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.

Cover: The sphere graphic on the lower left includes images from many of Glenn’s research facilities and technologies. The four images across the middle highlight Glenn’s research in photovoltaic technology (far left), including flexible solar arrays and advanced solar concentrators (second from left). Glenn’s Vacuum Facility 5 (second from right) is a key facility for testing photovoltaic power systems in space environments in preparation for in situ resource utilization for future exploration on Mars (far right, artist’s conception of a Mars habitat) and elsewhere in the solar system.

“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
Dear Formal and Informal Educators,

The students you work with today are the scientists, technicians, engineers, and mathematicians of tomorrow. Creativity, curiosity, analytical thinking, and the ability to successfully utilize the engineering design process are characteristics and skills necessary for NASA’s future workforce. Engineering design challenges, like the one shared in this guide, create authentic learning experiences that allow students to develop these skills through rigorous and engaging science, technology, engineering, and mathematics (STEM) content.

This design challenge looks at applications of alternative energy in space exploration and ties in to current research being done by engineers at NASA’s Glenn Research Center to develop and improve fuel cells, solar cells, batteries, and radioisotope power systems. These engineers have supported the NASA education team in developing this content to ensure accuracy and relevance.

This facilitation guide is designed for versatility. It includes the engineering design challenge, supporting science investigations, and background information for both facilitators and students about concentrating and converting solar energy to usable electricity. The supporting science investigations take approximately 30 to 60 minutes each to complete. The guide has been written for students in middle grades, but its contents can be modified to increase or decrease the complexity. The challenge problem can be implemented in as little as 1 week but can continue, open-ended, as your students test and improve their designs.

All the activities are designed with both you and your students in mind. They include simple explanations of relevant background information, clear step-by-step instructions of each process, reflective student sheets, and driving questions to assess student understanding. You can use all the materials presented in this guide or customize your implementation of the challenge with resources that best fit the setting in which you operate.

NASA supports educators and facilitators, like you, who play a key role in preparing students for careers in STEM fields through engaging content. Thank you for helping us share this learning experience with your students.

Engineering Design Challenge Team
Glenn Research Center
Office of Education
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Introduction to the Engineering Design Challenge

Figure 1.—This computer-generated view depicts a sunrise on Mars. This view was created using three-dimensional information from NASA’s Mars Global Surveyor orbiter and color information based on general Mars color characteristics. (NASA)
Facilitator’s Overview

NASA Education staff and NASA scientists and engineers have collaborated to create an evidence-based [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. 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 common basic level of understanding about the EDP and how it relates to this challenge. Materials include an alignment to Next Generation Science Standards, connections to the Common Core State Standards for Mathematics and Literacy, and background information highlighting NASA’s challenge-related science and research.

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.

These user-friendly sections help you support your students as they work in teams to complete the EDC. At the conclusion, your students will be able to articulate the steps they have taken in the EDP and report that information and their challenge solution in a presentation that can be shared with NASA and other participants. Good luck as you help create the next generation of STEM professionals!

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

Facilitator’s Role

The facilitator should be comfortable coaching learners through the challenges presented within this guide. The facilitator should provide an educational atmosphere where students have the opportunity to fulfill their potential for intellectual, emotional, physical, and psychological growth; evaluate a student’s needs and abilities; and determine methods and techniques to best present the subject areas.

What is the Engineering Design Process?

The EDP (Fig. 2, page 6) 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.
There are many times that a solution from this process fails to meet the original goal. As an example, the sticky note was created by an engineer who was attempting to make a super-strong glue for aircraft manufacturers. His prototype failed, instead creating an ultraweak glue that worked perfectly for attaching paper to surfaces without leaving a residue. While his prototype failed in terms of its original goals, it became a huge international success.

**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.

**Educational Methodology**

**Backward Design** is the primary instructional design model utilized to develop this EDC. Backward design is a process that creates learning experiences and instructional techniques to achieve specific learning goals. Backward design begins with the objectives, or more accurately, what students are expected to learn upon completion, and then proceeds backward to create lessons that achieve those desired goals.

**The 5E Instructional Model** has been widely adopted across formal and informal science education to facilitate student learning and is based on constructivist views of education, which espouse that students build understanding from experiences and new ideas. The activities included in this EDC will be sequenced according the phases of the 5E Instructional Model: Engagement, Exploration, Explanation, Elaboration, and Evaluation.
Identify a Need or a 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

Challenge Overview

NASA is currently working on systems to land crewed missions far from Earth (Fig. 3). 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.

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 for when humans arrive. Such a system could use solar power to collect resources, such as water, 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 a solar cell that will power the system to move the water.

Criteria and Constraints

1. The solar cell(s) 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.
Challenge Organization

To model an authentic engineering work environment, students may be organized in the following way:

1. Assign the students to work in teams of four.
2. Have each team choose a team name.
3. Have each team designate a team member who will lead in the following roles. (Note: All team members should work on the project as a group. The designation is for primary responsibility only.)
   - Design engineer – creates sketches, outlines, patterns, and plans for ideas generated by the team
   - Technical engineer – assembles, maintains, repairs, and/or modifies the structural components of the pumping system
   - Operations engineer – sets up and operates the pumping system to complete a process or test
   - Technical writer/videographer – records and organizes data and prepares documentation (text, pictures, video, etc.) to be reported and published
4. Using the EDP model, complete at least two iterations of designing, building, and modifying the pumping system. Test each system to determine the minimum time required to move the water. Perform a minimum of three tests for each iteration. Be sure to record your data.
5. Allow teams the opportunity to communicate and share ideas and results.
Learning Outcomes

Education Standards

The engineering standards addressed here are tailored for middle 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. This guide contains supplemental material that may be used in addressing the standards noted here. It is not intended to be a curricular unit in these areas.

Standards Addressed

<table>
<thead>
<tr>
<th>Next Generation Science Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Design</strong></td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• MS–ETS1–2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waves and Electromagnetic Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• MS–PS4–2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.</td>
</tr>
</tbody>
</table>

Connected Concepts

<table>
<thead>
<tr>
<th>Common Core State Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mathematics</strong></td>
</tr>
<tr>
<td>• MP.2 Reason abstractly and quantitatively.</td>
</tr>
<tr>
<td>• MP.4 Model with mathematics.</td>
</tr>
<tr>
<td>• 6.RP.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.</td>
</tr>
<tr>
<td>• 6.RP.3 Use ratio and rate reasoning to solve real-world and mathematical problems.</td>
</tr>
<tr>
<td>• 7.RP.2 Recognize and represent proportional relationships between quantities.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td><strong>English Language Arts</strong></td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• 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).</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research.</td>
</tr>
<tr>
<td>• SL.6-8.5 Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.</td>
</tr>
</tbody>
</table>
Evidence of Learning

The EDC 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 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

Prior to starting the EDC, 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. The EDP will vary from team to team; 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

Lastly, student teams should use the Student Presentation Rubric (page 76) to clearly communicate their progress through the EDC. The Student Presentation Organizer (page 72) and the Team Progress Chart (page 74) are tools students can use to help them create a final product that clearly reflects their journey through the EDP.

The finished presentation must meet the following guidelines:

- Include an introduction that identifies the team, the challenge, and the presentation title. For example: “This is team (team name) and we worked on the ‘Powered and Pumped Up’ 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 not be accepted.

- The presentation should document every step students took to complete the challenge, including the Supporting Science Investigations. Encourage students to use their Student Team Challenge Journal to help build the presentation.
- Identify any information provided by NASA scientists and engineers that helped in the design or testing of the system.
- Explain which characteristics of the design provided the most reliable results and why.
- Keep the total presentation length between 3 and 5 minutes.

Once the video or slide presentation is complete, submit according to the guidelines on the Glenn EDC website: https://www.nasa.gov/glenn-engineering-design-challenges
We can identify the challenge and the criteria. Challenge was restated and all criteria and constraints were described.

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.

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.

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.

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.

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.

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.

Our team made design improvements after testing the prototype. All 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.

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

Figure 4.—A NASA educator facilitates an activity with students using small solar panels. (NASA)
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 must be knowledgeable and diligent in providing safe learning environments. Students should receive safety instructions about the topics being taught. Safety assessments should accompany lessons, and records must be kept on student results. The facilitator must properly supervise students while they are working, inspect and maintain equipment and tools to ensure they are in proper working condition, keep all students safe, ensure that a safe environment exists, and ensure that proper procedures are being followed in the classroom and laboratory. Parents should be informed that a safe environment exists during the program.

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

- 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.
- Make safety a priority during all activities.
- Wear safety goggles when conducting all investigations and the challenge.

Figure 5.—NASA researcher wearing personal protective equipment (PPE) appropriate for his work in this Kennedy Space Center lab. PPE should be selected to match the potential risks of the work to be done.
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 EDP iterations to fit their specific needs. It is estimated that the entire EDP for this challenge will take up to 10 hours.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Approximate Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilitator Preparatory Work</td>
<td>2 hours</td>
</tr>
<tr>
<td><strong>Engagement:</strong></td>
<td></td>
</tr>
<tr>
<td>• Access prior knowledge</td>
<td>1 hour</td>
</tr>
<tr>
<td>• Watch the introductory video</td>
<td></td>
</tr>
<tr>
<td>• Present background information</td>
<td></td>
</tr>
<tr>
<td><strong>Exploration and Explanation:</strong></td>
<td></td>
</tr>
<tr>
<td>• Supporting Science Investigation 1: Solar S’mores</td>
<td>2 hours</td>
</tr>
<tr>
<td>• Supporting Science Investigation 2: How Intense Are You?</td>
<td>30 minutes</td>
</tr>
<tr>
<td>• Supporting Science Investigation 3: What's the Point?</td>
<td>30 minutes</td>
</tr>
<tr>
<td><strong>Elaboration:</strong></td>
<td></td>
</tr>
<tr>
<td>• Introduction to the Engineering Design Process (EDP)</td>
<td>30 minutes</td>
</tr>
<tr>
<td><em>The following activities address the other steps of the EDP. They may be completed in any logical order and should be repeated as often as necessary to complete the challenge.</em></td>
<td></td>
</tr>
<tr>
<td>• Identify a Need or Problem</td>
<td>20 minutes</td>
</tr>
<tr>
<td>• Research</td>
<td>1 hour</td>
</tr>
<tr>
<td>• Design</td>
<td>1 hour</td>
</tr>
<tr>
<td>• Prototype</td>
<td>1 hour</td>
</tr>
<tr>
<td>• Test, Evaluate, and Redesign</td>
<td>2 hours</td>
</tr>
<tr>
<td>• Communicate, Explain, and Share</td>
<td>30 minutes</td>
</tr>
<tr>
<td><strong>Evaluation:</strong></td>
<td></td>
</tr>
<tr>
<td>• Creating solution presentations</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>• Student debriefing questions</td>
<td></td>
</tr>
</tbody>
</table>
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:

- 3 V, 70 mA solar cells with wires (1 minimum, 2 preferred)
- Small 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., margarine tubs)
- At least 200 mL tap water
- Buckets, sponges, and other items to hold water and clean up spills
- Stopwatch
- Writing utensils
- Ruler or measuring tape
- Light source (100-W bulb and clamping socket—at least 1 per class)
- Scale for weighing (minimum capacity 1000 g)
- Box lid, tray, or similar 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 and mirrors
- 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)
Engagement: Accessing Existing Knowledge

Prior to starting the EDC, it is 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 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?
- Why do humans want to live on other planets?
- What do microscopes and telescopes have in common?
- Where can we observe pumping systems in use?

Introductory Video

Invite students to watch the challenge’s introductory video, found at the Glenn Research Center EDC website: https://www.nasa.gov/glenn-engineering-design-challenges

EDCs and the 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. It is important for students to be immersed in this vocabulary throughout the challenge.

Keep in mind that it is not enough to simply build a design to solve the challenge. Students must also clearly communicate their questions and their solutions using appropriate STEM vocabulary. As a facilitator, lead by example by incorporating these words as part of your natural dialogue. Examples might include the following:

- “Does that solution meet all the criteria and constraints?”
- “Is that material transparent or opaque?”
- “Would a concave or convex lens work better in this situation?”
- “How could you increase the absorption of light by the solar cell?”

A list of related STEM vocabulary words is included in the Student Team Challenge Journal (page 77). As with any new experience, repeated exposure will aid in student retention. If practical or appropriate, a vocabulary wall can be created to assist in this task.

Provide students with the Student Team Challenge Journal beginning on page 49. Additional sheets should be made available as students work through the challenge. Where possible, engage students by relating the information to their everyday lives. For example,

- Discuss the health risks of prolonged exposure to ultraviolet light waves and the importance of using sunblock to prevent skin burning.
- Discuss the use of photovoltaic cells in some calculators and watches.
- Visit a local solar power array or installation.
- Observe what happens when a candy bar is left in the sunlight and discuss the absorption of infrared energy into the chocolate.
Demonstrate some of the topics discussed in the background information by using objects readily available in the classroom. For example, shine a flashlight onto various objects and ask students to note any **reflection**, **refraction**, or **absorption**.

**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 (Figs. 7 and 8). 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](http://youtu.be/wE-z_TJyzil). After viewing the video, have students discuss what they learned about what an engineer does.

*Figure 7.—Aerospace Engineer Chris Randall tests rocket parts and life support systems to ensure they work as planned. (NASA)*

*Figure 8.—Simulation System Engineer Debbie Martinez works on developing general aviation flight simulation software. (NASA)*

Some examples of NASA-engineered products include the following:

- **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.

It is important for students to understand that engineers help to improve society. It is also essential to address misconceptions about engineers. Men and women 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](https://www.nasa.gov/audience/forstudents/careers/profiles/index.html).
Background Information

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. The intangible desire to explore and challenge the boundaries of what we know and where we have been has provided benefits to our society for centuries.

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.

Since 1958, NASA 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 Moon landings and the Space Shuttle Program years, to today’s orbiting International Space Station (ISS), NASA is on the forefront of manned space flight. NASA’s newest and most advanced human spacecraft, Orion, will usher in a new era of space exploration (Fig. 9). It will serve as the exploration vehicle that will carry a crew to space, provide emergency abort capability, sustain the crew during space travel, and provide safe reentry from deep space at return velocities. Orion was tested in December 2014 in a successful unmanned orbital flight test. It will be launched on a heavy-lift cargo rocket, the Space Launch System (SLS), the most powerful rocket ever built. Destinations for Orion include near-Earth asteroids, our own Moon, the moons of Mars, and eventually Mars itself.

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.

Figure 9.—Illustration of the Orion Spacecraft. (NASA)
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 EDC 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 (Fig. 10). 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 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 over 13 years.

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?

The **photovoltaic cell**, or solar cell, is a specialized semiconductor that converts solar energy to electricity (Fig. 11). 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 (Fig. 12) 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 PET scans and gamma-knife surgeries.
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. 13). 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. 14).

Absorption (Fig. 15) 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. 16), 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.
Refraction (Fig. 17) 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 glass).

![Refraction](image)

**Figure 17.—Refraction of light through materials of different density.**

**Lenses**

Lenses can also be used to manipulate light (Fig. 18). 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.

![Diverging and Converging Lenses](image)

**Figure 18.—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/data/Photovoltaics_FactSheet_rev508.pdf](https://www.grc.nasa.gov/WWW/portal/apps/pv/tablet/data/Photovoltaics_FactSheet_rev508.pdf)
Exploration: Supporting Science Investigations

During the Exploration Phase, students will conduct hands-on or problem-solving activities or investigations designed to help explore the topics and make connections to related concepts. These Supporting Science Investigations are designed to help with students’ understanding of the background material.

The primary goal of these investigations is to teach students how to collect, concentrate, and retain the Sun’s energy. These concepts will be used during the EDC.

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

- **Investigation 1: Solar S’mores (page 25)**
  - The Sun produces wave energy.
  - Wave energy can be reflected through the use of a mirror-like surface.
  - Wave energy can be absorbed through the use of a dark material.
  - Wave energy can be converted into heat energy.

- **Investigation 2: How Intense Are You? (page 28)**
  - Light is a form of wave energy.
  - Light waves will become diffused as they travel over a distance.
  - The amount of diffusion is linear and can be calculated for any given distance.
  - The amount of diffusion varies depending on the angle at which the light reaches a surface.

- **Investigation 3: What’s the Point? (page 31)**
  - A lens manipulates light.
  - There are multiple types of lenses, some of which focus light while others diffuse it further.
  - For every lens, there is a specific distance from which light will be focused in the smallest area.

*Figure 19.—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.*
Supporting Science Investigation 1: Solar S’mores

The Sun is a great source of wave energy. It provides visible waves that we see as light, ultraviolet waves that can cause sunburns, and infrared waves that we feel as heat. In this exercise, we will use the infrared energy from the Sun to create a delicious snack!

A solar oven is a box that uses reflection and absorption to trap some of the Sun’s energy to make the air inside the oven hotter than the air outside the oven. This is very similar to the way a greenhouse works. We can use this heat to cook, and in this activity, we will use it to make s’mores!

Concepts Learned

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

- The Sun produces wave energy.
- Wave energy can be reflected through the use of a mirror-like surface.
- Wave energy can be absorbed through the use of a dark material.
- Wave energy can be converted into heat energy.

Materials

Each group of 2 students will need the following (Fig. 21):

- A bright, sunny day—very important!
- Cardboard box with attached lid, such as a pizza or pie box
- Aluminum foil
- Clear plastic wrap
- Black construction paper
- Glue stick
- Tape (transparent tape, duct tape, masking tape, or any available tape)
- A long, sturdy stick, such as a drinking straw, a knitting needle, or a wood dowel
- Ruler or straightedge
- Scissors
- 2 graham crackers
- 2 large marshmallows
- 1 plain chocolate bar (thin)
- Paper plate—dessert size, black or other dark color
- Oven gloves or towel
- Napkins
- Meat thermometer—should be able to register below 37.78 °C (100 °F)
Procedure: Constructing the Solar Oven

Important: During each stage of the building process, ask students guiding questions.

1. Cut a small pizza box lid, leaving the hinge intact and a 2.5-cm (1-in) border around the lid (Fig. 22).

2. Cut a flap in the front of the pizza box to use as a door to the oven.

3. Cut a square of black construction paper to line the inside base of the box; glue into place.

   Q: What purpose do you think the black paper serves?
   A: The black paper will help absorb heat.

4. Line the inside of the lid and the interior of the box with foil; glue into place. Ensure that the foil is as smooth as possible.

   Q: What purpose do you think the smooth foil serves?
   A: The foil will help reflect the heat evenly throughout the box.

5. Use the stick to hold the lid of the box open at an approximately 45° angle. Use tape to secure the stick.

   Q: Does the angle of the lid matter?
   A: Yes. Sunlight should be reflected into the box.

6. Place a layer of plastic wrap over the opening and tape it to the outside of the box.

   Q: Why do we need a plastic layer?
   A: Sunlight has to pass through and get trapped in the box so it will warm up.

7. Insert the meat thermometer into the side of the box so that the gauge is visible but the stem is completely inside the box. Students will record the temperature inside the box on the Data Collection Sheet.

8. At this point, the oven is built (Fig. 23), but it will need to be preheated prior to cooking. Place the box in a sunny area outside and adjust the angle of the lid to reflect as much sunlight as possible into the box.

   Q: What locations might be better for absorbing heat?
   A: Students should identify places that are very sunny and/or absorb the Sun’s heat well. Examples include locations with asphalt, blacktop, concrete, and no shade.

   Q: What locations might be less effective for absorbing heat?
   A: Under a tree; in deep grass.

9. During the preheating process, record the temperature inside the box every 10 minutes.
10. While the oven is preheating, break the graham crackers into halves and place one of the halves on the paper plate. Place a marshmallow on top of the graham cracker, followed by a piece of chocolate. Do NOT place a second cracker on top of the chocolate yet!

Important: In this recipe, the marshmallow needs to be UNDER the chocolate. This is due to the longer melting time required by the solar oven.

11. After 30 minutes of preheating, QUICKLY remove the plastic wrap from the solar oven, place the paper plate containing the s’more inside the box, and re-cover with plastic wrap (Fig. 24).

12. Take another reading of the temperature inside the box; record in the first space of the Cooking Temperature column.

13. Adjust the flap as necessary during the cooking process to maximize the amount of sunlight entering the box.

14. Record the temperature inside the box every 10 minutes during the cooking process to a maximum of 1 hour.

15. Leave the s’more in the solar oven until the chocolate has melted and the marshmallow softens. Note: Unlike s’mores made with an open flame, the marshmallow will not turn brown or carmelize.

16. Carefully remove the paper plate from the box using the oven gloves (or a towel, if necessary).

17. Add a second graham cracker half to the top of the s’more, squish, and eat!

18. Have students complete the additional tasks on the Data Collection Sheet.

19. Proceed to the Explanation: Supporting Science Investigations Discussion section on page 33 to help students process the concepts for application to the challenge.

Differentiation Suggestions

Modifications

- Prebuild the ovens. Students begin investigation with Step 8.
- Use a glass sheet instead of plastic wrap.
- Use stick-on thermometer strips instead of mercury-filled oven thermometers.

Enrichments

- Build multiple ovens per group, place them in different locations (e.g., grass field, rooftop, and asphalt surface), and compare results.
- Use different brands and sizes of marshmallows and compare results.
- Construct ovens of varying sizes and compare results.
Supporting Science Investigation 2: How Intense Are You?

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 measure this effect.

Concepts Learned

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

- Light is a form of wave energy.
- Light waves will become diffused as they travel over a distance.
- The amount of diffusion is linear and can be calculated for any given distance.
- The amount of diffusion varies depending on the angle at which the light reaches a surface.

Materials

Each group of 2 students will need the following (Fig. 25):

- 2 rulers
- 15-cm length of foam pipe insulation
  (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 (page 59)
Procedure

Prior to beginning this activity, make the room as dark as practical by turning off lights, closing blinds. Ensure enough light remains for safety.

1. 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. 26). Secure with tape.
2. Place the graph paper provided on page 59 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.
3. 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.
4. Turn the flashlight on and begin your observations. The flashlight should only be directed toward the paper and NOT toward any person.
5. Use the data table to record (in cm) the diameter of the circle of light at each height.
6. 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.
7. Have students complete the additional tasks on the Data Collection Sheet. Proceed to the Explanation: Supporting Science Investigations Discussion section on page 33 to help students process the concepts for application to the challenge.

Differentiation Suggestions

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?”

1. Center flashlight beam on yellow dot below.
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 3: What’s the Point?

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: concave, where the lens is thicker at the outer edges than it is in the middle, and convex, where it is thicker in the middle than the outer edges.

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.

Concepts Learned

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

- A lens manipulates light.
- There are multiple types of lenses. Some concentrate light, while others diffuse it further.
- For every lens, there is a specific distance from which light is focused into the smallest area.

Materials

Each group of 3 students will need the following:

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

Procedure

Prior to beginning this activity, make the room as dark as possible by turning off lights, closing blinds, and so forth. Ensure enough light remains for safety.

1. 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.
2. Hold the magnifying lens between the light and the wall at 80 cm from the wall (Fig. 27). Observe any changes to the light that is projected on the wall. Students should identify the outer edges and inner circle of the light that has passed through the magnifying lens.
3. 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.
4. Have students complete the additional tasks on the Data Collection Sheet.
5. Proceed to the Explanation: Supporting Science Investigations Discussion section on page 33 to help students process the concepts for application to the challenge.
Differentiation Suggestions

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.
Explanation: Supporting Science Investigations Discussion

The following investigation discussions are designed to reinforce the student’s 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 Science Supporting Investigation are included in this guide. Ask one of the Discussion Questions to begin the Think-Pair-Share process.
2. Provide approximately 5 minutes for students to think independently.
3. Next, provide approximately 5 minutes for the students to share in pairs.
4. Finally, have students share their ideas in a class discussion.
Investigation Discussion 1: Solar S’mores

Concepts Learned

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

- The Sun produces wave energy.
- This energy can be reflected through the use of a mirror-like surface.
- This energy can be absorbed through the use of a dark material.
- The energy can be transferred into another medium, in this case air.

Discussion Questions

1. The Solar S’mores activity used the infrared energy from the Sun to heat a solar oven on Earth. If we were able to perform this same investigation on another planet, such as Mars, would the oven perform the same, better, or worse than it does here on Earth, and why?
2. What modifications to the design might make it more effective on another planet?
Investigation Discussion 2: 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 diffused as they travel over a distance.
- The amount of diffusion is linear and can be calculated for any given distance.
- The amount of diffusion varies depending on the angle at which the light reaches a surface.

Discussion Questions
1. In the “How Intense Are You?” activity, we learned that wave energy from the Sun diffuses as it travels away from the Sun. If our challenge is to collect as much of this energy as possible, what could we do to reverse the impact of light diffusion?
2. Would being on another planet, such as Mars, make it easier or more difficult to reverse the impact of light diffusion?
Investigation Discussion 3: 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 diffuse it further.
- 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?
Elaboration: The Engineering Design Challenge

Introduction to the Challenge

Discuss the information covered in the EDC with your students. Using the background information starting on page 19, explain how NASA’s exploration of planets, such as Mars, will require the collection and storage of water and other resources for use by future inhabitants. Explain the EDP and how students will progress through the various practices. Emphasize that students may choose any path through the model but should be able to explain why they selected a particular path.

Set up at least one test area for students to use to evaluate their solutions (Fig. 28). Additional test areas should match the original, and each area should include the following:

- Scale for determining whether student solutions meet mass requirement
- Clean tabletop surface, approximately 1 square meter in size
- Utility work light with 100-W 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

As a class, discuss the individual components of this challenge. Demonstrate how to wire the solar cell(s) and pump by twisting all of the red wires together and all of the black wires together, then securing each connection with tape (Fig. 29).

Provide each student with the EDC Student Team Challenge Journal. Introduce the EDP 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.

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**Figure 28.—Setup of test area.**

**Figure 29.—Wiring setup for one solar cell or multiple cells.**
Prior to concluding the session, ask each team to present their initial findings to the class and discuss how they will attempt to solve the challenge. Encourage students to use the vocabulary words to assist in describing their ideas.

As students proceed through the process, they should record steps accomplished on the Team Progress Chart. 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 EDC, teams must use the EDP. As they work the steps of the EDP, students will be engaging in authentic engineering practices.

The following section explains how each step relates to this challenge and describes how to facilitate each activity.

**Identify a Need or Problem**

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

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. This step was completed during the Introduction to the Challenge Problem, although it may be reiterated with your students as needed.

**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?

**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.

**Enrichments**

- 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 page from the Student Team Challenge Journal.*

Research is done to learn more about the identified need or problem and potential solution strategies. For this challenge, guide students to explore how solar panels are currently used in commercial applications. An additional focus area to research is solar concentrators. It is important to remember that NASA subject matter experts (SMEs) are available to assist in answering questions. SME connections can be requested at the NASA Glenn EDC website: [https://www.nasa.gov/glenn-edcs-submit-student-solutions](https://www.nasa.gov/glenn-edcs-submit-student-solutions)

**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?

**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.

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. Students must create the initial design from scratch, but if time is limited, consider guiding teams to redesign aspects of that initial design as opposed to exploring totally new solutions for each iteration.

**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?
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. 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 following guiding questions as discussion prompts to focus student understanding.

- What is one strength of each student’s individual 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 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.

**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?

**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 meter of duct tape).

Test and Evaluate

**Students complete the Test and Evaluate page from the Student Journal.**

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?

**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

*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 EDP.
Communicate, Explain, and Share

*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.

**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?

**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 students conduct poster presentations and describe their results to other teams.
Evaluation: Student Debriefing Questions

The following questions are designed to help start a discussion with your students. It is important to use open-ended questions that do not automatically lead students to a specific answer. Avoid questions that can be answered “Yes” or “No.”

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?
   
   With questions 3 and 4, we are confirming that the 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 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?
    
    Students can visualize themselves as astronauts as a way to evaluate their solution in a real-world context.
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 EDC. The Student Team Challenge Journal was designed to help document each stage of the 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 ‘Powered and Pumped Up’ 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 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 document is complete, submit the presentations using the process explained on the NASA Glenn EDC website: https://www.nasa.gov/glenn-edcs-submit-student-solutions
Options for Differentiating Instruction

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

Modifications

- For the “Solar S’mores” activity, consider prebuilding the ovens and using stick-on thermometer strips instead of mercury-filled oven thermometers. Additionally, a glass sheet may be used instead of plastic wrap.
- For “What’s the Point?” consider taping the flashlight to a table to maintain a constant distance from the wall.
- For the EDC, consider wiring the solar cell and pump ahead of time as younger students may struggle with this activity. If necessary, build the entire machine for the students and focus solely on how to improve performance.

Enrichments

- For “Solar S’mores,” consider building multiple ovens per group, placing them in different locations (e.g., grass field, rooftop, or asphalt surface), and comparing the results.
- For “How Intense Are You?” have students repeat the experiment with multiple iterations of various angles (30°, 45°, and 60°) to witness the effect on the inner and outer circles as angles increase.
- For “What’s the Point?” have students measure the diameter of the circle that is projected on the wall to include in their observations, or consider purchasing a light meter. Instead of shining the light onto a table or wall, shine the light into the light meter. Modify the challenge so that the goal is to have the highest reading on the meter.
- For the EDC, use multiple solar cells and experiment with wiring the cells in either serial or parallel configurations.
- If desired, a challenge can be added by advising students that the rocket designed to send their machine to Mars has not met its design specifications. As such, this machine must be reduced to 600 g without affecting performance.
- Provide one or more realistic scenarios that test a design’s ability to perform under unfavorable conditions. Examples might include operations under limited lighting conditions (use a smaller and/or dimmer bulb), operations in a dust storm (cover parts of the solar cell with sand), or operations under heavy loads (add more water to the supply tank).

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 Worksheet included here to determine the cost of their solution as tested.
- Next, advise students that NASA plans to mass-produce their machine for use at multiple locations on Mars, but due to financial constraints, the annual budget has been reduced by 15 percent. Students will be required to redesign their machine to reduce costs, but without reducing performance.
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 pumping system.

<table>
<thead>
<tr>
<th>Line Item Number</th>
<th>Material</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Item Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>14</td>
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</tbody>
</table>

Total Cost:
Student Team Challenge Journal

Figure 30.—Students study materials before beginning construction of a model solar-powered water heater. (NASA)
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 send them into space. One alternative could be nuclear power, but this EDC will focus on solar power.

The Sun emits a tremendous amount of energy, or electromagnetic radiation, every second of every day. One way to think of this is in comparison to a large power station here on Earth. 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 to the other planets, but it is still an incredibly large amount. 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?

Solar power is a primary source of power for many NASA satellites, landers, and rovers as well as for the International Space Station. The requirements of space flight, primarily weight and size constraints, demand that solar energy systems be as efficient and lightweight as possible. To achieve this, researchers at NASA are working to create new, lightweight materials that make solar energy more efficient.

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 take panoramic images of the Martian landscape. Scientists look at these images and select promising geological targets that may tell part of the story of water in Mars’ past. Through remote control, the rovers drive to selected locations to perform mechanized scientific investigations. The rovers are equipped with tools to study a diverse collection of rocks and soils that may hold clues to past water activity on Mars. The Mars Exploration 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 solar cells that collect the Sun’s energy. The original lifespan of these rovers was projected to be 90 days. Spirit finally stopped moving after 6 years, but Opportunity has exceeded the 90-day projection for its battery life by over 13 years and continues its journey today.

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 for other home and business needs.
How Does Solar Power Work?

The photovoltaic cell, or solar cell, is a specialized semiconductor that converts solar energy to electricity (Fig. 31). 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. A single solar cell would not supply sufficient power on its own, so solar cells are typically joined together to create a solar panel.

Electromagnetic Radiation and Waves

Electromagnetic radiation is all around us, although it is mostly invisible to the naked eye. It is produced in the form of waves of various sizes (Fig. 32), all of which travel at the speed of light. Large low-frequency waves, like radio waves and microwaves, can travel great distances but are easily blocked by buildings and other objects. As the waves get smaller, we move into infrared energy. We cannot see infrared energy, but we can feel it in the form of heat. One unique feature of infrared waves is the way they react to the materials they touch. Dark materials absorb the energy and become warm because of it, while light materials reflect the waves and stay cool. Visible light energy is just a very small part of electromagnetic radiation.
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. 33). In fact, the only reason our eyes can see is because light hits everything around us and reflects that light into our eyes. This is why we cannot see as well at night. We can use reflection to move light around objects or to amplify light to make things brighter. Examples of this include telescopes, binoculars, and microscopes. Light can also bend. The bending of light around edges or small slits is called diffraction (Fig. 34).

Absorption (Fig. 35) 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. This is because white objects are better at reflecting light, while black objects are better at absorbing light.

Diffuse reflection, or scattering (Fig. 36), 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.
Refraction (Fig. 37) 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 glass).

![Refraction of light through materials of different density.](image)

Lenses

Lenses can also be used to manipulate light. 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 (Fig. 38). Lenses can be thicker in the center than on the edge, or converging (Fig. 38). These lenses can gather light to concentrate it or diffuse light to disperse it.

![Diverging and converging lenses refract light.](image)

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/data/Photovoltaics_FactSheet_rev508.pdf](https://www.grc.nasa.gov/WWW/portal/apps/pv/tablet/data/Photovoltaics_FactSheet_rev508.pdf)
Supporting Science Investigation 1: Solar S’mores

Concept

The Sun is a great source of wave energy. It provides visible waves that we see as light, ultraviolet waves that can cause sunburns, and infrared waves that we feel as heat. In this exercise, we will use the infrared energy from the Sun to create a delicious snack!

A solar oven is a box that uses reflection and absorption to trap some of the Sun’s energy to make the air inside the oven hotter than the air outside the oven. This is very similar to the way a greenhouse works. We can use this heat to cook, and in this activity, we will use it to make s’mores!

Materials

Each group of 2 students will need the following:

- A bright, sunny day—very important!
- Cardboard box with attached lid, such as a pizza box or a pie box
- Aluminum foil
- Clear plastic wrap
- Black construction paper
- Glue stick
- Tape (transparent tape, duct tape, masking tape, or any available tape)
- A long, sturdy stick, such as a drinking straw, a knitting needle, or a wood dowel
- Ruler or straightedge
- Scissors
- 2 graham crackers
- 2 large marshmallows
- 1 plain chocolate bar (thin)
- Paper plate—dessert size, black or other dark color
- Oven gloves or towel
- Napkins
- Meat thermometer (digital, to record temperature in degrees Celsius)
Procedure: Constructing the Solar Oven

1. Cut a small pizza box lid, leaving the hinge intact and a 2.5-cm (1-in) border around the lid (Fig. 40).
2. Cut a flap in the front of the pizza box to use as a door to the oven.
3. Cut a square of black construction paper to line the inside base of the box. Glue the paper into place.
4. Line the inside of the rest of the box with foil; glue the foil into place. Ensure that the foil is as smooth as possible.
5. Use the stick to hold the lid of the box open at an approximately 45° angle. Tape the stick into place.
6. Place a layer of plastic wrap over the opening and secure to the outside of the box.
7. Insert the thermometer into the side of the box so that the gauge is visible but the stem is completely inside the box. Record the temperature inside the box on the Data Collection Sheet.
8. At this point, your oven is built (Fig. 41), but it will need to be preheated prior to cooking. Place the box in a sunny area outside and adjust the angle of the lid to reflect as much sunlight as possible into the box.
9. During the preheating process, record the temperature inside the box every 10 minutes.
10. While the oven is preheating, break the graham crackers into halves. Place one of the halves on the paper plate. Place a marshmallow on top of the graham cracker, followed by a piece of chocolate. Do NOT place a second cracker on top of the chocolate yet! Important: In this recipe, the marshmallow needs to be UNDER the chocolate. This is due to the longer melting time required by the solar oven.
11. After 30 minutes of preheating, QUICKLY remove the plastic wrap from the solar oven, place the paper plate containing the s’more inside the box, and re-cover with plastic wrap (Fig. 42).
12. Take another reading of the temperature inside the box; record in the first space of the Cooking Temperature column.
13. Adjust the flap as necessary during the cooking process to allow the maximum amount of sunlight to enter the box.
14. Record the temperature inside the box every 10 minutes during the cooking process to a maximum of 1 hour.
15. Leave the s’mores in the solar oven until the chocolate has melted and the marshmallow softens. Note: Unlike s’mores made with an open flame, the marshmallow will not turn brown or caramelize.
16. Carefully remove the paper plate from the box using oven gloves (or a towel, if necessary).
17. Add a second graham cracker half to the top of the s’more, squish, and eat!
18. Complete the additional tasks on the Data Collection Sheet.
Data Collection Sheet

Use the chart below to record the temperature of your oven at these intervals.

<table>
<thead>
<tr>
<th>Preheating Time</th>
<th>Temperature</th>
<th>Cooking Time</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>Start</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 minutes</td>
<td>10 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 minutes</td>
<td>20 minutes</td>
<td></td>
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<td>30 minutes</td>
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<td>40 minutes</td>
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<td></td>
<td></td>
<td>50 minutes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 minutes</td>
<td></td>
</tr>
</tbody>
</table>

Use the graph below to plot the temperature of your solar oven as it **preheated** outside in the sunlight. (You will use a separate graph to plot the cooking temperature.)

Describe the graph you plotted above. What happened to the temperature of the oven during the preheating time?
Why do you think that happened?

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Use the graph below to plot the temperature of your solar oven as the s’mores **cooked** outside in the sunlight.

![Graph](image_url)

Describe the graph you plotted above. What happened to the temperature of the oven during the cooking time?

_________________________________________________________________________

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Why do you think that happened?

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What was the purpose of the black paper on the base of the box?

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Why was it important to keep the foil as smooth as possible inside the box?

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Supporting Science Investigation 2: 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 measure this effect.

Materials

Each group of 2 students will need the following:

- 2 rulers
- 15-cm length of foam pipe insulation
  (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 (page 59)

Procedure

Prior to beginning this activity, make the room as dark as practical by turning off lights, closing blinds, etc. Make sure that enough light remains for safety.

1. 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. 44). Secure with tape.
2. Place the graph paper provided on page 59 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.
3. 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.
4. Turn the flashlight on and begin your observations. The flashlight should only be directed toward the paper and NOT toward any person.
5. Use the data table to record the diameter (in cm) of the circle of light at each height.
6. 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.
7. Complete the additional tasks on the Data Collection Sheet.
Graph Paper for “How Intense Are You?”

Center flashlight beam on yellow dot below.

Count how many 1-cm squares are illuminated by the flashlight’s beam. This is the diameter of the beam.

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.

<table>
<thead>
<tr>
<th>Flashlight Height</th>
<th>Diameter of Circle, cm</th>
<th>Observations: Brightness of Circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 cm</td>
<td></td>
<td>![Shade for brightness]</td>
</tr>
<tr>
<td>8 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plot the results of your investigation on the graph.
Describe what happens to the diameter of the circle as the distance from the light source increases.

_________________________________________________________________________

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_________________________________________________________________________

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

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.

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.

Was your prediction accurate? YES / NO

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________
Supporting Science Investigation 3: 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 lens: concave, where the lens is thicker on the outside than it is in the middle, and convex, where the middle is thicker than the outside. Some lenses concentrate light and some diffuse 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.

Materials

Each group of 3 students will need the following:

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

Procedure

Prior to beginning this activity, make the room as dark as possible by turning off lights, closing blinds, etc. Make sure that enough light remains for safety.

1. 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.
2. 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.
3. Hold the magnifying lens between the light and the wall at 80 cm from the wall (Fig. 44). Observe any changes to the light that is projected on the wall.
4. 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.
5. Complete the additional tasks on your Data Collection Sheet.
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.

What information did you use to make your prediction?

Complete the table below using the results from your investigation.

<table>
<thead>
<tr>
<th>Distance between magnifying glass and wall</th>
<th>Observations of light projected on the wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Magnification</td>
<td></td>
</tr>
<tr>
<td>80 cm</td>
<td></td>
</tr>
<tr>
<td>70 cm</td>
<td></td>
</tr>
<tr>
<td>60 cm</td>
<td></td>
</tr>
<tr>
<td>50 cm</td>
<td></td>
</tr>
<tr>
<td>40 cm</td>
<td></td>
</tr>
<tr>
<td>30 cm</td>
<td></td>
</tr>
<tr>
<td>20 cm</td>
<td></td>
</tr>
<tr>
<td>10 cm</td>
<td></td>
</tr>
</tbody>
</table>

What was the actual distance where the light was at its smallest point?

Did the amount of light change during the investigation? How do you know?

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

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?
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 diagram (Fig. 45) to help solve this challenge.

![Diagram of the Engineering Design Process]

Figure 45.—This Engineering Design Process model was adapted from the 2016 Massachusetts Science and Technology/Engineering Curriculum Framework (published April 2016, 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 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 following pages should document your EDP. Use as many sheets as you need to document each step of the process.

1. Always fill in the page number. This will help you keep your notes 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.
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 resources, such as water, from the soil or atmosphere and store them until humans arrive some time later.

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 a solar cell to power the system. The solar cell 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 challenge’s introductory video, answer the following questions.

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.

1. 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

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?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Sketch your pumping system in the space below and label each part of your drawing.
The Engineering Design Process: 
Select the Best Possible Solution

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.

<table>
<thead>
<tr>
<th>Designer Name</th>
<th>Does this design meet all problem criteria and constraints?</th>
<th>What are the strongest elements of this design?</th>
<th>What elements need to be improved?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 _______________________

1. List what resources will need to be gathered.

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

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

<table>
<thead>
<tr>
<th>Team Member</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsibilities in the building process</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Engineering Design Process:
Test and Evaluate

Page Number_________

Does the pump function as intended?  
YES  NO

If not, explain why in more detail:
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

Which of the following criteria and constraints does the pump 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.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to pump 200 mL of water, sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best time in iteration, sec</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>Current Time</th>
<th>−</th>
<th>Original Time</th>
<th>=</th>
<th>Difference</th>
<th>÷</th>
<th>Original Time</th>
<th>× 100</th>
<th>Percent Change</th>
</tr>
</thead>
</table>

Other Observations
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
The Engineering Design Process: Provide Feedback

Page Number_________

Indicate the step you are providing feedback on.

____________________________________

____________________________________

____________________________________

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

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

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

Which step of the EDP will your team move to now?

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

Explain why your team chose this step.

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________
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.

<table>
<thead>
<tr>
<th>Welcome</th>
<th>Tell the title of your presentation, introduce your team, and tell what challenge your team worked on.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Design Process Practice</td>
<td>Ideas for what should be included in each step of the presentation</td>
</tr>
<tr>
<td>Identify the Need or Problem</td>
<td>Talk about the problem and the constraints. Discuss the constraints that will need to be met to solve the problem.</td>
</tr>
<tr>
<td>Research</td>
<td>Discuss what your team discovered during the research and through your interaction with a NASA SME. Who did you speak with? What did you learn? Where did you find answers to your questions? Describe how solar energy is relevant to everyday life.</td>
</tr>
<tr>
<td>Design</td>
<td>Show each team member's original designs. Show what each team member contributed to the original team drawing.</td>
</tr>
</tbody>
</table>
**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.

<table>
<thead>
<tr>
<th>Summary Data Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration</td>
</tr>
<tr>
<td>Original Test</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

**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 in which order. This table, along with your Student Presentation Organizer, will assist you in summarizing your team’s entire process from beginning to end.

<table>
<thead>
<tr>
<th>Practice Order</th>
<th>Which engineering practice did your team do?</th>
<th>Notes on what your team did or learned during this practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Identify a Need or Problem</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<td>3</td>
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<td>13</td>
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<td></td>
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<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solution Presentation

The final stage of the challenge is to document your progress for sharing with other groups who have completed this EDC. 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 ‘Powered and Pumped Up’ 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 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!

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

**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

**Forces** – pushes or pulls

**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** – a material through which no light can pass; 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 glass)

**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** – a material that allows light to pass through so that objects behind can be distinctly seen; 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](https://www.nasa.gov/sites/default/files/atoms/files/solar_power_5-12.pdf)

**NASA Glenn Solar Research** – Learn about solar research happening at the NASA Glenn Research Center.  

**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/](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](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](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.  

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](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](https://www.youtube.com/watch?v=8j6SmPmN7B8)

[https://www.youtube.com/watch?v=sm6RrQb5698](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](https://www.youtube.com/watch?v=ZD5_fjSm0rs)
Back cover: This solar simulator in NASA’s photovoltaic lab tests next-generation space solar cells. It contains 1,500 light sources and emits light invisible to the human eye.