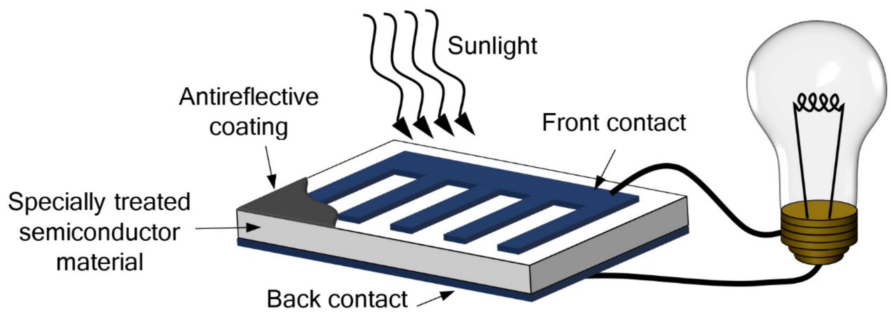


Figure 10. How a solar cell generates electricity.

The **photovoltaic cell**, or solar cell, is a specialized semiconductor that converts solar energy to electricity. A thin slice of chemically treated material, such as silicon or gallium arsenide, absorbs solar energy, causing the material to release electrons that can then flow through a connected circuit. Appliances such as light bulbs, refrigerators, and computers receive power when they are connected to this flow of electrons.

Electromagnetic Radiation and Waves

Light waves, also known as **electromagnetic radiation**, are all around us. Electromagnetic radiation is mostly invisible to the naked eye. It is produced in the form of waves of various sizes, all of which travel at the speed of light. At one end of the spectrum are low-frequency waves, including radio waves and microwaves. These large waves are easily blocked by buildings and other objects. Next are infrared waves. We cannot see infrared energy, but we can feel it in the form of heat. Visible light energy is just a very small part of the electromagnetic spectrum. As the waves increase in frequency, we move into ultraviolet energy. This form of radiation is potentially harmful to human skin and eyes. The highest frequency waves are x rays, which are used to visualize bones through skin and muscle, and gamma rays, which are used in a variety of medical treatments, including positron emission tomography (PET) scans and gamma-knife surgeries.

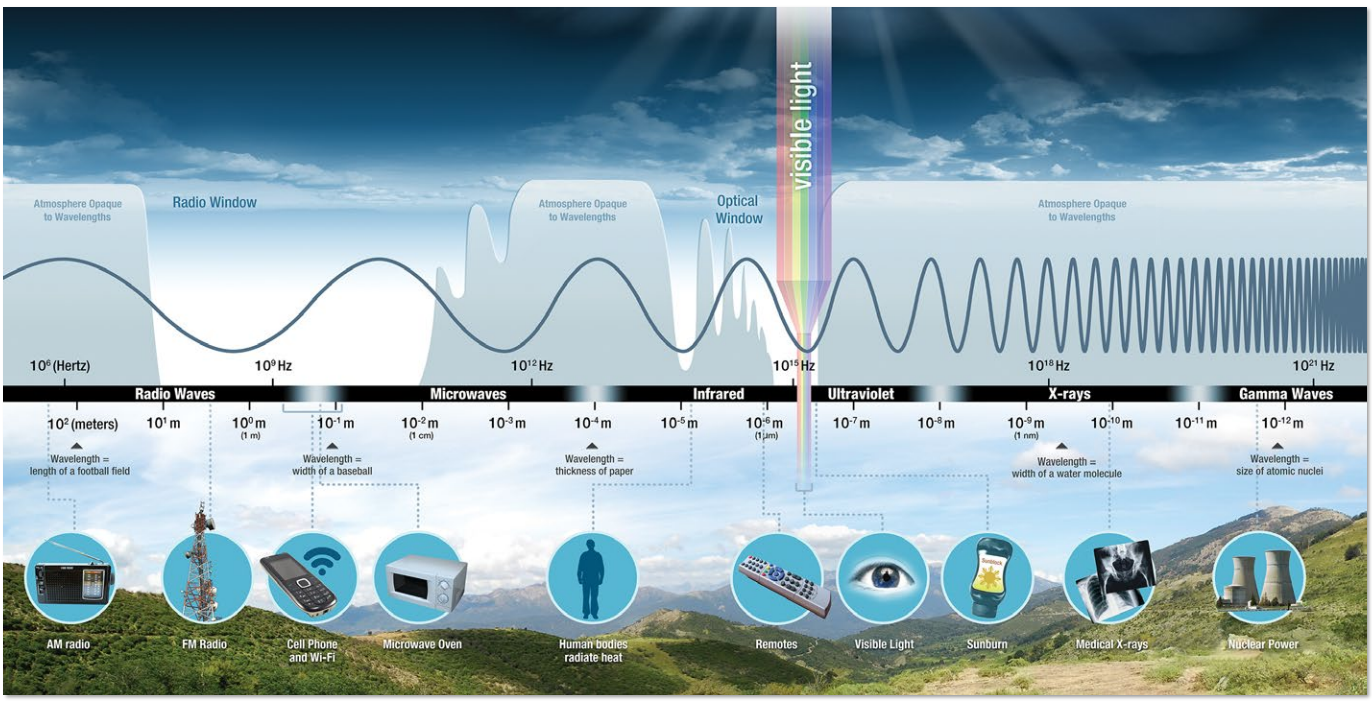


Figure 11. The electromagnetic spectrum.

Controlling Light

Light typically moves in straight lines, although it can behave differently based on the matter it encounters.

When light strikes a surface, some or all of the light can be bounced off or **reflected** (Fig. 12). In fact, the only reason humans can see is because light reflects off of everything around us and into our eyes. When it is nighttime, there is very little light to reflect off objects, so we cannot see well. We can use reflection to move light around objects or to amplify light to make things brighter. Examples include telescopes, binoculars, and microscopes. Light can also bend. The bending of light around edges or small slits is called **diffraction** (Fig. 13).

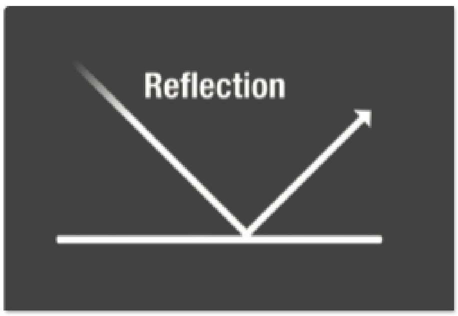


Figure 12. Reflection of a beam of light.

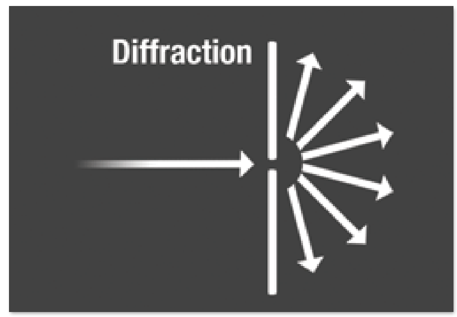


Figure 13. Diffraction of a beam of light.

Absorption (Fig. 14) is the way in which the energy of light is taken up, or stored, by an object (matter). Light that is not reflected by an object is absorbed by that object and converted into a different form of energy, usually heat. Darker colors tend to absorb light, while lighter colors reflect light. Imagine being outside on a bright sunny day. You would feel warmer wearing a black t-shirt and cooler wearing a white one.

Diffuse reflection, or **scattering** (Fig. 15), of light takes place when the surface of the object is not smooth. These rays will reflect in many different directions based on the unevenness of the object's surface.

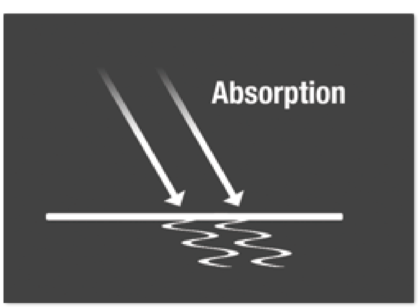


Figure 14. Absorption of light.

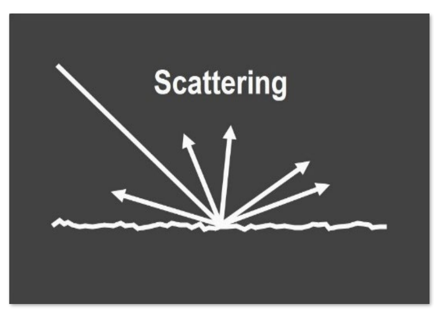


Figure 15. Scattering of light on a rough surface.

Refraction (Fig. 16) is the change in direction of a light or energy wave caused by a change in the wave's speed as it passes from one medium (such as air) into another with a different density (such as water).

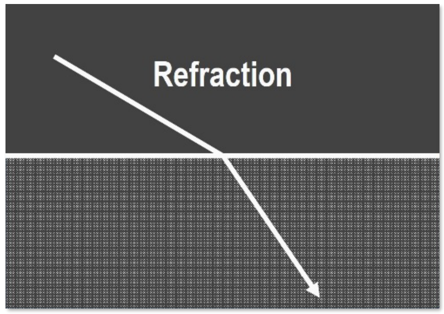


Figure 16. Refraction of light through materials of different density.

Lenses

Lenses can also be used to manipulate light (Fig. 17). A simple **lens** is a piece of glass or plastic having two polished surfaces that form part of a sphere or ball. One of the surfaces must be curved; the other surface may be curved or flat. Lenses that are thinner in the center than the edge are called **diverging** lenses. Lenses that are thicker in the center than on the edge are called **converging** lenses. Lenses can diffuse light to disperse it or gather light to concentrate it.

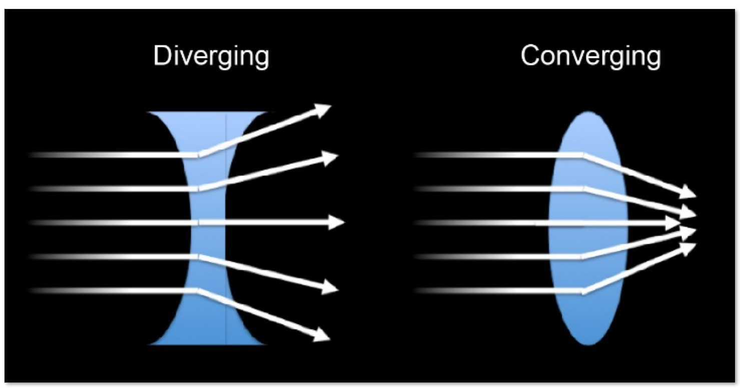


Figure 17. Diverging and converging lenses refract light.

Microscopes use lenses to capture and spread out light coming from a small object. This makes it appear as if the light is reflecting off a larger object and forms an image your eye is able to see. Telescopes focus a relatively small amount of dispersed light from a distant planet or star to a concentrated point that your eye can detect.

For more information, visit

- https://www.grc.nasa.gov/WWW/portal/apps/pv/tablet/index.html
- https://www.grc.nasa.gov/WWW/portal/apps/pv/tablet/data/Photovoltaics_FactSheet_rev508.pdf
- http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

Engagement: Accessing Existing Knowledge

Prior to starting the engineering design challenge, it will be useful to identify students' existing knowledge and level of understanding using a series of guided questions related to this specific challenge. This discussion will allow facilitators to tailor the challenge and the Supporting Science Investigations to the group, maximizing the educational benefit.

The following questions provide a starting point from which additional topics may be discussed.

- How can we use the Sun as energy?
- How will humans be able to live on other planets?
- Where in your everyday life do you see forms of alternative energy in use?
- What do you use that is solar powered?
- What do microscopes and telescopes have in common?
- Where can we observe pumping systems in use?

STEM Vocabulary

Engineering design challenges and the engineering design process (EDP) are concepts that may be unfamiliar to your students. Younger students in particular may not have heard words like "criteria" or "constraints," which are commonly associated with engineering design.

A list of related STEM vocabulary words is included in this guide. If practical or appropriate, a vocabulary wall can be created to assist in familiarizing students with these words.

Student Team Challenge Journal

Before moving on to the Supporting Science Investigations, provide students with the Student Team Challenge Journal. Additional sheets should be made available as students work through the challenge. Where possible, engage students by relating the information to their everyday lives.

Exploration: Supporting Science Investigations

The following pages contain three Supporting Science Investigations to help with students' understanding of the background material. Ideally, students will perform all three investigations, but facilitators should ensure that at least one of these investigations is completed prior to commencing the engineering design challenge. These investigations will explore the primary concepts used during the challenge.

Figure 18. Vacuum Chamber 5 (VF–5) at NASA's Glenn Research Center provides an environment that simulates space-like conditions. VF–5 has been used to test electric propulsion systems and power systems for in situ resource utilization.

This section includes the following Supporting Science Investigations and their respective concepts:

- Investigation 1: How Intense Are You?
  - Light is a form of wave energy.
  - Light waves will become dispersed as they travel over a distance.
  - The amount of dispersion varies depending on the angle at which the light reaches a surface.

- Investigation 2: What's the Point?
  - A lens manipulates light.
  - There are multiple types of lenses. Some focus light, while others disperse it farther.
  - For every lens, there is a specific distance from which light will be focused in the smallest area.

- Investigation 3: Shed Some Light
  - Light travels in a straight line.
  - Flat, smooth surfaces can be used to reflect light.
  - Dispersed light can be reflected.

Supporting Science Investigation 1: How Intense Are You?

Concept

The intensity of light waves changes as the waves move away from the source. Imagine standing under a street lamp at night. The light from the lamp is brightest when you are directly under the lamp. As you move away from the lamp, the light becomes dimmer. As you continue to move away from the lamp, eventually the light does not illuminate the sidewalk anymore.

The same is true for the Sun. The farther we travel away from the Sun, the dimmer its light waves become and the harder it is to use its energy. How much do light waves spread as they travel through space? The following activity will model this effect.

Materials

Each group of two students will need the following:

- 2 rulers
- Foam pipe insulation, 15 cm long

  (Diameter will be based on the size of the flashlight. The flashlight should fit inside the insulation, or be attached to the insulation, so that a beam of light is created.)
- Tape
- Scissors
- Flashlight (LED preferred)
- Graph paper (provided)

Figure 19. Materials for "How Intense Are You?" activity.

Procedure

1. For this investigation, the room will have to be dark enough for students to clearly see the light from the flashlight.
2. Insert the flashlight into the foam pipe insulation, or attach it to the insulation, so that the light will pass vertically down the pipe when the flashlight is on (Fig. 20). Secure with tape.
3. Place the graph paper provided on a flat surface. Student 1 will hold the flashlight in a vertical position at a 90° angle to the paper (or as close to 90° as possible) so that the light is centered on the yellow circle.
4. Student 1 will position the flashlight above the graph paper at the following heights, measuring from the light-emitting end of the foam pipe insulation: 4 cm, 8 cm, 12 cm, 16 cm, and 20 cm. For each position, Student 2 will measure the diameter of the circle of light.

Figure 20. Conducting the investigation. The ruler is behind the flashlight in the foam insulation.

5. Turn on the flashlight and begin your observations. The flashlight should only be directed toward the paper and NOT toward any person.
6. Use the data table to record (in cm) the diameter of the circle of light at each height.
7. Observe the brightness of the light. Determine the brightness at each measurement and indicate on the graph how the brightness compares with the 4-cm brightness value.
8. Have students complete the Data Collection Sheet.

Options for Differentiating Instruction

The following suggestions may be used when modifying this engineering design challenge for students outside the designated age range or ability levels.

Modification

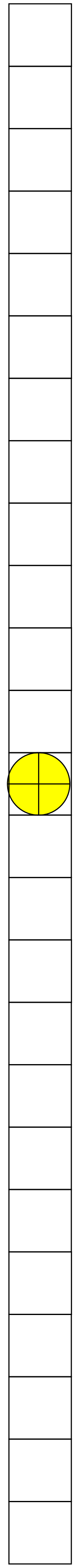
- If students are unable to accurately measure the size of the circles, a relative measurement may be made (bigger, smaller, about the same size, etc.).

Enrichments

- Have students repeat the experiment with multiple iterations of various angles (30°, 45°, and 60°) to witness the effect on the diameter of the circles as angles increase.
- Use various sizes and types of flashlights. Just make sure the foam pipe insulation is attached to create a straight beam of light.

Graph Paper for "How Intense Are You?" (Next Page)

1. Center the flashlight beam on the yellow dot.
2. Count how many 1-cm squares are illuminated by the flashlight's beam. This is the diameter of the beam.
3. Record your result on the Data Collection Sheet.



Supporting Science Investigation 2: What's the Point?

Concept

Lenses can be used to manipulate light. A simple lens is a piece of glass or plastic having two polished surfaces. One of the surfaces must be curved; the other surface may be curved or flat.

There are two main types of lenses. A concave lens is thicker on the outside than it is in the middle, creating diffused light. A convex lens is thicker in the middle than it is on the outside, creating concentrated light.

Microscopes use lenses to focus light and capture light from a specimen to form an image. The image becomes enlarged through this process. Telescopes do the same thing, only they do it for objects far out in space.

In this investigation, students will use a flashlight and a magnifying glass to investigate how a lens can manipulate light.

Materials

Each group of 3 students will need the following:

- Flashlight (LED preferred)
- Tape measure
- Magnifying glass
- Additional lenses (optional)

Procedure

Figure 21. Observe what happens when a lens is placed between the light source and the wall.

1. For this investigation, the room will have to be dark enough for students to clearly see the light from the flashlight.
2. Position the flashlight 1.5 m from a plain wall. This position is to replicate the position of the Sun. The light should NOT move.
3. Ask students to predict the distance between the lens and the wall where the light through the magnifying lens will be at the smallest point. Have them record their prediction on their Data Collection Sheet.
4. Hold the magnifying lens between the light and the wall at 80 cm from the wall (Fig. 21). Observe any changes to the light projected on the wall. Students should identify the outer edges and inner circle of the light that has passed through the magnifying lens.

5. Continue to move the magnifying lens closer to the wall at 70 cm, 60 cm, 50 cm, 40 cm, 30 cm, 20 cm, and 10 cm. Record your observations of the changes that are occurring to the light on the wall.
6. Have students complete the additional tasks on the Data Collection Sheet.
7. Proceed to the Explanation: Supporting Science Investigations Discussion section to help students process the concepts for application to the challenge.

Options for Differentiating Instruction

The following suggestions may be used when modifying this engineering design challenge for students outside the designated age range or ability levels.

Modification

- To maintain a constant distance from the wall, consider taping the flashlight to a table.

Enrichments

- Students can measure the diameter of the circle that is projected on the wall to include in their observations.
- Consider purchasing a light meter. Instead of shining the light onto a wall, shine the light into the light meter. Change the goal of the investigation to obtain the highest reading on the meter.

Supporting Science Investigation 3: Shed Some Light

Concept

Light waves travel in a straight line until they encounter an object. Based on the object encountered, the light waves can be absorbed, refracted, or scattered. When light encounters a smooth, flat surface, it can be reflected. The direction in which the light will travel next depends on the light's angle as it reaches the surface. Even dispersed light can be reflected.

Mirrors provide the type of smooth, flat surface that light requires in order to be reflected. Objects that are white can also reflect light, but not as directly. Telescopes, microscopes, and binoculars use reflected light to change the way we observe objects.

In this investigation, students will use a flashlight and mirrors to explore how light is reflected.

Materials

Each pair of students will need the following:

- Flashlight
- Tape measure
- Astronaut figure, approximately 3 cm tall
- 2 mirrors (suggested size is 6 x 6 cm)
- 4-oz paper cup (for platform)
- Landscape illustration
- Cardboard, 55 x 25 cm (22 x 10 in.)
- Tape

Procedure

Part 1

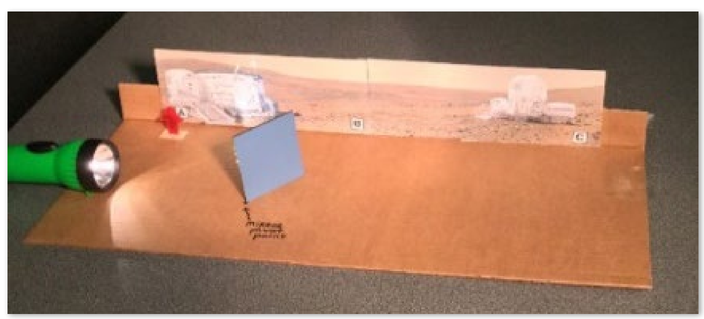


Figure 22. Setup for Part 1.

1. For this investigation, the room will have to be dark enough for students to clearly see the light from the flashlight.
2. Score the cardboard at 5 cm along the long edge and fold this section up at a right angle. Photocopy the landscape illustration from the guide. Cut on the dotted line and tape the two pictures to the 5 x 55 cm edge of the cardboard as shown in Figure 22. Set the cardboard on a table so the landscape illustration is at a right angle to the table.
3. Place the flashlight on the table parallel to and left of the landscape picture as shown in Figure 22. The flashlight should be 15 cm in front of the landscape picture. The light-projecting end of the flashlight should point to the right and be aligned with the "A" edge of the landscape picture. Tape the flashlight in place during this part of the investigation.
4. Measure 15 cm from the light-emitting end of the flashlight and draw a black dot on the cardboard as shown in Figure 22. This will be the pivot point for the mirror during this part of the investigation.

5. Turn on the flashlight. Place the astronaut figure in front of position A and place a corner of the mirror on the pivot point. Position the mirror so it can be rotated in such a way that the light is reflected from the flashlight and illuminates the astronaut (see Fig. 22). Have students record their observations for position A.
6. Student 1 will keep the corner of the mirror at the pivot point while Student 2 moves the astronaut to position B. Rotate the mirror so the light is reflected and illuminates the astronaut. Have students record their observations for position B.
7. Repeat for position C. Have students record their observations for position C.

Part 2

1. Place the platform (4-oz paper cup) in front of position A and place the astronaut on top of the platform as shown in Figure 23. Turn on the flashlight. Using the same pivot point from Part 1, rotate the corner of the mirror to reflect the flashlight beam off the mirror to illuminate the astronaut.

Figure 23. Setup for Part 2.

2. Move the platform and the astronaut to position B. Using the pivot point, rotate the corner of the mirror to reflect the light off the mirror to illuminate the astronaut.
3. Repeat for position C.
4. Have students describe on their data sheets what they noticed about the position of the mirror and how it had to be moved to illuminate the astronaut at positions A, B, and C.
5. Remove the flashlight from the cardboard.

Part 3

1. Place the astronaut at position B as shown in Figure 24. Place the platform (4-oz paper cup) 5 cm in front of the astronaut. Place the flashlight 20 cm in front of the platform.
2. Turn on the flashlight. The astronaut should be in the shadow of the platform, and the dispersed light should be projected onto the landscape picture. Have students draw a diagram that shows the shape of the light from the flashlight that they see on the base of the cardboard landscape.

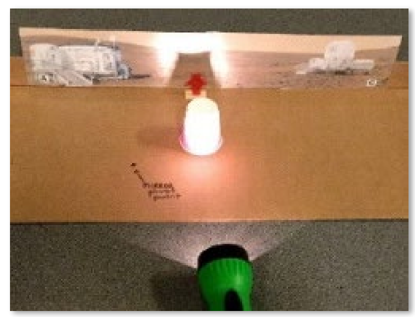


Figure 24. Setup for Part 3.

3. Each team member has a mirror. Position the mirrors anywhere within the dispersed light to guide the reflection from the dispersed light onto the astronaut.
4. Add the mirror positions to the diagram and include arrows to show the direction of the light and the reflections.
5. Have students describe what they did to manipulate the light.

Options for Differentiating Instruction

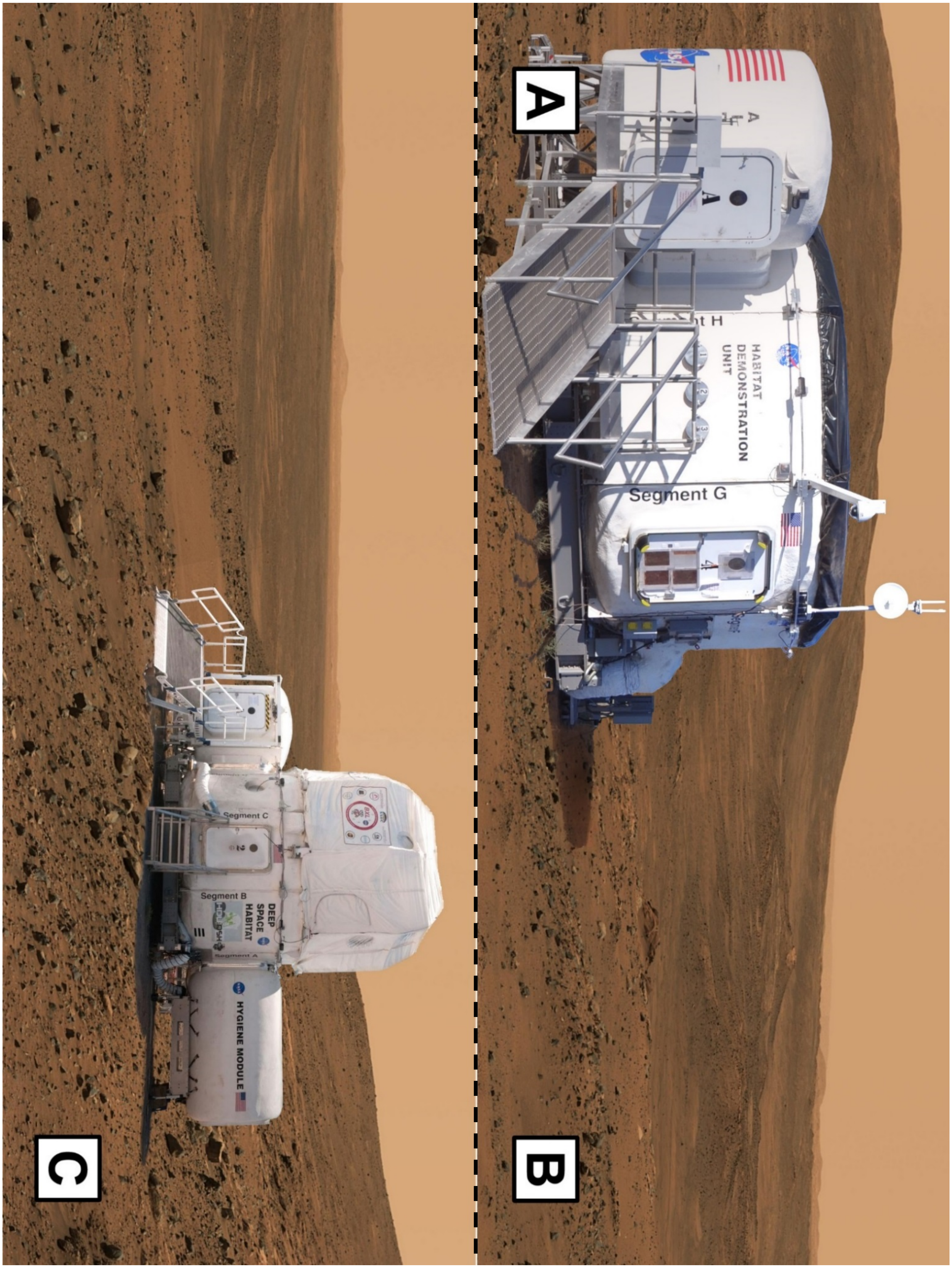
The following suggestions may be used when modifying this engineering design challenge for students outside of the designated age range or ability levels.

Modification

- Students may omit Part 2 of the activity (illuminating the astronaut on the platform).

Enrichment

- Students can try using multiple mirrors to illuminate the astronaut.


A
B
C
HABITAT
DEMONSTRATION
UNIT
Segment G
Segment C
Segment B
DEEP
SPACE
HABITAT
HYGIENE MODULE

Explanation: Supporting Science Investigations Discussion

The following investigation discussions are designed to reinforce students' understanding of the specific concepts learned during the Supporting Science Investigations.

Each discussion is based on the standard Think–Pair–Share strategy, which encourages individual participation, collaborative learning, and higher-level thinking. This strategy consists of three parts:

- **Think**: Students think independently about the question that has been posed.
- **Pair**: Students are paired to discuss their thoughts.
- **Share**: Students share their ideas with the whole class.

Focus on one question at a time. When students are done sharing their thoughts and ideas on the first question, move to the second question and repeat the process.

Procedure

1. Discussion Questions for each Supporting Science Investigation are included in this guide.
2. Ask one of the Discussion Questions to begin the Think–Pair–Share process.
3. Provide approximately 5 minutes for students to think independently.
4. Next, provide approximately 5 minutes for the students to share in pairs.
5. Finally, have students share their ideas in a class discussion.

Investigation Discussion 1: How Intense Are You?

Concepts Learned

The following scientific concepts should be realized by performing this investigation:

- Light is a form of wave energy.
- Light waves will become dispersed as they travel over a distance.
- The amount of dispersion varies depending on the angle at which the light reaches a surface.

Discussion Questions

In the "How Intense Are You?" activity, we learned that wave energy from the Sun disperses as it travels away from the Sun.

1. If our challenge is to collect as much of this energy as possible, what could we do to reverse the impact of light dispersion?
2. Would being on another planet, such as Mars, make it easier or more difficult to reverse the impact of light dispersion?

Investigation Discussion 2: What's the Point?

Concepts Learned

The following scientific concepts should be realized by performing this investigation:

- A lens manipulates light.
- There are multiple types of lenses. Some focus light while others disperse it farther.
- For every lens, there is a specific distance that focuses the light into the smallest area.

Discussion Questions

In this activity, we determined that for each lens there was a specific distance between the light source and the lens that would generate the smallest circle on the wall.

1. What kind of setup would focus the greatest possible amount of sunlight into the smallest possible area? Draw your proposed setup, label it, and be prepared to explain your idea to others.
2. How would you modify the setup to focus the light into an area exactly 5 cm in diameter?

Investigation Discussion 3: Shed Some Light

Concepts Learned

The following scientific concepts should be realized by performing this investigation:

- Light travels in a straight line.
- Flat, smooth surfaces can be used to reflect light.
- Dispersed light can be reflected.

Discussion Questions

In this activity, we used mirrors to reflect light to a specific location.

1. What kind of changes to the reflected light did you observe as you went through this activity?
2. How could this information help you design improvements to the pumping system for the challenge?

Elaboration: The Engineering Design Challenge

Using the Engineering Design Process

Discuss the engineering design process (EDP) with students and explain how students will use this process to work through the engineering design challenge. The following pages explain how each step of the EDP relates to the challenge and how to facilitate the process. Regardless of the step being undertaken by each team, it is important that they work in a scientific manner. Explain the EDP sheets and how to use the appropriate pages for recording group ideas. It is important for students to understand that they may choose any path through the EDP, but they should be able to communicate why they selected a particular path.

Discuss with your students the information covered within the engineering design challenge. Using the background information, talk about current NASA missions and how those relate to this challenge. As a class, discuss the individual components of this challenge. Explain the specific criteria and check with students for understanding. Discuss with students what the constraints mean, how and why they are important, and how they relate to their everyday experiences.

A budgetary constraint can also be added as follows:

- Provide students with a price sheet that lists the cost of the items they have used to complete the challenge.
- Have teams use the Budget Reporting Data Sheet included here to determine the cost of their solution as tested.
- Next, advise students that NASA plans to mass-produce their design for use, but due to financial constraints, the annual budget has been reduced. Students will be required to redesign their prototype to reduce costs, but without reducing performance.

Engineering Design Process

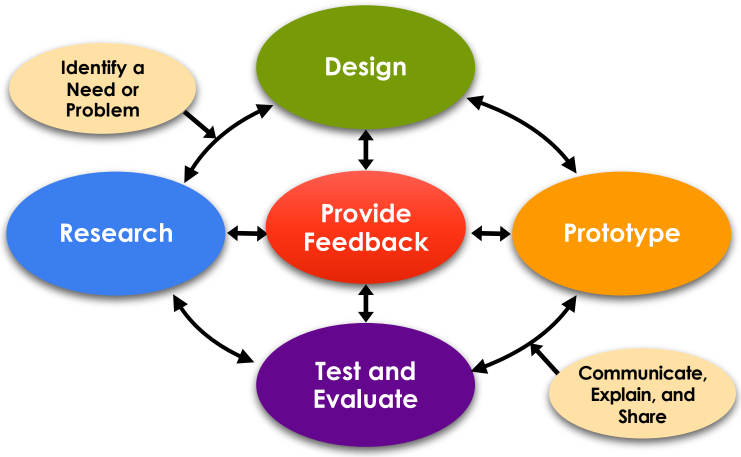


Figure 25. Engineering Design Process model (model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf).

Identify a Need or Problem. Engineering design begins by identifying a need or problem to be solved, improved, and/or fixed. This typically includes articulation of criteria and constraints that will define a successful solution.

Research. Constructive investigation is performed to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and it can be an ongoing part of design.

Design. All gathered information is used to inform the creation of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. A prototype is constructed based on the design model(s) and is used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

Test and Evaluate. The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype's performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, redesigning, and refining the need or problem.

Provide Feedback. Oral or written feedback provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to convey how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Communication of explanations must be clear and analytical.

The Engineering Design Challenge

The Challenge

Teams of students will design, build, and improve a stand-alone, solar-powered pumping system to move water as quickly as possible between two containers. Students will use light-concentrating materials, shapes, and structures to maximize the collection of simulated solar energy. The energy will then be directed toward solar cells that will power the system to move the water.

Figure 26. Technicians work on NASA's InSight lander during a solar array deployment test. The lander will use solar power to operate its science equipment on the surface of Mars. (NASA)

Criteria and Constraints

1. The solar cells must be at least 20 cm from the light source.
2. The entire system (not including the light source and the water) cannot have a mass of more than 750 g.
3. The system must move 200 mL of water from a storage tank to a habitat tank.
4. The water must be moved through a minimum of 50 cm of tubing.
5. The system must NOT use siphoning as a means to accelerate the movement of water.

Options for Differentiating Instruction

The following suggestions may be used when modifying this engineering design challenge for students outside the designated age range or ability levels.

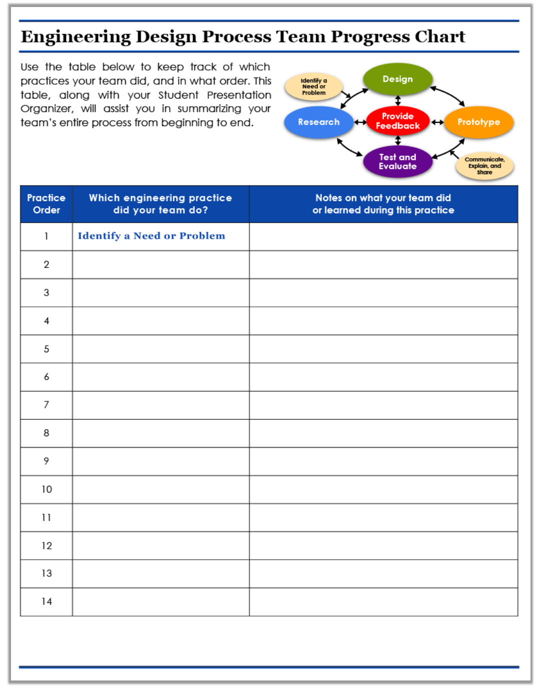
Modification

Consider pre-making the solar battery configuration so students can focus solely on the construction of the light-concentrating setup.

Enrichment

Consider changing one of the following variables: solar cell combination, size of the pump, or amount of water that needs to be moved. Changing any of these will allow students to explore possible scenarios that NASA engineers are currently investigating.

Student Team Challenge Journals



Engineering Design Process Team Progress Chart

Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will assist you in summarizing your team's entire process from beginning to end.

Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	Identify a Need or Problem	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Students will be creating their Student Team Challenge Journals as they move through the engineering design process (EDP) to solve the challenge. Take time prior to starting the challenge to explain the best way for students to document their work and what the goals are for completing the challenge. The pages should document how student teams moved through the EDP. Students should be instructed to use as many sheets as needed to document each step of the process.

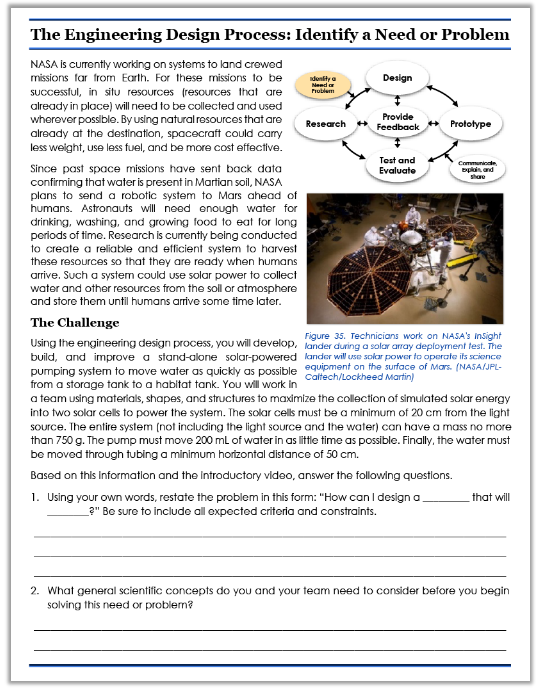
1. Always fill in the page number. This will help keep the pages in order.
2. On the Provide Feedback sheet, use the "Next Steps" section to justify your next step in the process. As an example: "We are moving back to the design phase as the prototype failed to meet the criteria. It was 50 g over the limit."
3. When documenting the prototype stage, make note of any challenges you faced building your design and how you resolved them.

As students proceed through the process, they should record steps accomplished on the Team Progress Chart, found at the back of the Student Team Challenge Journal. Think of this chart as a Table of Contents for the journals that are being created as students move through the process.

In order to successfully complete the engineering design challenge, teams must use the EDP. As they work the steps of the EDP, students will be engaging in authentic engineering practices.

Identify a Need or Problem

Students complete the Identify a Need or Problem page from the Student Team Challenge Journal.



The Engineering Design Process: Identify a Need or Problem

NASA is currently working on systems to land crewed missions far from Earth. For these missions to be successful, in situ resources (resources that are already in place) will need to be collected and used wherever possible. By using natural resources that are already at the destination, spacecraft could carry less weight, use less fuel, and be more cost effective.

Since past space missions have sent back data confirming that water is present in Martian soil, NASA plans to send a robotic system to Mars ahead of humans. Astronauts will need enough water for drinking, washing, and growing food to eat for long periods of time. Research is currently being conducted to create a reliable and efficient system to harvest these resources so that they are ready when humans arrive. Such a system could use solar power to collect water and other resources from the soil or atmosphere and store them until humans arrive some time later.

Figure 35. Technicians work on NASA's InSight lander during a solar array deployment test. The lander will use solar power to operate its science equipment on the surface of Mars. (NASA/JPL-Caltech/Lockheed Martin)

The Challenge

Using the engineering design process, you will develop, build, and improve a stand-alone solar-powered pumping system to move water as quickly as possible from a storage tank to a habitat tank. You will work in a team using materials, shapes, and structures to maximize the collection of simulated solar energy into two solar cells to power the system. The solar cells must be a minimum of 20 cm from the light source. The entire system (not including the light source and the water) can have a mass no more than 750 g. The pump must move 200 mL of water in as little time as possible. Finally, the water must be moved through tubing a minimum horizontal distance of 50 cm.

Based on this information and the introductory video, answer the following questions.

1. Using your own words, restate the problem in this form: "How can I design a ________ that will ________?" Be sure to include all expected criteria and constraints.

2. What general scientific concepts do you and your team need to consider before you begin solving this need or problem?

Engineering design begins by identifying a need or problem that an attempt can be made to solve, improve, and/or fix. This typically includes articulation of criteria and constraints that will define a successful solution.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- How can our team design a _____ that will _____?
- What needs to be solved or improved?
- What are we trying to accomplish?

Instructional Procedure

1. Review the engineering design process with students.
2. Show the NASA Beginning Engineering Science and Technology (BEST) video titled "Repeatability," found at https://www.youtube.com/watch?v=-2Az1KDn-YM.
3. Ask students to identify the specific criteria and constraints of the design challenge.
4. Have students fill out the Identify a Need or Problem page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

- Allow students extra time to discuss the challenge itself, the problem that needs to be solved, and how the problem could be solved.
- Introduce criteria and constraints one at a time. Allow student designs to meet one challenge requirement successfully before introducing additional requirements.

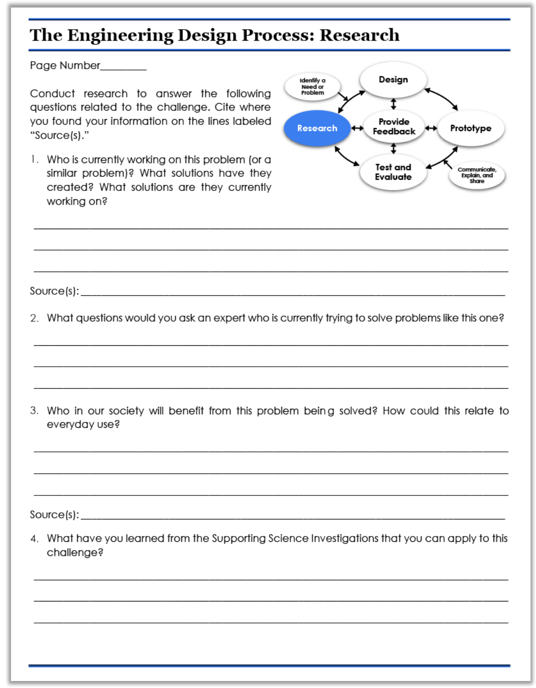
Enrichment

- Require students to write a letter or an email to a friend as if they were explaining their first job as a newly hired NASA engineer.

Research

Students complete the Research pages from the Student Team Challenge Journal.

Research is done to learn more about the identified need or problem and potential solution strategies. Students can use resources from the Internet, the library, or discussion with experts to examine how this problem or similar problems are currently being solved.


The Engineering Design Process: Research

Page Number______

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

Source(s): ______

2. What questions would you ask an expert who is currently trying to solve problems like this one?

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

Source(s): ______

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Where can you find more information about the topic?
- What questions would you ask an expert or an engineer who is currently working on this problem?
- Who in our society will benefit from this problem being solved?

Instructional Procedure

1. Help students answer any questions they have about the challenge. Use the Internet or a school library to research answers.
2. Write down any unanswered questions and save them to ask the NASA subject matter expert (SME) during live connections.
3. Have team members fill out the Research pages in the Student Team Challenge Journal.

Differentiation Suggestions

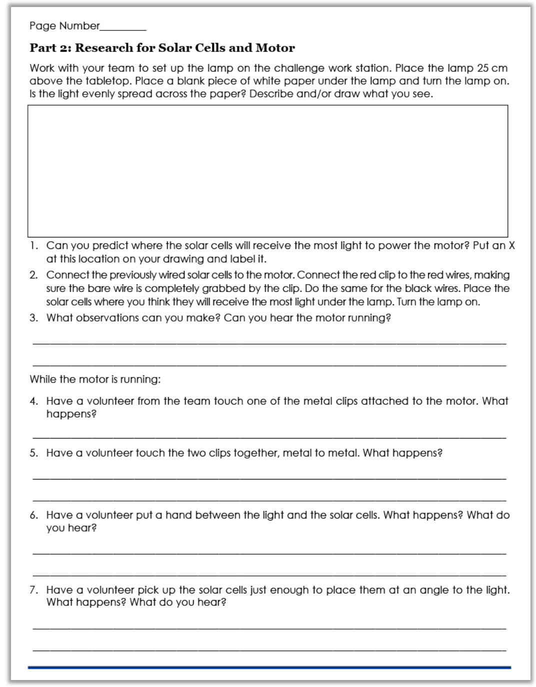
Modifications

- Provide a list of reputable online resources students can use.
- Arrange a visit to a library.
- Pair up students to complete their research together.

Enrichment

- Have students provide a properly formatted citation for one or more resources.

Research for Solar Cells and Motor


Page Number________

Part 2: Research for Solar Cells and Motor

Work with your team to set up the lamp on the challenge work station. Place the lamp 25 cm above the tabletop. Place a blank piece of white paper under the lamp and turn the lamp on. Is the light evenly spread across the paper? Describe and/or draw what you see.

1. Can you predict where the solar cells will receive the most light to power the motor? Put an X at this location on your drawing and label it.
2. Connect the previously wired solar cells to the motor. Connect the red clip to the red wires, making sure the bare wire is completely grabbed by the clip. Do the same for the black wires. Place the solar cells where you think they will receive the most light under the lamp. Turn the lamp on.
3. What observations can you make? Can you hear the motor running?

While the motor is running:

4. Have a volunteer from the team touch one of the metal clips attached to the motor. What happens?
5. Have a volunteer touch the two clips together, metal to metal. What happens?
6. Have a volunteer put a hand between the light and the solar cells. What happens? What do you hear?
7. Have a volunteer pick up the solar cells just enough to place them at an angle to the light. What happens? What do you hear?

Further investigation of the setup offers an opportunity for students to familiarize themselves with the complex challenge components. The setup features two solar cells and a motor that work together, yet are sensitive to variations in the amount of light, which will change the energy output. Allowing students to explore these components early in the engineering design process will help them focus in later steps on the challenge constraints and problem to be solved.

See Figure 27 for the ideal way to set up the engineering design challenge. Use this as a guide when working with students.

Each student team needs the following materials:

- Scale for determining whether student solutions meet mass requirement
- Clean tabletop surface, approximately 1 square meter in size
- Small submersible water pump with tubing
- Two solar cells (3 V, 70 mA) with wires
- Utility work light with 100-W clear light bulb positioned at least 25 cm above test area

  (Facilitators should check lamp height after students have placed their systems underneath. Lamp height should remain constant for the duration of the challenge.)
- Ruler or tape measure to determine solutions meet requirements for tubing length and distance from light
- Stopwatch or timer for timing systems
- Bottle or pitcher containing 250 to 500 mL of water

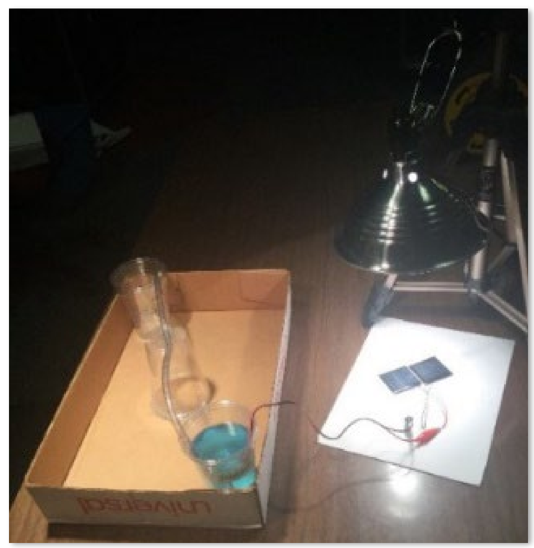


Figure 27. Setup of test area.

As a class, discuss the individual components of this challenge. Demonstrate how to wire the solar cells and pump by twisting all of the red wires together and all of the black wires together, then securing each connection with electrical tape (Fig. 28).

Additional investigation into the setup of the solar cells and pumping system will provide practice with the timing of the water transfer. This will be helpful for students. The Research pages in the Student Team Challenge Journal include this guidance for teams.

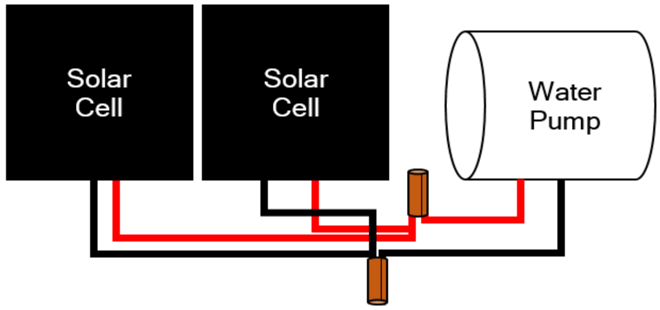
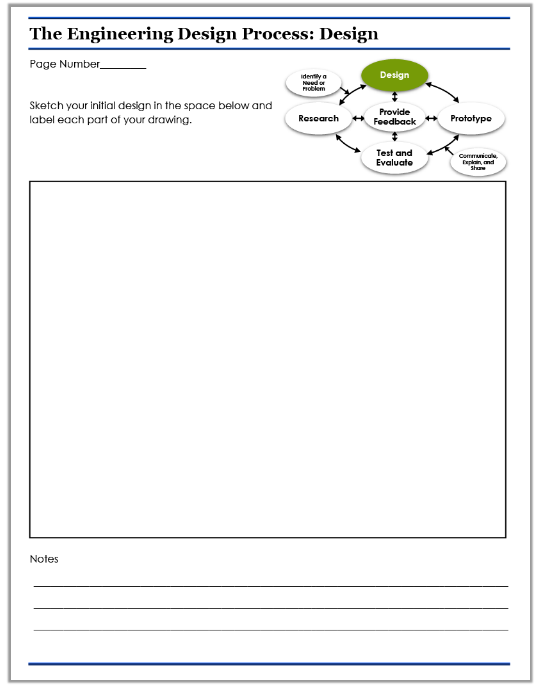


Figure 28. Wiring setup for the challenge.

Provide each student with the Student Team Challenge Journal. Introduce the engineering design process practices and explain how to use the corresponding sheets for recording students' ideas. For example, when students create the initial design, the Design sheet should be used.

Design



Students complete the Design pages from the Student Team Challenge Journal.

The design stage includes modeling possible solutions, refining the models, and choosing the model that best meets the original need or problem.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What are all the different ways each member of the team can imagine to solve the problem?
- What do we need to add to the design?
- What could go wrong if we add to the design?
- Do the drawings address all the criteria and constraints?

Instructional Procedure

1. Ask each team member to brainstorm individually and make sketches representing ideas for a solution. Students must clearly label and identify each part of their drawing.
2. Each team member should make sure that designs meet all constraints and criteria.
3. Have students sketch their ideas on the Design page in the Student Team Challenge Journal.
4. Ask team members to discuss their ideas and drawings with the rest of the team.
5. Have students record the strengths of each of the designs.
6. Have students fill out the Best Possible Solution page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

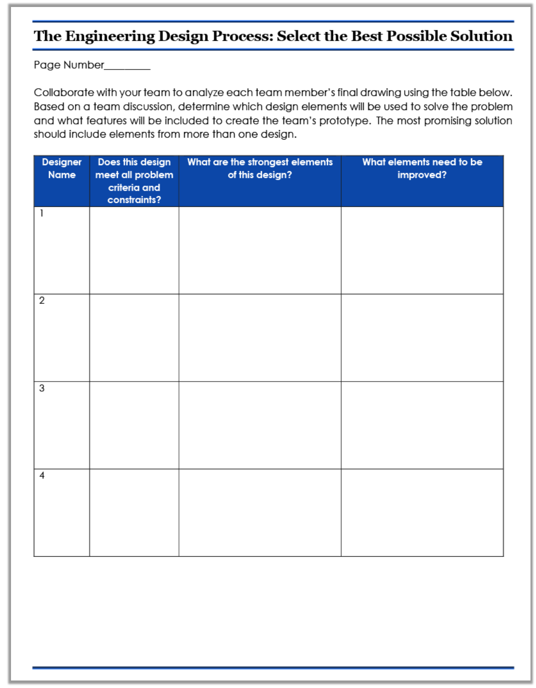
- Encourage students to create a series of storyboards rather than a single complete drawing.
- Show students the building materials to help them visualize their sketch prior to beginning the drawing.

Enrichment

- Require students to specify measurements.

Analyzing the Designs

Team members analyze each member's final drawing using the table provided in the Student Team Challenge Journal.



The Engineering Design Process: Select the Best Possible Solution

Page Number________

Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

Based on a team discussion, team members will determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What is one strength of each student's individual design?
- How can that be incorporated into a group design?
- Are the strengths in each design related to the criteria and constraints of the challenge?
- Are elements from each team member's design represented in the final design?

Differentiation Suggestions

Modification

- Have students pick one aspect or characteristic at a time from each team member's drawing to discuss in the group.

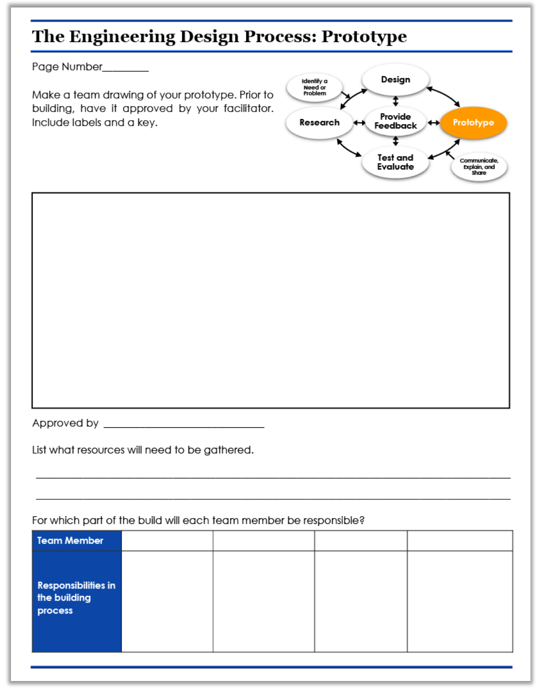
Enrichment

- Require students to draw one or more parts of the design to scale.

Prototype

Students complete the Prototype page from the Student Team Challenge Journal.

A prototype is constructed based on the design model and used to test the proposed solution. A final design should be drawn precisely and labeled with a key. Facilitators should approve final drawings before building begins. Facilitators are expected to assist students as necessary to ensure classroom safety.



The Engineering Design Process: Prototype

Page Number________

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.

Approved by ____________________

List what resources will need to be gathered.

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What resources does your team need to gather?
- What is the plan?
- Who is doing what?

Instructional Procedure

1. Ask each team to identify the design that appears to solve the problem.
2. A final diagram of the design should be drawn precisely and labeled with a key.
3. Have each team determine what materials they will need to build their design and assign responsibilities to team members for prototype completion.
4. Be sure to approve the final drawings before building begins.
5. After teams receive their materials to build their prototype, have them complete a budget sheet showing their building material costs.
6. Have teams construct their prototypes using their drawings.
7. Have teams fill out the Prototype page in the Student Team Challenge Journal.

Differentiation Suggestions

Modification

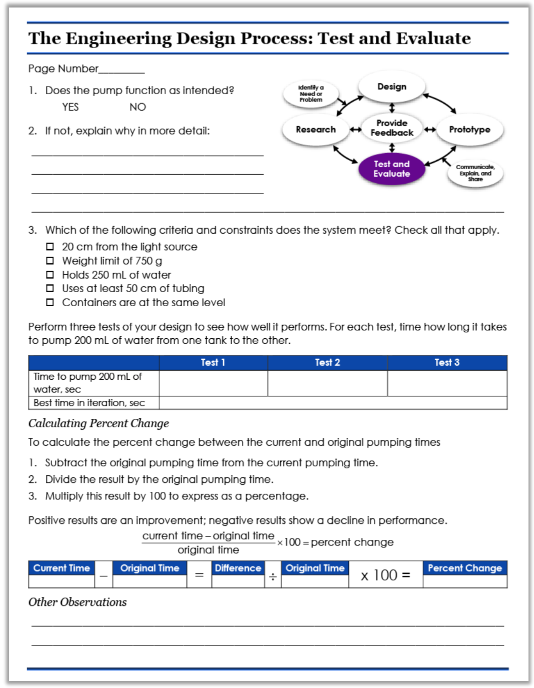
- Give students extra time to explore various materials prior to building the model.

Enrichment

- Limit materials to add complexity (e.g., only 1 m of duct tape).

Test and Evaluate

Students complete the Test and Evaluate page from the Student Team Challenge Journal.


The Engineering Design Process: Test and Evaluate

Page Number________

1. Does the pump function as intended?
   YES NO
2. If not, explain why in more detail:

3. Which of the following criteria and constraints does the system meet? Check all that apply.
   - ☐ 20 cm from the light source
   - ☐ Weight limit of 750 g
   - ☐ Holds 250 mL of water
   - ☐ Uses at least 50 cm of tubing
   - ☐ Containers are at the same level

Perform three tests of your design to see how well it performs. For each test, time how long it takes to pump 200 mL of water from one tank to the other.

	Test 1	Test 2	Test 3
Time to pump 200 mL of water, sec			
Best time in iteration, sec			

Calculating Percent Change

To calculate the percent change between the current and original pumping times

1. Subtract the original pumping time from the current pumping time.
2. Divide the result by the original pumping time.
3. Multiply this result by 100 to express as a percentage.

Positive results are an improvement; negative results show a decline in performance.

$$\frac{\text{current time} - \text{original time}}{\text{original time}} \times 100 = \text{percent change}$$

Current Time		Original Time		Difference		Original Time		Percent Change
	−		=		÷		x 100 =	

Other Observations

Student teams should test their prototypes to determine how effectively they addressed the need or problem and collect data to serve as evidence of their success or need for improvement. Remind students that they must test their prototypes a minimum of three times for each iteration to ensure the validity of their results.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Did the team collect enough data to analyze the design?
- How did the prototype perform when tested?
- Did the design meet or exceed the criteria and constraints?

Instructional Procedure

1. Visit each team and test their designs to ensure they meet all challenge criteria and constraints.
2. Have teams fill out the Test and Evaluate page in the Student Team Challenge Journal.

Differentiation Suggestions

Modification

- Encourage students to test only one criteria or constraint at a time rather than all of them at once.

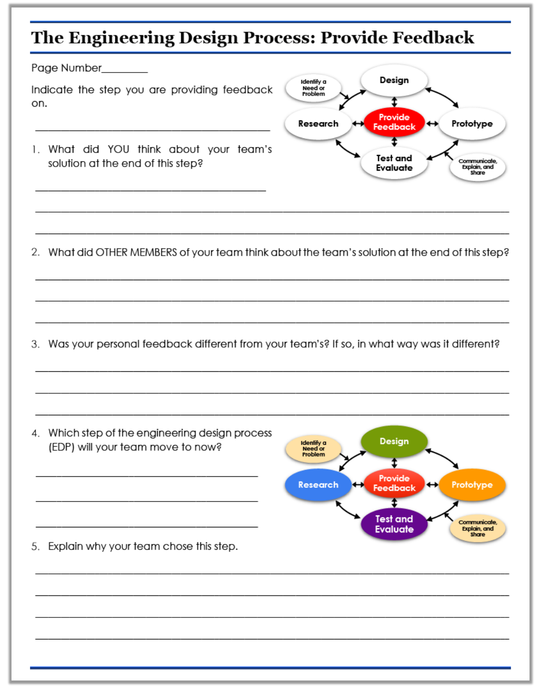
Enrichment

- Create a scatter plot of test results.

Provide Feedback and Communicate, Explain, and Share

Students complete the Provide Feedback page from the Student Team Challenge Journal as frequently as necessary.

Throughout the process, students will take time to reflect on their progress and consider what steps should be taken next. For this challenge, students will exchange feedback with their peers, both one-on-one and as a classroom. Oral and written peer feedback will help students improve their solutions and designs. It is important for students to learn the peer-review process and to be accepting of others' suggestions. Students will complete the Provide Feedback page after each step to maintain direction and focus during the engineering design process (EDP).



The Engineering Design Process: Provide Feedback

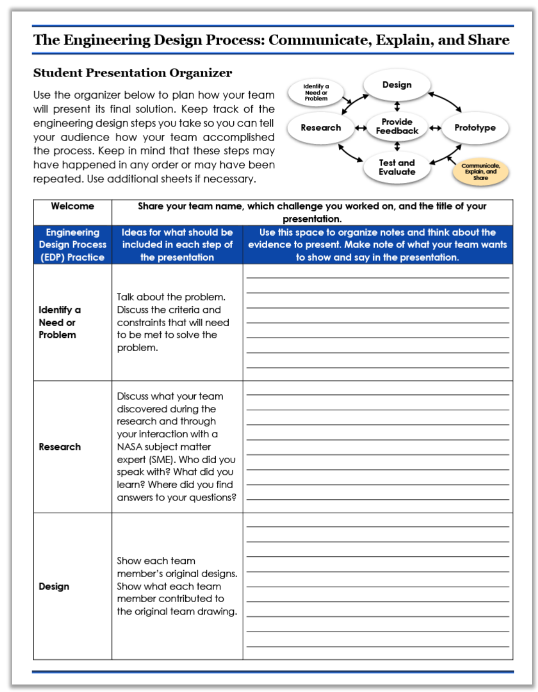
Page Number_______

Indicate the step you are providing feedback on.

1. What did YOU think about your team's solution at the end of this step?
2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?
3. Was your personal feedback different from your team's? If so, in what way was it different?
4. Which step of the engineering design process (EDP) will your team move to now?
5. Explain why your team chose this step.

Students complete the Communicate, Explain, and Share page from the Student Team Challenge Journal.

Communicating, explaining, and sharing the solution and design is essential to conveying how it works, how it solves the identified need or problem, and how it meets the criteria and constraints. This step will be achieved through the production of a video or slide presentation that will be submitted at the end of this challenge.



The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process. Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	Ideas for what should be included in each step of the presentation	Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What did or did not work in the latest iteration of the design? Why or why not?
- What are the pros and cons of this solution?
- Did each team show that they used all of the process of the EDP?

Instructional Procedure

1. Ask team members to document and report the results of their designs.
2. Have students identify what changes were made with each iteration of the design and what the team believed caused the design to succeed or fail.

3. Students should complete the corresponding sheets in the Student Team Challenge Journal to help them think about how they completed each step of the EDP.
4. Students should use the Team Progress Chart to document progress as they work on their solutions.
5. Teams should use the Student Presentation Organizer to guide them through the creation of the team video or slide presentation.

Differentiation Suggestions

Modification

- Provide a few basic yes/no questions for students to answer to determine whether their design was successful or not.

Enrichment

- Have student teams use a variety of media to create their presentation.

Evaluation: Student Debriefing Questions

The following questions are designed to help start a discussion with your students. After the design challenge is complete, have teams work together to answer these questions.

1. Why did your team use this approach to solve the problem?
2. How did your research help you decide that this was the best solution?

   Encourage students to talk about their thought processes. How did they make their decisions? Was their approach logical and well reasoned? Do they understand the goals?

3. What changes did you make to your design during your iterations of redesign?
4. How could you further improve on your design?

   Questions 3 and 4 will confirm that students have correctly identified the flaws in their designs and are working to correct them.

5. What were the greatest challenges for your team throughout this process?

   Emphasize to students that even the most successful engineers have setbacks.

6. What strategies did your team use that proved effective in overcoming challenges?

   Have students elaborate on why they chose certain options or strategies. Did collaborative discussion or debate help them generate more or better ideas?

7. How did you use the engineering design process (EDP) to help with your design?

   Make sure students talk about each practice and discuss how the process helped them complete the challenge.

8. What concerns must be considered in constructing a quality pumping system?

   Emphasize safety and meeting the criteria and constraints. Encourage students to utilize proper scientific terminology (e.g., structure, mass, and photovoltaic principles) and the vocabulary embedded in this guide.

9. What specific problems did you need to address in designing the pumping system?

   This could include technical problems as well as interpersonal problems. Emphasize how the students worked to find a solution to each problem. Was test data consistent? Have students describe any unusual results and discuss what might have happened to cause them.

10. If you were an astronaut heading to Mars, would you trust your team's pumping system during an extended stay on the planet? Why or why not?

    This question can serve two purposes. One allows students to visualize themselves as astronauts as a way to evaluate their solution in a real-world context. The other allows students to consider various career pathways such as electrical or mechanical engineer, repair technician, or payload scientist.

Creating Solution Presentations

For the final stage of the challenge, students will document their progress in a video or slide presentation to share with other groups who have completed this engineering design challenge. The Student Team Challenge Journal was designed to help document each stage of the engineering design process (EDP). Encourage students to use their journals to help build the presentation.

Submission Guidelines

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name) and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.
- The presentation should document every step students took to complete the challenge, including the Supporting Science Investigations.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

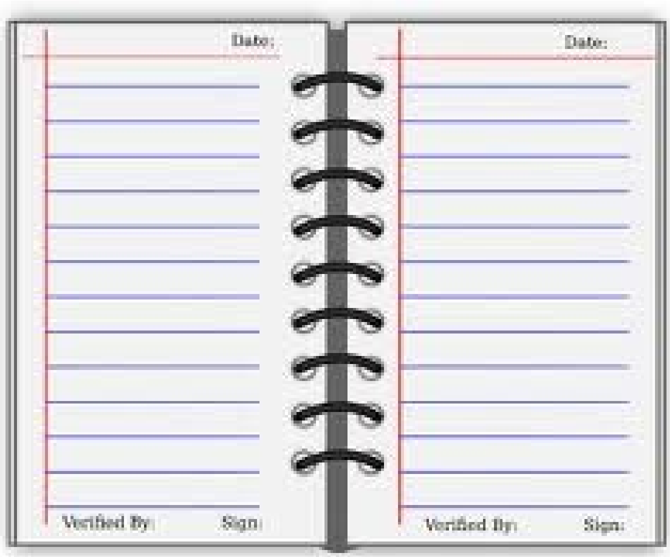
Once the video or slide presentation is complete, submit according to the guidelines on the Glenn engineering design challenge website: https://www.nasa.gov/glenn-engineering-design-challenges

Budget Reporting Worksheet

Directions: As a team, complete the cost sheet below. Be sure to include all materials needed, unit cost, quantity, and the item total needed to complete your design. At the end, total up the entire cost of your solution.

Line Item Number	Material	Unit Cost	Quantity	Item Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
			Total Cost:	

Student Team Challenge Journal



Supporting Science Investigation 1: How Intense Are You?

Concept

The intensity of light waves changes as the waves move away from the source.

Imagine standing under a street lamp at night. The light from the lamp is brightest when you are directly under the lamp. As you move away from the lamp, the light becomes dimmer. As you continue to move away from the lamp, eventually the light does not illuminate the sidewalk anymore.

The same is true for the Sun. The farther we travel away from the Sun, the dimmer its light waves become and the harder it is to use its energy. How much do light waves spread as they travel through space? The following activity will model this effect.

Materials

Each group of 2 students will need the following:

- 2 rulers
- Foam pipe insulation, 15 cm long

  (Diameter will be based on the size of the flashlight. The light-emitting end of the flashlight should either fit inside the insulation or be attached to the insulation so that a beam of light is created when the flashlight is turned on.)
- Tape
- Scissors
- Flashlight (LED preferred)
- Graph paper (provided next page)

Figure 29. Conducting the investigation. Ruler is behind flashlight and foam pipe insulation tube.

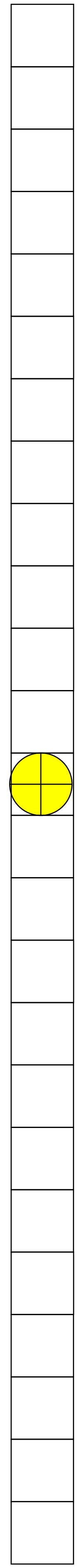
Procedure

1. For this investigation, the room will have to be dark enough to clearly see the light from the flashlight.
2. Insert the flashlight into the foam pipe insulation, or attach it to the insulation, so that the light will pass vertically down the pipe when the flashlight is on (Fig. 29). Secure with tape.
3. Place the graph paper provided on a flat surface. Student 1 will hold the flashlight in a vertical position at a 90° angle to the paper (or as close to 90° as possible) so that the light is centered on the yellow circle.
4. Student 1 will position the flashlight above the graph paper at the following heights, measuring from the light-emitting end of the foam pipe insulation: 4 cm, 8 cm, 12 cm, 16 cm, and 20 cm. For each position, Student 2 will measure the diameter of the circle of light at each height.
5. Turn on the flashlight and begin your observations. The flashlight should only be directed toward the paper and NOT toward any person.

6. Use the data table to record the diameter (in cm) of the circle of light at each height.
7. Observe the brightness of the light. Determine the brightness of each measurement and indicate on the graph how the brightness compares with the 4-cm brightness value.
8. Complete the additional tasks on the Data Collection Sheet.

Graph Paper for "How Intense Are You?" (Next page)

1. Center the flashlight beam on the yellow dot.
2. Count how many 1-cm squares are illuminated by the flashlight's beam. This is the diameter of the beam.
3. Record your result on the Data Collection Sheet.

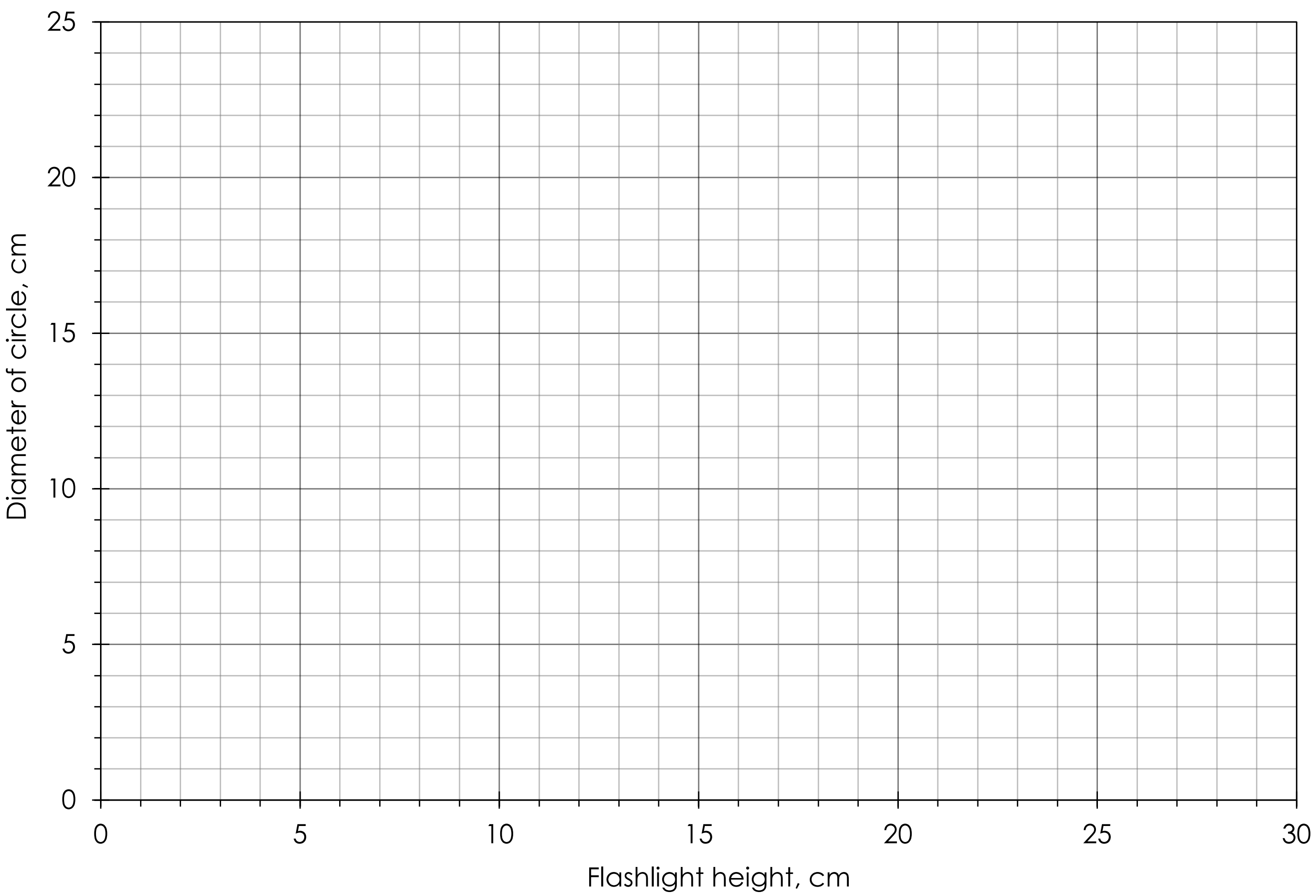


Data Collection Sheet

Complete the table below using the results from the investigation. To indicate the brightness of the light, consider the 4-cm view to be the brightest. Shade in the table for the other measurements, using the 4-cm view for comparison.

Flashlight Height	Diameter of Circle, cm	Observations: Brightness of Circle
4 cm		
8 cm		
12 cm		
16 cm		
20 cm		

Plot the results of your investigation on the graph.



Powered and Pumped Up

1. Describe what happens to the diameter of the circle as the distance from the light source increases.

____

____

____

2. Describe what happens to the brightness of the light as the distance from the light source increases.

____

____

____

3. Using the graph, predict the diameter of the circle if the flashlight is held at 24 cm. Fill in your answer below.

   I predict that the size of the circle will be _______ cm.

4. Using the flashlight, perform the investigation at 24 cm and measure the actual diameter of the circle created. Fill in your answer below.

   After measuring the actual results, the diameter of the circle was _______ cm.

5. Was your prediction accurate? YES / NO

6. If your prediction was not accurate, can you determine why?

____

____

____

7. Describe the relationship between the diameter of the circle of light and the flashlight height.

____

____

____

Supporting Science Investigation 2: What's the Point?

Concept

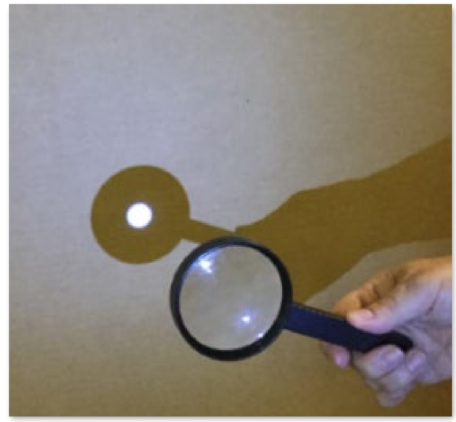


Figure 30. Observe what happens when a lens is placed between the light source and the wall.

Lenses can be used to manipulate light. A simple lens is a piece of glass or plastic having two polished surfaces. One of the surfaces must be curved; the other surface may be curved or flat.

There are two main types of lenses. A concave lens is thicker on the outside than it is in the middle, creating diffused light. A convex lens is thicker in the middle than it is on the outside, creating concentrated light.

Microscopes use lenses to focus light and capture light from a specimen to form an image. The image becomes enlarged through this process. Telescopes do the same thing, only they do it for objects far out in space.

In this investigation, you will use a flashlight and a magnifying glass to investigate how a lens can manipulate light.

Materials

Each group of 3 students will need the following:

- Flashlight (LED preferred)
- Magnifying glass
- Tape measure
- Additional lenses (optional)

Procedure

1. For this investigation, the room will have to be dark enough to clearly see the light from the flashlight.
2. Position the flashlight 1.5 m from a plain wall. This position is to replicate the position of the Sun. The light should NOT move.
3. On your Data Collection Sheet, predict the distance between the lens and the wall where the light through the magnifying lens will be at the smallest point.
4. Hold the magnifying lens between the light and the wall at 80 cm from the wall (Fig. 30). Observe any changes to the light projected on the wall.
5. Continue to move the magnifying lens closer to the wall at 70 cm, 60 cm, 50 cm, 40 cm, 30 cm, 20 cm, and 10 cm. Use the Data Collection Sheet to record your observations of the changes that are occurring to the light on the wall.
6. Complete the additional tasks on your Data Collection Sheet.

Data Collection Sheet

1. Predict the distance between the lens and the wall where the light through the magnifying lens will be at the smallest point.

____

2. What information did you use to make your prediction?

____

____

Complete the table below using the results from your investigation.

Distance between magnifying glass and wall	Observations of light projected on the wall
No Magnification	
80 cm	
70 cm	
60 cm	
50 cm	
40 cm	
30 cm	
20 cm	
10 cm	

3. What was the actual distance where the light was at its smallest point? ____________________
4. Did the amount of light change during the investigation? How do you know?

____

____

____

5. Describe how the position of the lens is important to producing the smallest spread of light.

____

____

____

6. What effect can a lens have on the light generated from a source? Do you think a lens will have the same effect on sunlight?

____

____

Supporting Science Investigation 3: Shed Some Light

Concept

Light waves travel in a straight line until they encounter an object. Based on the object encountered, the light waves can be absorbed, refracted, or scattered. When light encounters a smooth, flat surface, it can be reflected. The direction in which the light will travel next depends on the light's angle as it reaches the surface. Even dispersed light can be reflected.

Mirrors provide the type of smooth, flat surface that light requires in order to be reflected. Objects that are white can also reflect light, but not as directly. Telescopes, microscopes, and binoculars use reflected light to change the way we observe objects.

In this investigation, you will use a flashlight and mirrors to explore how light is reflected.

Materials

Each pair of students will need the following:

- Flashlight
- Tape measure
- Astronaut figure, approximately 3 cm tall
- 2 mirrors (6 x 6 cm)
- 4-oz paper cup (for platform)
- Landscape illustration
- Cardboard, 55 x 25 cm (22 x 10 in.)
- Tape

Procedures and Data Collection Sheet

Prior to beginning this investigation, place the flashlight perpendicular to the mirror surface. Turn on the flashlight and observe what happens. Does the light go through the mirror? Where does the reflection shine?

____

____

Astronauts must complete investigations and explorations while on other planets. Can they use the sunlight available to them to illuminate the areas where work needs to be done?

____

____

Part 1

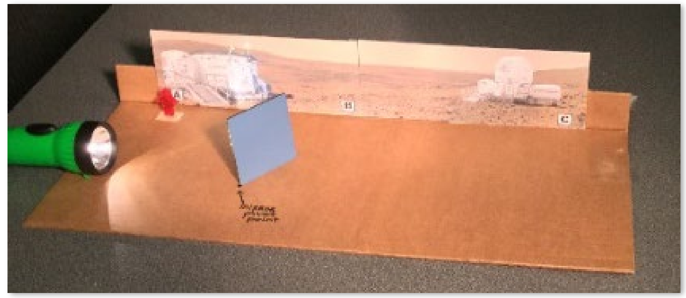


Figure 31. Setup for Part 1.

1. For this investigation, the room will have to be dark enough to clearly see the light from the flashlight.
2. Score the cardboard at 5 cm on the long edge and fold this section up at a right angle. Cut the landscape picture in half along the dotted line and tape the two pictures to the 5 x 55 cm edge of the cardboard as shown in Figure 31. Set the cardboard on a table so the landscape illustration is at a right angle to the table.
3. Place the flashlight on the table parallel to and left of the landscape picture as shown in Figure 31. The flashlight should be 15 cm in front of the landscape picture. The light-projecting end of the flashlight should point to the right and be aligned with the "A" edge of the landscape picture. Tape the flashlight in place during this part of the investigation.
4. Measure 15 cm from the light-emitting end of the flashlight and draw a black dot on the cardboard as shown in Figure 31. This will be the pivot point for the mirror during this part of the investigation.
5. Turn on the flashlight. Position the astronaut at position A and place the corner of the mirror at the pivot point. Rotate the mirror to get the light beam to illuminate the astronaut.
   - Draw a diagram of the setup.
   - Label the astronaut, the flashlight, and the mirror.
   - Draw an arrow from the light to the mirror.
   - Draw an arrow from the mirror to the astronaut.

Diagram

6. What did you do to get light to reflect onto the astronaut?

____

____

____

7. Place the astronaut at position B, keeping the mirror at the pivot point. Rotate the mirror to get the light beam to shine on the astronaut.

8. What did you do to get light to reflect onto the astronaut?

___

___

___

9. Position the astronaut at position C, keeping the corner of the mirror at the pivot point. Rotate the mirror to get the light beam to shine on the astronaut.
   - Draw a diagram of the arrangement of the flashlight, the astronaut, and the mirror. Label the astronaut, the flashlight, and the mirror.
   - Draw an arrow from the light to the mirror.
   - Draw an arrow from the mirror to the astronaut.

Diagram

10. What did you do to get light to reflect onto the astronaut?

___

___

___

11. Identify the differences between the two diagrams.

___

___

___

Part 2

1. Place the platform (4-oz paper cup) in front of position A and put the astronaut on top of the platform as shown in Figure 32. Using the same pivot point from Part 1, rotate the corner of the mirror to reflect the flashlight beam off the mirror so that it shines on the astronaut.
2. Move the platform with the astronaut to position B. Using the pivot point, rotate the corner of the mirror to reflect the light off the mirror to shine on the astronaut.

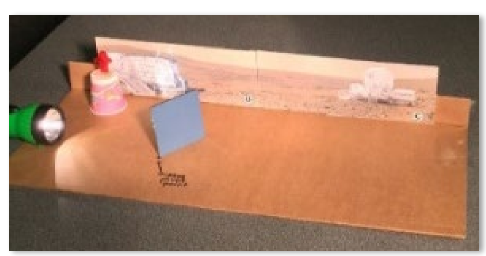


Figure 32. Setup for Part 2.

3. Repeat for position C.
4. Compare your observations about the change in the positioning of the mirror and how it relates to the position of the astronaut.

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5. Remove the flashlight from the cardboard.

Part 3

1. Place the astronaut against the cardboard landscape at position B as shown in Figure 33. Place the platform (4-oz paper cup) 5 cm in front of the astronaut. Place the flashlight 20 cm in front of the platform.
2. Turn on the flashlight. The astronaut should be in the shadow of the platform, and you should be able to see the dispersed light projected onto the landscape. Observe the dispersed light pattern projected onto the base of the cardboard.

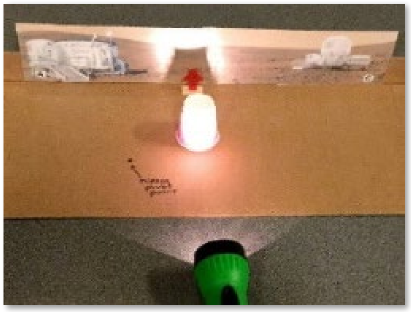


Figure 33. Setup for Part 3.

- Draw a diagram that shows the shape of the light projected onto the landscape base.
- Label the astronaut, the platform, and the flashlight.

Diagram

3. Each team member has a mirror. Position the mirrors anywhere within the dispersed light to guide the reflection from the dispersed light onto the astronaut.
4. Add the position of the mirrors to the diagram you made above. Include arrows to show the direction of the light and the direction of the reflections.
5. Describe what you did to manipulate the light.

____

____

The Engineering Design Process

The engineering design process (EDP) consists of a series of steps, each designed to help you develop a solution to a problem. Start with "Identify a Need or Problem" and use the EDP diagram shown here to help solve this challenge.

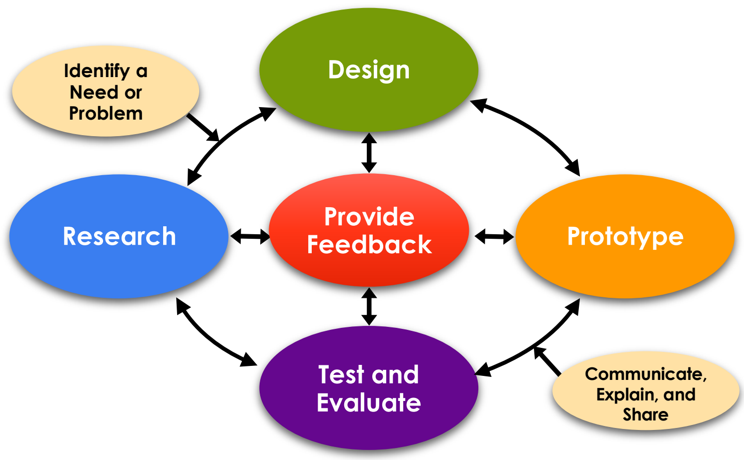


Figure 34. Engineering design process model (model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf).

Identify a Need or Problem. This step is designed to ask one of these general questions:

- How can I design a __________ that will __________?
- How can I improve a _________ to make it better?

The criteria and constraints are defined during this step.

Research. Use resources such as the Internet, a library, or NASA subject matter experts (SMEs) to examine how this problem (or a similar problem) is currently being solved.

Design. Think of solutions that might solve the problem. Select the solution you think is most likely to succeed. Refine it into a full design. Keep other solutions for future reference.

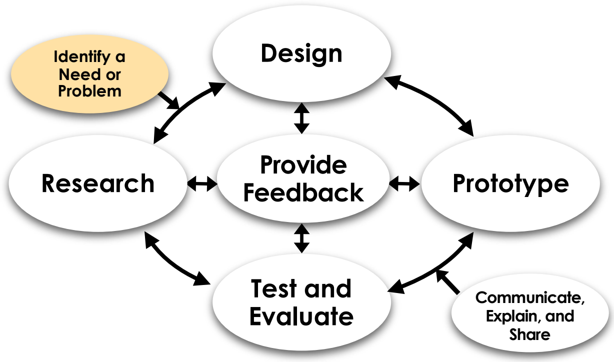
Prototype. Construct a full-size or scale model of the selected solution.

Test and Evaluate. Test the prototype to see how effective it is in solving the need or problem. Compare the data to the design criteria to see if the goals were met.

Provide Feedback. Record and share lessons learned about the design based on testing. Discuss how improvements can be made, or if the design should be discarded and another design attempted.

Communicate, Explain, and Share. Present your solution and explain how the solution has been improved through the EDP.

The Engineering Design Process: Identify a Need or Problem



NASA is currently working on systems to land crewed missions far from Earth. For these missions to be successful, in situ resources (resources that are already in place) will need to be collected and used wherever possible. By using natural resources that are already at the destination, spacecraft could carry less weight, use less fuel, and be more cost effective.

Since past space missions have sent back data confirming that water is present in Martian soil, NASA plans to send a robotic system to Mars ahead of humans. Astronauts will need enough water for drinking, washing, and growing food to eat for long periods of time. Research is currently being conducted to create a reliable and efficient system to harvest these resources so that they are ready when humans arrive. Such a system could use solar power to collect water and other resources from the soil or atmosphere and store them until humans arrive some time later.

Figure 35. Technicians work on NASA's InSight lander during a solar array deployment test. The lander will use solar power to operate its science equipment on the surface of Mars. (NASA/JPL-Caltech/Lockheed Martin)

The Challenge

Using the engineering design process, you will develop, build, and improve a stand-alone solar-powered pumping system to move water as quickly as possible from a storage tank to a habitat tank. You will work in a team using materials, shapes, and structures to maximize the collection of simulated solar energy into two solar cells to power the system. The solar cells must be a minimum of 20 cm from the light source. The entire system (not including the light source and the water) can have a mass no more than 750 g. The pump must move 200 mL of water in as little time as possible. Finally, the water must be moved through tubing a minimum horizontal distance of 50 cm.

Based on this information and the introductory video, answer the following questions.

1. Using your own words, restate the problem in this form: "How can I design a _________ that will ________?" Be sure to include all expected criteria and constraints.

____

____

____

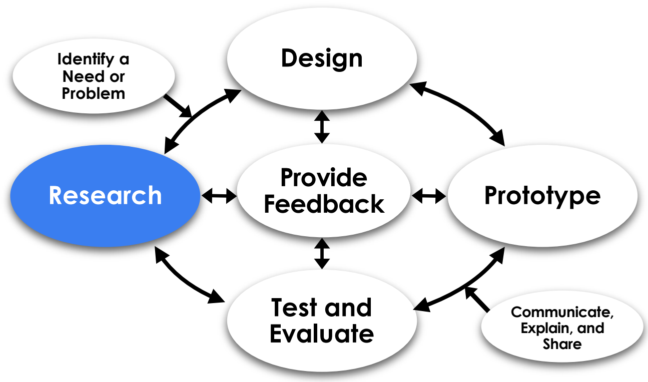
2. What general scientific concepts do you and your team need to consider before you begin solving this need or problem?

____

____

The Engineering Design Process: Research

Page Number________



Part 1

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

____

____

____

Source(s): ____

2. What questions would you ask an expert who is currently trying to solve problems like this one?

____

____

____

____

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

____

____

____

Source(s): ____

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

____

____

Page Number________

Part 2: Research for Solar Cells and Motor

Work with your team to set up the lamp on the challenge work station. Place the lamp 25 cm above the tabletop. Place a blank piece of white paper under the lamp and turn the lamp on. Is the light evenly spread across the paper? Describe and/or draw what you see.

1. Can you predict where the solar cells will receive the most light to power the motor? Put an X at this location on your drawing and label it.
2. Connect the previously wired solar cells to the motor. Connect the red clip to the red wires, making sure the bare wire is completely grabbed by the clip. Do the same for the black wires. Place the solar cells where you think they will receive the most light under the lamp. Turn the lamp on.
3. What observations can you make? Can you hear the motor running?

____

____

While the motor is running:

4. Have a volunteer from the team touch one of the metal clips attached to the motor. What happens?

____

5. Have a volunteer touch the two clips together, metal to metal. What happens?

____

____

6. Have a volunteer put a hand between the light and the solar cells. What happens? What do you hear?

____

____

7. Have a volunteer pick up the solar cells just enough to place them at an angle to the light. What happens? What do you hear?

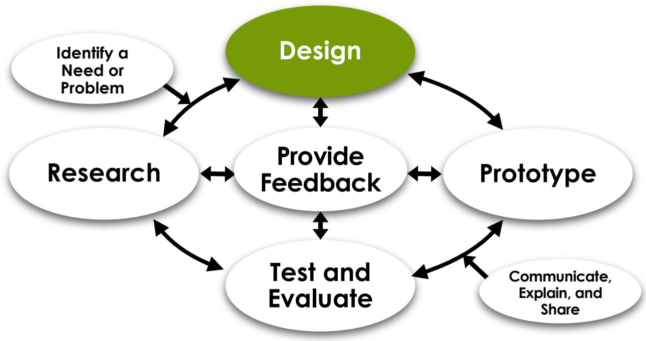
____

____

The Engineering Design Process: Design

Page Number________

Sketch your initial design in the space below and label each part of your drawing.



Notes

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The Engineering Design Process: Select the Best Possible Solution

Page Number________

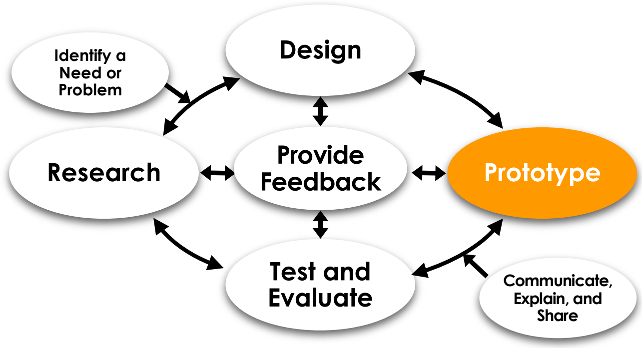
Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

The Engineering Design Process: Prototype

Page Number________

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.



Approved by ______________________________

List what resources will need to be gathered.

____

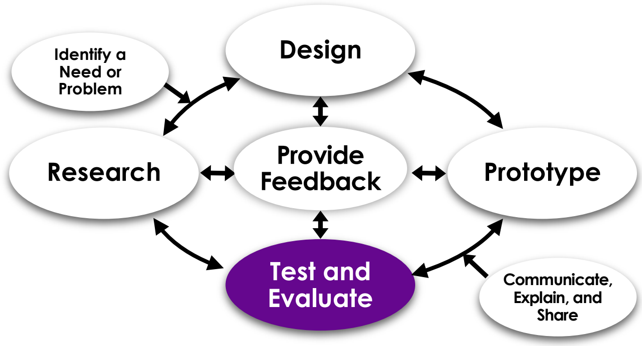
____

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

The Engineering Design Process: Test and Evaluate

Page Number________



1. Does the pump function as intended?

   YES NO

2. If not, explain why in more detail:

____

____

____

____

3. Which of the following criteria and constraints does the system meet? Check all that apply.
   - ☐ 20 cm from the light source
   - ☐ Weight limit of 750 g
   - ☐ Holds 250 mL of water
   - ☐ Uses at least 50 cm of tubing
   - ☐ Containers are at the same level

Perform three tests of your design to see how well it performs. For each test, time how long it takes to pump 200 mL of water from one tank to the other.

	Test 1	Test 2	Test 3
Time to pump 200 mL of water, sec			
Best time in iteration, sec			

Calculating Percent Change

To calculate the percent change between the current and original pumping times

1. Subtract the original pumping time from the current pumping time.
2. Divide the result by the original pumping time.
3. Multiply this result by 100 to express as a percentage.

Positive results are an improvement; negative results show a decline in performance.

$$\frac{\text{current time} - \text{original time}}{\text{original time}} \times 100 = \text{percent change}$$

Current Time	–	Original Time	=	Difference	÷	Original Time	x 100 =	Percent Change

Other Observations

____

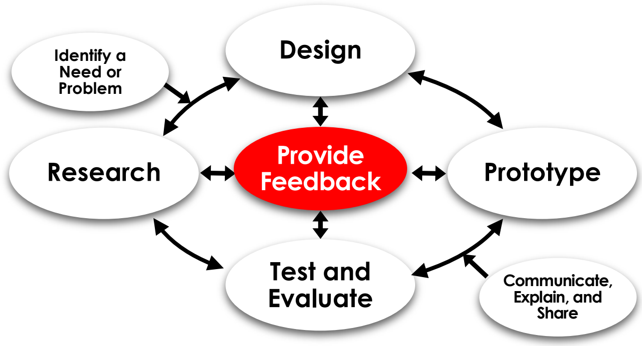
____

The Engineering Design Process: Provide Feedback

Page Number_________

Indicate the step you are providing feedback on.

____



1. What did YOU think about your team's solution at the end of this step?

____

____

____

2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?

____

____

____

3. Was your personal feedback different from your team's? If so, in what way was it different?

____

____

____

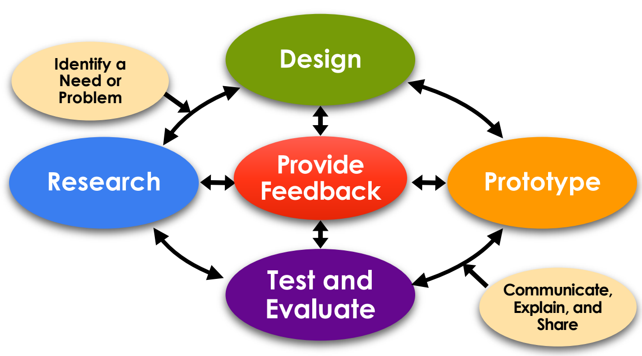
4. Which step of the engineering design process (EDP) will your team move to now?

____

____

____

____



5. Explain why your team chose this step.

____

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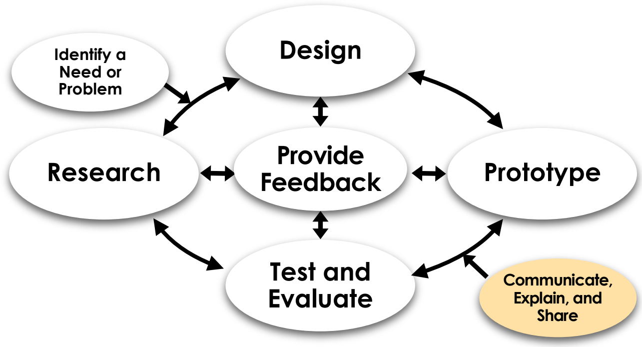
____

____

The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process. Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

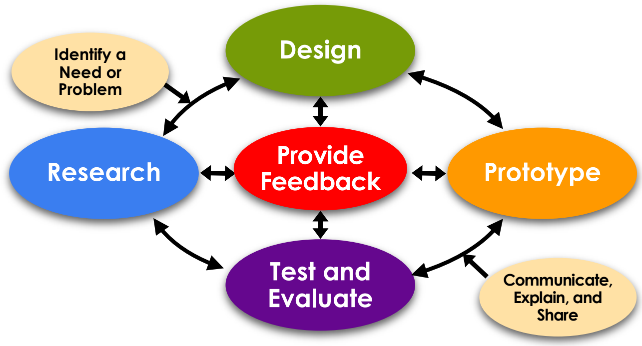


Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	**Ideas for what should be included in each step of the presentation**	**Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.**
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Prototype	Show materials used and how you put the prototype together.	
Test and Evaluate	Talk about how your team tested the design and discuss the results. Using the data, discuss the strengths and weaknesses of your team prototype.	
Provide Feedback	Describe how your team members communicated with each other to improve the solution. Also describe how you discussed options with people outside your group.	
Communicate, Explain, and Share	Talk about your data. Was your team able to solve the problem or not? What improvements did your team make to reach your final solution? Discuss any further action your team would take to improve this solution.	

Engineering Design Process Team Progress Chart

Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will assist you in summarizing your team's entire process from beginning to end.



Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	**Identify a Need or Problem**	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Solution Presentation

The final stage of the challenge is to document your progress for sharing with other groups who have completed this engineering design challenge. Your journey may be documented using video or slide presentations.

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.

- The presentation must document every step you took to complete the challenge, including the Supporting Science Investigations. Use every page of your Student Team Challenge Journal to help complete this presentation.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

Student Presentation Rubric

This rubric will be used to assess your final presentation. Use it as a checklist to make sure you have included something from every category. Try to achieve as many 3's as you can!

Engineering Design Process	Exemplary = 3	Proficient = 2	Novice = 1	Not Included = 0
We can **identify** the challenge and the criteria.	Challenge was restated and all criteria and constraints were described.	Challenge was restated with only the challenge criteria.	Only the challenge story was stated.	Team did not include a description of the challenge or the criteria.
We can discuss the results of our **research**, the Supporting Science Investigations, and connections with a NASA scientist or engineer.	Three or more facts relating to the challenge were discussed.	Two facts relating to the challenge were discussed.	One fact relating to the challenge was discussed.	No facts relating to the challenge were discussed.
Each of our team members sketched an original **design** that demonstrated the challenge criteria and constraints.	All criteria and constraints were represented (sketches and photos) in each team member's design.	Two criteria were represented (sketches and photos) in each team member's design.	One criterion was represented (sketches and photos) in each team member's design.	No criteria were represented.
Our final team **design** represented elements from each team member's original design.	Team design included the best from each member's design to represent the challenge and the criteria.	Team design included ideas from two team members' designs to represent the challenge and the criteria.	Team design included ideas from one team member's design to represent the challenge and the criteria.	Team was not able to provide a design to represent the challenge and the criteria.
Our team constructed a **prototype** to represent the challenge criteria and constraints.	A prototype was completed that met all of the challenge criteria and constraints.	A prototype was completed that met only two of the challenge criteria and constraints.	A prototype was completed that met only one of the challenge criteria and constraints.	A prototype was completed that did not meet the challenge criteria or constraints.
Our team collected and recorded data to **test and evaluate** our model's solutions.	Data were collected by testing to represent all of the criteria and constraints.	Data were collected by testing to represent only two criteria.	Data were collected by testing to represent only one criterion.	No data were collected and/or no testing was completed.
Our team was able to explain our design, gather **feedback**, and explain how we solved the challenge.	Difficult issues were explained and their solutions described.	Difficult issues were explained with no solutions offered.	Discussion of difficult issues was unclear and no solutions were presented.	No discussion of difficult issues was included.
Our team made **design** improvements after testing the prototype.	All improvements to the prototype were described.	Two improvements to the prototype were described.	One improvement to the prototype was described.	No improvements to the prototype were described.
Our team followed the **presentation process** to communicate our team **design.**	All the presentation requirements and procedures were met.	Three or more of the presentation requirements and procedures were met.	One or two of the presentation requirements and procedures were met.	The presentation requirements and procedures were not met.

Vocabulary List

Absorption. The way in which the energy of a photon is taken up by matter

Concave lens. A lens that is thinner in the middle than at the edges

Constraints. Statements about what a problem's solution **may not** do

Convex lens. A lens that is thicker in the middle than at the edges

Criteria. Statements about what a problem's solution **must** do

Diffusion. The action of spreading the light from a light source

Electricity. A form of energy resulting from the existence of charged particles (such as electrons or protons), either as a static (unmoving) accumulation of charge or as a dynamic (moving) current

Force. A push or a pull

In situ. A source in its original place

Iteration. One cycle of a repetitive process

Lens. A curved, transparent object; usually made of glass or plastic and used to direct light

Light. Electromagnetic radiation within a certain portion of the electromagnetic spectrum; usually refers to light that is visible to the human eye

Opaque. Not able to be penetrated by light; opposite of **transparent**

Photovoltaic cell. A device for converting solar energy into direct current electricity using semiconducting materials

Photovoltaic effect. The creation of voltage or electric current in a material upon exposure to light

Prototype. A first model of something from which other forms are developed

Reflection. The light or image seen when light bounces off a surface; bouncing a wave or ray off a surface

Refraction. The change in direction of a light or energy wave caused by a change in the wave's speed as it passes from one medium (such as air) into another with a different density (such as water)

Solar cell. A semiconducting material that is treated to convert light energy into electrical power to flow through an electrical circuit

Solar power. The conversion of sunlight into electricity, either directly (using **photovoltaic cells**) or indirectly (using concentrated solar power)

Transparent. Able to be penetrated by light; opposite of **opaque**

NASA Resources

Online Resources

Future Flight: Solar Power. Build a solar-powered car that runs on sunlight.
https://www.nasa.gov/sites/default/files/atoms/files/solar_power_5-12.pdf

NASA Glenn Solar Research. Learn about solar research at the NASA Glenn Research Center.
https://www.grc.nasa.gov/WWW/portal/apps/pv/mobi/index.html

In Situ Resource Utilization. Discover NASA's plans to harness natural resources from exploration sites throughout the solar system.
https://www.nasa.gov/exploration/analogs/isru/

My NASA Data: Think GREEN. Utilizing Renewable Solar Energy. Use satellite data and graphing skills to determine a region's greatest renewable energy potentials.
https://mynasadata.larc.nasa.gov/lesson-plans/lesson-plans-middle-school-educators/?page_id=474?&passid=78

NASA's Journey to Mars. Visit the Journey to Mars homepage to learn about NASA's efforts to accomplish its goal of sending humans to the Red Planet.
https://www.nasa.gov/topics/journeytomars/index.html

Solar Electric Propulsion. Read an overview and download a fact sheet on Solar Electric Propulsion, a spacecraft-propelling technology powered by photovoltaic cells.
https://www.nasa.gov/mission_pages/tdm/sep/index.html

Recommended Videos

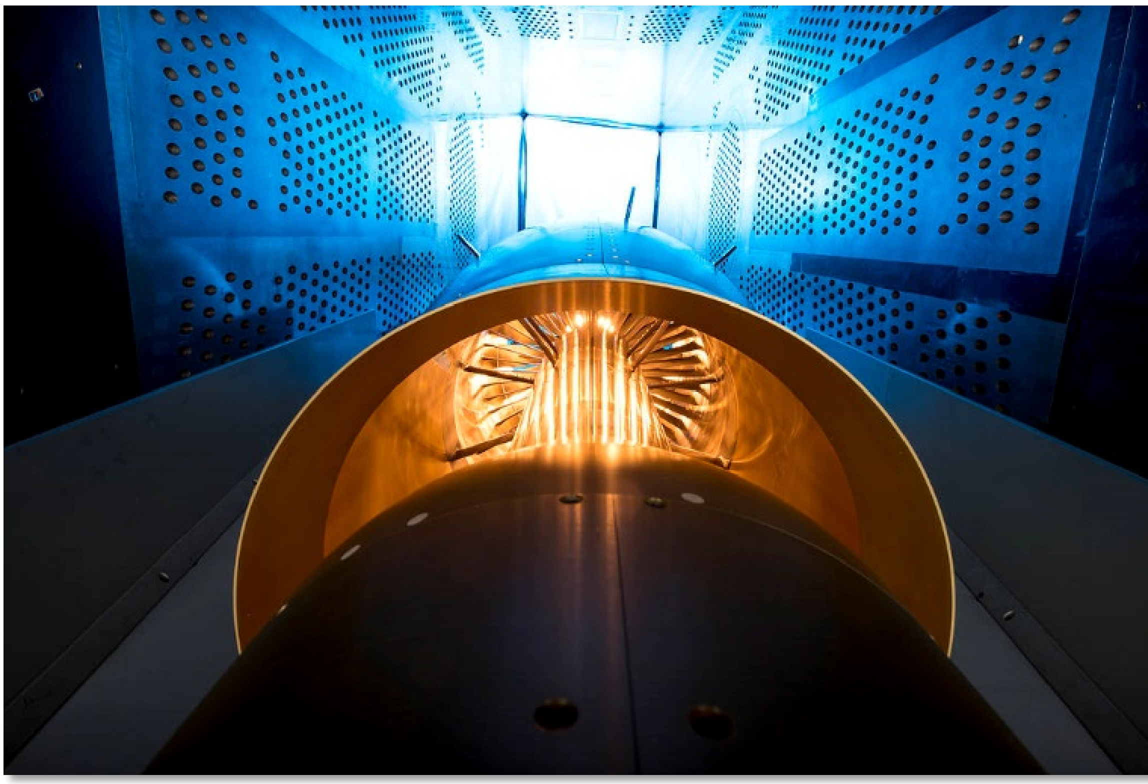
NASA Women's History Month Profile, Karin Bozak. Glenn Research Center. Meet a NASA electrical engineer who works on NASA's Solar Electric Propulsion project.
https://www.youtube.com/watch?v=uqSQPoaw3mk

Real World: Solar Power in Space. Learn how space technologies use solar power as an alternate energy supply.
https://www.youtube.com/watch?v=8j6SmPmN7B8

Real World: Solar Power on Earth. Learn how NASA-inspired technologies produce solar power here on Earth.
https://www.youtube.com/watch?v=sm6RrQb5698

Real World: STS–119 Brings More Power to the Space Station – Find out how STS–119 carried the giant arrays that now allow the station to house a crew of six.
https://www.youtube.com/watch?v=ZD5_fjSm0rs

Back cover: Tests performed inside the 8- by 6-Foot Supersonic Wind Tunnel at NASA Glenn Research Center showed that a new fan and inlet design could withstand turbulent boundary layer airflow and increase efficiency. Results of the tests can be applied to cutting-edge aircraft designs that NASA and its partners are pursuing. (NASA)



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