



BUILDING A PERMANENT HUMAN PRESENCE IN SPACE

GRADES K-4

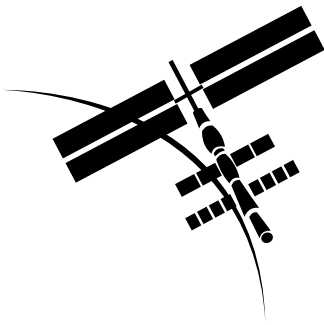
LESSON 3: SOLAR ARRAYS FOR THE SPACE STATION

The United States and its partners around the world are building the International Space Station (ISS), arguably the most sophisticated engineering project ever undertaken. The ISS is an orbiting laboratory where astronauts conduct research in a variety of disciplines including materials science, physiology in microgravity environments, and Earth remote sensing. The ISS provides a permanent human presence in low Earth orbit.

This lesson is one of many grade K-12 lessons developed by Challenger Center to bring the ISS experience to classrooms across the nation. It is part of Building a Permanent Human Presence in Space, one of several Education Modules developed for Challenger Center's Journey through the Universe program. This Education Module addresses the essential question "How can we build a permanent human presence in space?" Start the *Journey* at www.challenger.org/journey.



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LESSON 3: SOLAR ARRAYS FOR THE SPACE STATION

LESSON AT A GLANCE

LESSON OVERVIEW

Engineers must come up with unique designs when developing devices that will be used in space. These designs must meet the demands of the space environment and the limitations of rockets available to launch things into orbit. One such design challenge is the solar arrays for the International Space Station. In this lesson, students will compare the operating life of solar cells to batteries. They then will use models of the solar arrays and the cargo bay of the Space Shuttle to explore safe, effective ways to package the solar arrays for transport into space.

LESSON DURATION

Two 45-minute class periods



CORE EDUCATION STANDARDS

National Science Education Standards

Standard E1: Abilities of Technological Design

- Identify a simple problem
- Propose a solution
- Implementing proposed solutions
- Evaluate a product or design
- Communicate a problem, design, and solution

Standard E2: Understanding about science and technology

- People have always had problems and invented tools and techniques (ways of doing something) to solve problems. Trying to determine the effects of solutions helps people avoid some new problems.



ESSENTIAL QUESTION

- ▶ What are the issues that must be considered when packing and transporting equipment into space?



CONCEPTS

Students will learn the following concepts:

- ▶ Solar arrays convert energy from the Sun into usable electricity.
- ▶ Models are an excellent tool for designing and understanding large objects.
- ▶ When building a structure, engineers have to factor in constraints such as time, money, and size.



OBJECTIVES

Students will be able to do the following:

- ▶ Identify issues such as cost and volume when transporting equipment into space.
- ▶ Construct a model of a solar array.
- ▶ Design a method for folding and packing the solar array model.
- ▶ Test the design of this solar array model.

SCIENCE OVERVIEW

Why does the International Space Station (ISS) have solar panels? Why are they so big? Why not just use batteries?

These are sensible questions asked by children and engineers. Children ask because they're curious and want to understand. Engineers ask the same questions because it's their job to do so, in order to find the best way possible to solve a problem (and they're curious, too). There are important questions that need to be asked, and answered, in order to understand the choices and decisions that have to be made in building things. Every man-made object and part in the space station had to be put there by human beings; it had to be made by human beings; and it had to be designed by human beings. Every man-made object is the work of an engineer, whether the object is destined for use on the space station or here on the ground. Every feature or defect in a man-made object is the result of a decision made by a person—there are no accidents, only unexpected results. With objects in space, design choices have to be determined long before the object is made and put to use, because it is very hard to fix problems that appear afterwards. Engineers need to think through the details of everything that they want to do in building a complicated space facility like the ISS, long before anything can be built.

The solar panels are an important feature of the ISS, carefully engineered to do a job in space. The ISS needs electricity to cool and to heat the station (depending on whether it is in sunlight or in the Earth's shadow), to heat food, to run the lights, to run the many computers and scientific experiments on board, to operate the robot arm, to turn the fans and run the pumps that remove stale air and replace it with fresh air, and to purify the air and waste water. All of these activities require electricity, and it has to come from somewhere. The electrical power system on the ISS is the second most important designed feature in the station; without it, the station is just a metal can full of air. The only feature more important is the station's ability to hold air for the astronauts.

A PATH TO POWER: STORED ENERGY

One way to power a spacecraft is to pack it with energy before flight. This is the method used with the Apollo manned missions in the 1960s and -70s, and used today with the Space Shuttle. These spacecraft used (or use) a device called a fuel cell. The fuel cells in spacecraft make electricity by combining hydrogen and oxygen, which also makes

water. This is the same chemical reaction as burning hydrogen in air. Uncontrolled hydrogen burning is essentially an explosion, but the fuel cell does it under controlled conditions to produce electricity very efficiently and safely. Energy has to be used here on Earth to produce pure hydrogen and oxygen for fuel before the spacecraft flies. That energy is recovered in the spacecraft when the hydrogen and oxygen recombine in the fuel cell to make water. The water from the fuel cell is used by astronauts for drinking and washing, so that little additional water needs to be launched. Fuel cells and their fuel are expensive, but they are reliable and the water is a useful byproduct.

A different way to store energy is with a battery. The earliest artificial satellites used simple battery power. Batteries are relatively heavy and do not make a useful byproduct like water. On the other hand, a battery is self-contained and does not require handling fuel like liquid hydrogen or liquid oxygen. Rechargeable batteries are common in spacecraft to help even out the power supplied by other systems.

The problem with either batteries or fuel cells is that eventually they will run out of energy—a fuel cell will use up all of its fuel, a battery will use up its charge. A used-up fuel cell is not massive once all the water has been used and disposed of. However, a discharged battery weighs as much as a fully-charged battery. A spacecraft returning to Earth from space carries the weight of its used-up batteries. In either case, fuel cells or batteries, once the stored energy is gone, it's gone.

A DIFFERENT PATH TO POWER: IN-FLIGHT GENERATION

The other way to obtain electricity for a spacecraft is to generate it in the spacecraft. Spacecraft traveling into “deep space” (away from the Sun) often carry devices called RTGs—radioisotope thermoelectric generators. RTGs are devices that capture the energy that is released by radioactive plutonium in order to make electricity from it. RTGs do not produce a lot of electric power, only a few hundred watts in the most modern devices—enough to power several one-hundred-watt light bulbs. Even a small nuclear reactor is much more powerful. However, a nuclear reactor also is more risky to launch into space than an RTG, which is designed to remain in one piece even through the worst-case scenario of a crash-landing on Earth. A reactor uses a larger amount of radioactive material, and it is more difficult to engineer a reactor to be as tough as an RTG. NASA's Project Prometheus is developing nuclear reactors for spacecraft, but it is not clear if any of these reactors would stay in Earth orbit. There are very strict safety requirements that new hardware must meet in order to qualify for space flight.

Solar Arrays
for the Space
Station

Lesson at a Glance

Science Overview

Conducting the
Lesson

Resources

The ISS has high power requirements. Normal operation demands about 78 kilowatts (kW) of electricity. Nuclear reactors are not available, RTGs do not produce enough power, and fuel cells and batteries run out of power. The ISS is slated for continued use while completing construction by about 2010, and presumably should remain useful for years afterward. It needs a way to produce electricity in flight, using current technology. That way is solar electric power.

Sunlight carries energy, but the amount of energy reaching a given area in a given amount of time is limited. If all the energy from sunlight falling on a patch of material in space could be captured and used as electricity, it would be about 1370 watts of power from each square meter. Real systems are not perfect, however. The best photovoltaic cells (solar cells) manufactured today are able to convert to electricity only about 20–25% of the energy they absorb from sunlight. The rest of the energy just warms the cell. A 25% efficient solar cell must cover a square 36 cm on a side in order to power a laptop computer (about 45 watts); a square 54 cm on a side is needed to power a 100 watt light bulb; a square 161 cm on a side is needed to power a 900 watt blow-dryer. The ISS demands the power of 87 blow-dryers, which is a surprisingly small amount of power to run a manned space facility. That means a square solar panel 15 m (50 feet) on a side is needed to meet the basic power requirements.

The real ISS solar panels cover a much bigger region than a 15 m square, in order to account for a number of additional concerns:

1. The ISS is in sunlight only about two-thirds of the time; the other one-third, it is in the Earth's shadow and needs to run all of its systems off of power from batteries that are recharged by the solar cells. The solar panels must recharge the batteries, as well as provide for the station's immediate power needs while in sunlight.
2. There needs to be excess capacity to provide for unusual power demands without the power system failing.
3. There needs to be excess capacity to account for failures of whole sections in the solar array electronics.
4. There is some space between active cells in the arrays of photovoltaic cells.
5. There needs to be excess capacity because the space environment slowly damages the photovoltaic cells so that they produce less electricity over time.
6. The solar panels are not always properly turned to face the Sun straight-on. There needs to be enough power to run the ISS when the solar panels are turned at an angle, so that the station will keep running while the error is corrected.

With these additional concerns in mind, the total area of the photovoltaic arrays for the ISS probably is four or more times the amount required to produce 78 kW from fresh, new solar cells under the best conditions possible .

ISS engineers had to find ways to fold up enormous sheets of stiff photovoltaic cells so that they could be launched into space with the launch vehicles that are available today, since the solar arrays had to open up to be much larger than the Space Shuttle. Solar cells are stiff and brittle. Some flexible solar cells are available, but they are much less efficient than regular rigid cells, which means many more of them are required to produce the same amount of electricity. The sheets of cells had to be able to spread out and to unfold automatically in space, so that astronauts had to go out into space as little as possible to put them together and to make them work with the space station.

In this lesson, students explore this design process to figure out how to fit model photovoltaic arrays into a model of the Space Shuttle cargo bay.

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for the Space
Station

Lesson at a Glance

Science Overview

Conducting the
Lesson

Resources

CONDUCTING THE LESSON

WARM-UP & PRE-ASSESSMENT



TEACHER MATERIALS

- ▶ Picture or overhead transparency of International Space Station

PREPARATION & PROCEDURES

1. Show students the picture of the International Space Station (ISS) located in the back of the lesson. Ask students if they know where the ISS is located. (*Desired answer: orbiting around the Earth*) Ask students how they think the ISS gets electrical power. (*Answers will vary: batteries, electricity, solar energy, propane, etc.*) Ask students to create a list of pros and cons for each type of energy they think the ISS uses. (*Desired answer: All of the energy sources, except solar energy, will eventually run out. You would need to continually bring batteries or fuel into space. Solar energy is always available and the safest option.*)
2. Ask students to describe a solar cell. (*Desired answer: something that takes the Sun's energy and turns it into useable electricity*) Show students the picture of the ISS again. Ask students if they can identify the solar arrays. After taking suggestions, point out the solar arrays and tell students that they are sheets with a lot of solar cells on them. Ask students to compare the size of the solar arrays to the size of the space station. (*Desired answer: they are much bigger*)
3. Ask students why they think the solar arrays need to be so big. (*Desired answer: The solar arrays need to collect a lot of sunlight to produce enough energy to run the ISS. There is a limit to how much energy you can get from sunlight, and even the best solar panels only convert about one-fourth of the power, the rest just heats up the solar panel. It takes a square solar panel 36 cm on a side to run a laptop computer, a panel 54 cm on a side to light a 100 watt light bulb, and a panel 162 cm on a side to run a 900 watt blow dryer.*)
4. Ask students how they think the solar arrays got into space. (*Desired answer: Space Shuttle or other rocket*) Tell students that they are much too big to fit directly into the Space Shuttle. Ask them to brainstorm ways the Space Shuttle could have taken them into space. (*Desired answer: fold them*) Tell students that they will be engineers and will have to design a way to get the solar arrays into space.

NOTES:

Solar Arrays
for the Space
Station

Lesson at a Glance

Science Overview

Conducting the
Lesson

*Warm Up &
Pre-Assessment*

*Activity:
Solar Array Design*

Lesson Wrap-Up

Resources

ACTIVITY: SOLAR ARRAY DESIGN

In this activity, students will use models of solar arrays and the cargo bay of the Space Shuttle to determine a safe, effective way of packaging solar arrays to go into space.

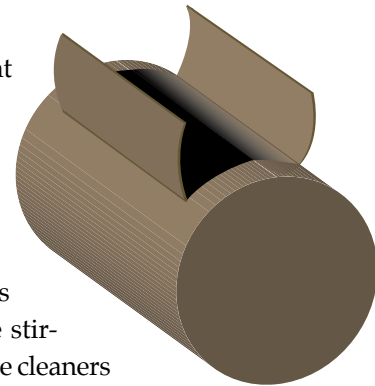


STUDENT MATERIALS (PER GROUP)

- 10 drinking straws of different lengths and types
- 30 hollow, plastic coffee stirrers
- 10 pipe cleaners
- 4 index cards (3" x 5")
- Tape
- 1 or 2 cylindrical cardboard containers (e.g., oatmeal)
- Scissors
- Student Worksheet

PREPARATION & PROCEDURES

1. This activity can be done by individual students or by small groups of students.
2. Before the students arrive, prepare the materials by cutting index cards into quarters so that they measure about 7.5 cm x 3 cm (3" x 1.25"), cut 10 coffee stirrers into quarters (pieces about 1" in length), and cut out the cylindrical cardboard container so that it opens like a Space Shuttle cargo bay. See diagram below. If your students are capable, you may have them prepare these materials on their own.
3. Pass out the age-appropriate Student Worksheet.



LESSON ADAPTATION

Talented and Gifted: Have your students replace the index cards with aluminum foil. Determine whether it is possible to unfold the arrays without damaging them. Much like real solar arrays, the foil is extremely thin.

4. Introduce the students to the materials and discuss what each of them represents: index cards = solar arrays containing lots and lots of solar cells; coffee stirrers = solar array support; pipe cleaners = hinges; cylindrical container = cargo bay. Tell your students that these are the **ONLY** supplies they will be getting.

5. With these materials, challenge your students to design a method of building the solar arrays so that they can be packed within the cargo bay. However, they should remember that they can cut everything except the index cards and the oatmeal box. They should draw a picture of their design on their Student Worksheet.

REFLECTION & DISCUSSION

Once students have completed their designs, compare them as a class and have students write about the challenges that had to be overcome to assemble their solar arrays. Lead a class discussion. Some possible questions to ask include:

- Was there more than one possible way to design the arrays?
- What was the most difficult obstacle to overcome?
- Would you change your design now that you have seen others? If so, how?

TRANSFER OF KNOWLEDGE

Challenge students to design a way to carry something delicate from home to school in their backpacks. Have the class decide on one object that they will all carry, such as an egg. Have students draw a diagram of their design, noting what materials they would use, how they would use them, and why.

EXTENSIONS

- The weight of equipment is an important factor when transporting it into space. Engineers try to design equipment to be as light and compact as possible. With this in mind, you can weigh each student's model to see which was lightest.

PLACING THE ACTIVITY WITHIN THE LESSON

When designing anything, certain constraints and restrictions exist, such as size and money. Transporting equipment into space is expensive; costs can be minimized by reducing the number of trips needed to take equipment into space. Discuss with students how their designs safely transported their model solar arrays, and also saved money.

Solar Arrays
for the Space
Station

Lesson at a Glance

Science Overview

Conducting the
Lesson

*Warm Up &
Pre-Assessment*

*Activity:
Solar Array Design*

Lesson Wrap-Up

Resources



ASSESSMENT CRITERIA FOR ACTIVITY

4 Points

- ▶ Accurately and thoroughly describe at least three problems that occurred in construction of the solar arrays.
- ▶ Used creative and reasonable ways to solve the most important problem(s).
- ▶ Identified how the problem was solved and showed a deep understanding of the problem and solution by thoroughly explaining what happened.
- ▶ Designed a creative and reasonable way to transport a delicate item in his/her backpack.

3 Points

- ▶ Accurately described at least three problems that occurred in construction of the solar arrays.
- ▶ Used creative and reasonable ways to solve the most important problem(s).
- ▶ Identified how the problem was solved and explained it briefly.
- ▶ Designed a practical and reasonable way to transport a delicate item in his/her backpack.

2 Points

- ▶ Described only two problems that occurred in construction of the solar arrays.
- ▶ Proposed only two ways to solve the most important problem(s).
- ▶ Identified how the problem was solved, but did not explain it.
- ▶ Designed a reasonable way to transport a delicate item in his/her backpack.

1 Point

- ▶ Described only one problem.
- ▶ Proposed only one way to solve the problem.
- ▶ Did not identify how the problem was solved.
- ▶ Did not explain why the problem was solved in that manner.
- ▶ Attempted to design a reasonable way to transport a delicate item in his/her backpack.

0 Points

- ▶ No description turned in.
- ▶ Answers incomplete or unreadable.

NOTES ON ACTIVITY:

**Solar Arrays
for the Space
Station**

Lesson at a Glance

Science Overview

**Conducting the
Lesson**

*Warm Up &
Pre-Assessment*

**Activity:
Solar Array Design**

Lesson Wrap-Up

Resources

LESSON WRAP-UP

LESSON CLOSURE

In this lesson, students realized that through engineering and creativity, seemingly impossible feats can be achieved. Discuss with students how they created a solution to transport solar arrays into space. Discuss how they used the same principles to design a way to transport a delicate item from home to school in their backpacks. The skills students learned in this lesson can be applied to a variety of situations in their personal life.

NOTES:

**Solar Arrays
for the Space
Station**

Lesson at a Glance

Science Overview

**Conducting the
Lesson**

*Warm Up &
Pre-Assessment*

*Activity:
Solar Array Design*

Lesson Wrap-Up

Resources

RESOURCES

INTERNET RESOURCES & REFERENCES

Student-Friendly Web Sites:

Dr. E's Energy Lab

<http://www.eere.energy.gov/kids/solar.html>

Power House Kids – Saving Energy

<http://www.powerhousekids.com/savingenergy/renewable.php>

Solar Energy – Energy from the Sun

<http://www.eia.doe.gov/kids/energyfacts/sources/renewable/solar.html>

Teacher-Oriented Web Sites:

FSEC Teacher Resources

<http://www.fsec.ucf.edu/ed/teachers/>

Montana Green Power

<http://www.montanagreenpower.com/solar/schools/teachers.html>

Renewable Energy Sources

<http://www.teachers.ash.org.au/jmresources/energy/renewable.html>

Teacher Solar Links

<http://www.fi.edu/pieces/phillips/HTML/teachers/links.htm>

Challenger Center

<http://www.challenger.org>

Journey through the Universe

<http://www.challenger.org/journey>

TEACHER ANSWER KEY

1. Drawings will vary but should involve the solar arrays folding to fit inside the model Space Shuttle's cargo bay.
2. Answers will vary but should address some problems that students faced when designing their solar arrays and how they solved those problems.

Solar Arrays
for the Space
Station

Lesson at a Glance

Science Overview

Conducting the
Lesson

Resources

*Internet Resources
& References*

*Teacher Answer
Keys*



STUDENT WORKSHEET FOR GRADES K-2

NAME _____ DATE _____

Solar Arrays get to space inside the Space Shuttle. It is your job to make solar arrays so that they can be folded up and fit inside the Space Shuttle's cargo bay.



Picture credit: <http://www.nasa.gov>

1. Draw a picture of your design in the space below.

2. What was hard about making your model? What did you do?





STUDENT WORKSHEET FOR GRADES 3-4

NAME _____ DATE _____

In order for solar arrays to get to the International Space Station, they must be carried there by the Space Shuttle. It is your job to design the solar arrays so that they can be folded up and fit inside the Shuttle's cargo bay.



Picture credit: <http://www.nasa.gov>

1. Draw a picture of your design in the space below.

2. Describe at least three problems you had in constructing your solar arrays and the solutions you used to solve them.





INTERNATIONAL SPACE STATION



Image downloaded from <http://spaceflight.nasa.gov/gallery/images/station/assembly/ndxpage1.html>

