UNIT PLAN

Solar Mobile Design Challenge

AUTHOR

Kristy Schneider

CONTACT

Teacher Contact: kristy.schneider@lacenterschools.org

CE Editor Contact: CEbrightfutures@b-e-f.org, 503-553-3950

DESCRIPTION

This unit involves students learning about transferring solar energy to small motors, exploring the center of gravity and testing light sources (including the sun). The culminating engineering design project gives students the chance to pull together their new learning in order to design a tabletop solar powered mobile. As students explore and test their prototype, a variety of variables such as circuitry types, balance/stability, motor speed and propeller direction need to be considered before the fastest moving mobile can be constructed.

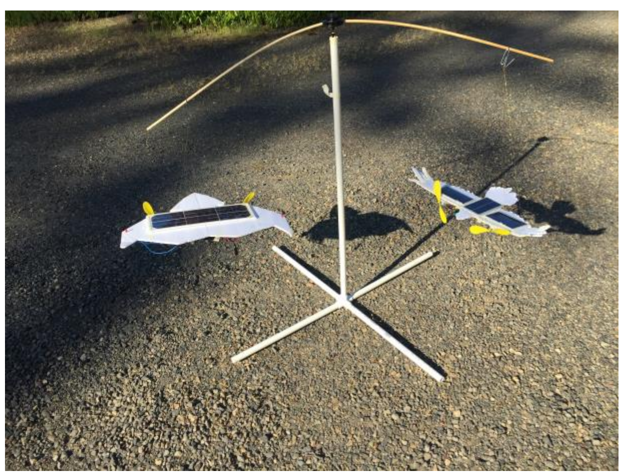


Figure 1 Student built solar powered mobiles

In the beginning of this unit, students will watch a short video and read an article about a solar powered aircraft, learning that manned and unmanned aircraft CAN be powered by solar (Read about the aircraft here: "NASA Solar Impulse Fact Sheet" https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-034-DFRC.html)

Questions that might arise are:

- How was the aircraft able to run just on solar power?

- Is there a way to power small aircrafts inside the classroom to learn more about solar power?
- How can various solar panels be connected in order to power stronger motors with propellers?
- How can the motors and solar panels be mounted on the aircraft in order to balance the aircraft?
- What kind of light could be used to power solar panels if the sun is not available?
- How can we fly the planes and night and store energy in batteries?
- What is the best reflector in order to reflect light to the solar panels?

Throughout the following lessons, students will follow a scenario where they are designing a small mobile for a children's technology museum. At the end of the unit, students will solve a design challenge and engineer a mobile by using solar panels mounted on the top of foam aircraft to power motors with propellers balanced on a central pole. The challenge is to transfer the most energy from the solar panels in order to gain optimal power to run the motors, which in the end gives their mobile the fastest speed.

Their final project will be a proposal and demonstration for the museum's board of directors.

GRADE LEVEL(S)

6; 7; 8

SUBJECT AREA(S)

Electromagnetic energy, solar renewable energy, energy transfer, circuits, engineering design construction, reflectivity, center of gravity, light energy sources

LEARNING GOAL(S)

1. Students will design circuits using various solar panels in order to power motors with propellers.
2. Students will learn about solar energy transfer in order to power the motors on their solar aircraft.
3. Students will research an aircraft and draw an outline of the aircraft onto foam board.
4. Students will explore the concept of center of gravity.
5. Students will test the efficiency of various light sources (incandescent, florescent, LED, halogen) for usage by a PV cell.
6. Students will use their prior testing results and knowledge to engineer a solar powered mobile.
7. Students will work to transfer the most energy from the solar panels considering all the tested variables in order to power the fastest, most efficient mobile.
8. Students will demonstrate and explain why their solar mobile should be chosen for the solar mobile display in the children's museum.

UNIT EXPERIENCES

Table 1. Suggested Teaching Times

Lesson/Experience	Time
Engage/Explore	
Discovery and Experimenting with Electricity • Lesson 1: Introducing the Solar Mobile Design Challenge • Lesson 2: Exploring Circuits and Optimum Power	55 min x 3 class periods= min **(165 min)**
Explain	
Some Variable Affecting the Mobile • Lesson 2: Exploring Circuits and Optimum Power • Lesson 3: Exploring Center of Gravity **Discovery and Experimenting with Light** • Lesson 4: Light Source Efficiency-Exploring Irradiance	55 min x 5= 275 min **(~6 hrs)** 55 min x 2 class periods= min **(~2 hrs)**
Elaborate/Evaluate	
Solar Mobile Engineering Design Challenge Lesson 5: Solar Mobile Design • Identifying the problem • Defining the constraints • Planning-developing possible solutions • Testing design variables for optimal performance • Evaluating • Reworking/retesting	55 min x 5= 275 min **(~6 hrs)**
Total	**55 min x 15 = (~12 hrs)**

NEXT GENERATION SCIENCE STANDARDS

Guiding Phenomenon	Since manned and unmanned aircraft CAN be powered by solar, how can we power small aircrafts mounted on tabletop mobiles? (http://www.solarimpulse.com/)

	(https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-034-DFRC.html)
Supplementary Phenomena	

Table 2. Next Generation Science Standards Assessed in This Unit

Performance Expectation	How is this Assessed?
MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.	**Lessons 1-3:** Students will use various solar panels and learn about solar energy transfer in order to power the motors on their solar plane. Students record this knowledge and use it for their final engineering design project.
MS-PS2-2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object	**Lesson 4:** Students investigate the Center of Gravity using a meter stick and clay. Then they participate in an activity that works with irregular objects and finding the Center of Gravity leading up to finding the center of their irregular shaped aircraft that will be used on the solar mobile.
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.	**Lesson 6:** Students record and discuss their results before, during and after the implementation of their team's solar mobile prototype. Students justify - in a demonstration and in writing - why their solar mobile is the model that should be chosen for public display.
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.	**Lessons 2/3/4/5:** Students work through modifications and apply what was learned about solar circuits, the center of gravity, and irradiance as they build their final model.

THREE DIMENSIONAL LINKAGES

NGSS focuses not only on content, but also on process and on building bridges between concepts within and across disciplines. The following tables outline the way in which this unit addresses this three-dimensionality.

Table 3. Three-Dimensionality: Disciplinary Core Ideas (DCIs)

Disciplinary Core Ideas	Linkage in Unit
ETS1.A Defining and Delimiting Engineering Problems The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.	Students identify constraints based on their background knowledge of principles of electrical circuits that they build in investigations in units 1-3. Students consider the constraints of the various materials tested as they work on the final design project.
PS4.B When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (MS-PS4-2)	**Lesson 5:** Students test a variety of light sources using a Pyranometer to see what is the optimal light source for their project. Students graph, analyze and discuss their results, which will then be applied during the engineering design challenge.

Table 4. Three-Dimensionality: Science and Engineering Practices (SEPs)

Science and Engineering Practices	Linkage in Unit
Asking questions and defining problems	**L1:** Students ask questions about how to power their aircraft (or airborne object). **L2:** Students ask questions about the best propellers for their aircrafts. **L4**: Students ask questions about balancing an object(s). **L5**: Students ask questions about irradiance to determine ideal light sources to propel mobiles. **L6:** Students ask questions about how to design and propel aircrafta on a mobile stand - optimizing power to their best advantage.
Developing and Using Models	**L4:** Students model the center of gravity of irregular shapes. **L6:** Students build a solar mobile model using solar circuits.
Planning and Carrying Out	**L5:** Students conduct investigations using Pyranometers.

Investigations	**L5:** Students test various light sources for irradiance.
Constructing Explanations and Designing Solutions	**L1-L6:** Students analyze results from their circuit and Pyranometer tests to optimize their solar mobile systems.
Engaging in Argument from Evidence	**L6:** Students discuss results and use evidence gathered from testing various prototypes to promote solar mobiles to a Children's Museum's board of directors.

Table 5. Three-Dimensionality: Crosscutting Concepts (CCCs)

Crosscutting Concepts	Linkage in Unit
Cause and effect: mechanism and evaluation	**L2/L6:** Students use Cause and Effect as they explore circuits and work through the engineering design process with their solar mobile.
Scale, proportion, and quantity	**L6:** Students use scale and proportions as they design their mobile aircraft and build their solar mobile model.
Systems and system models	**L2:** Students build a working, connected system as they explore circuits. **L3/6:** Students build a balanced mobile system as they solve the Solar Mobile Challenge.
Energy and matter: Flows, cycle, and conservation	**L2/3:** Students understand how energy travels from the Sun (and other light sources) to power solar panels, which, in turn, power motors to spin propellers. **L5:** Students work with a Pyranometer to measure irradiance from various artificial light sources and compare them to the Sun's natural irradiance.
Structure and function	**L1:** Students understand the function of solar panels. **L2:** Students identify the irradiance of various light sources as compared to the Sun. **L3:** Students build a Solar Mobile and test how it functions with various light sources.
Stability and Change	**L4:** Students explore Center of Gravity and apply what they learned to the final solar mobile.

COMMON CORE STATE STANDARDS

- **CCSS.ELA-LITERACY.RST.6-8.3:** Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
- **CCSS.ELA-LITERACY.W.6.9:** Draw evidence from informational texts to support analysis, reflection, and research.
- **CCSS.ELA-LITERACY.6-8.9**: Compare and contrast the information gained from experiments, simulations, video or multimedia sources with that gained from text on the same topic.

CONTENT BACKGROUND

STUDENT BACKGROUND

This unit does not require that students have extensive background knowledge in the immediate subject areas. Some basic knowledge of electrical circuits (series and parallel) in order to power a small motor would help speed the learning process.

Additionally, a familiarity with the engineering design process would help with the final project but can easily be taught along the way.

EDUCATOR BACKGROUND

Instructors should have a solid understanding of simple electrical circuits (series and parallel wiring-https://www.autodesk.com/products/eagle/blog/series-vs-parallel-circuits/) and be able to lead a discussion about the simple circuits that students will build during the second lesson's solar exploration.

A basic knowledge of circuit diagramming is required to facilitate students creating and keeping Engineering Notebooks.

If educators want to develop more foundational knowledge about circuits or energy fundamentals, the CE Bright Futures website has a resource page to help gain background knowledge on a number of scientific subjects. Visit www.cebrightfutures.org/learn

The concepts behind an object's Center of Gravity are important for carrying out this Unit. For helpful background information visit:

http://scienceprojectideasforkids.com/2010/center-of-gravity-vs-center-of-mass/

Instructors should also understand how to use the Vernier Pyranometer and understand irradiance readings. Visit the manufacturer's website for instructions on how to use the sensor here: https://www.vernier.com/products/sensors/solar-radiation-sensors/pyr-bta/

TEACHER MATERIALS TIPS

If using the KidWind Hubs from Vernier, instructors need to use a 15/64 " drill bit and drill out an additional 5mm into two opposing hub holes. A drill press works great if you have one. Explaining the circumference of the hole gives dowels more stability and allows the hub to have a better grip on the dowels.

Figure 2
Outside marked
with silver

Figure 3
Inside outlined
with silver

Teachers also need to widen the central hole of the hub by drilling a small amount (3 to 5mm, depending on your arrow tip) using a 3/16” bit drilled into the existing center hole. This will give the hub a more stable resting point on the arrow. Depending on your arrow tip size, you will need to drill approximately ¼” into the hole.

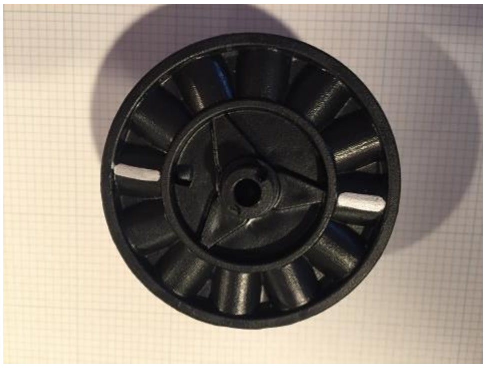
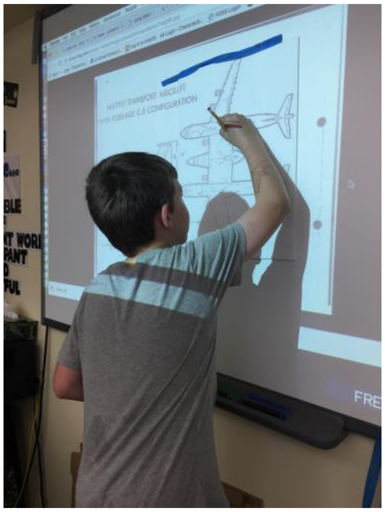


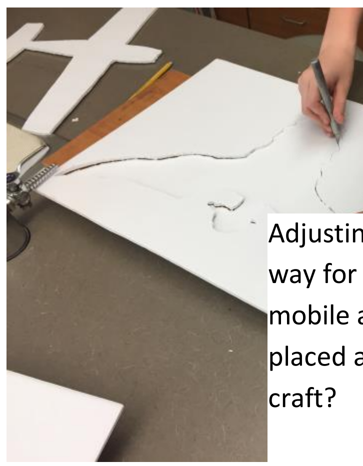
Figure 4 Kid Wind Vernier Hub with DIY widened central hole

Figure 5 Kid Wind Vernier Hub balancing on arrow tip

For this project, wooden dowls are suggested. Original prototypes used to develop this curricula included fiberglass rods for more flexibility. However, potential fiberglass shards in student fingers is not a good idea and wooden dowels are safer, albeit can crack with too much weight placed on them.

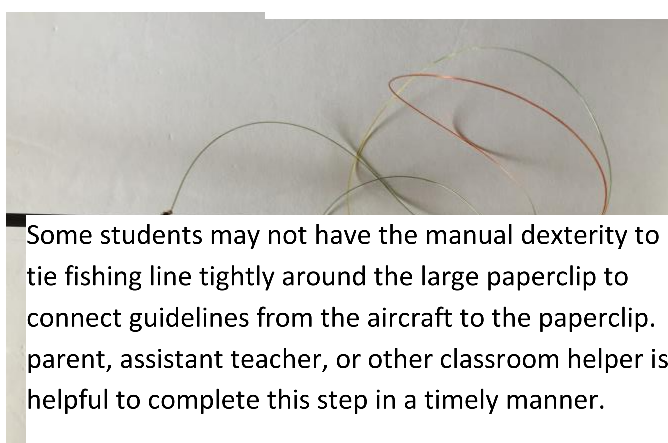


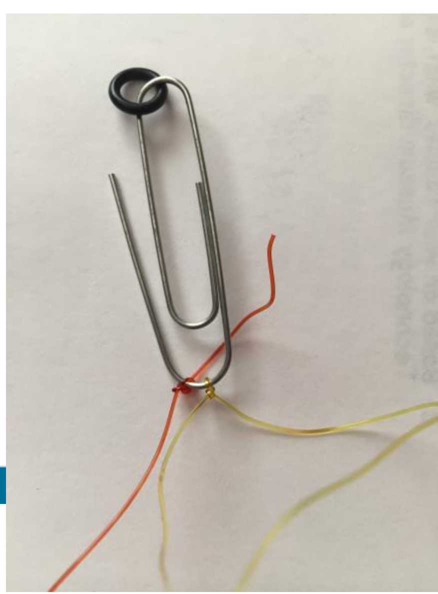
For building their unique aircrafts, students can conduct Internet research using the search terms “top down view black and white outline drawing,” project their image findings onto a blank surface, and trace. Doing this helps the production process move



Students can most easily cut thin foam boards with Exacto knifes. Cutting with scissors is much harder. **Be sure to go over safety rules of using Exactos.** If you do not trust your students’ maturity or skill level to work with Exacto knives, or your school

Adjustin[illegible] way for [illegible] mobile airplanes. Where should they be placed along the dowel to best balance their craft?





Some students may not have the manual dexterity to tie fishing line tightly around the large paperclip to connect guidelines from the aircraft to the paperclip. A parent, assistant teacher, or other classroom helper is helpful to complete this step in a timely manner.

THE ENGINEERING DESIGN CYCLE

This Solar Mobile Design Challenge follows Engineering Design Steps, which are outlined in the project rubric.

Students are asked to:

- Restate the design challenge
- Brainstorm
- Plan
- Create a project design (prototype)
- Build
- Test
- Evaluate
- Improve design
- Retest design
- Justify final design

VOCABULARY

Balance	A condition in which opposing forces are equal to each other.
Center of Mass	The point at which all of an object's mass may be considered to be concentrated.
Circuit	A complete and closed path through which a circulating current can flow.
Conductor	A material or object that conducts electricity
Diode	Diode, a semiconductor device with two terminals that only allow current to flow in one direction. A diode has two terminals, the positive side is called the anode, and the negative one is called the cathode.
Electricity	A flow of electrons, often through a circuit
Electromagnetic radiation	The entire range of light that exists, from radio waves to gamma rays. Most of which is not visible light.

Force	A push or a pull on an object.
Gravity	A force that pushes objects towards the center of the Earth.
Irradiance	A measure of absorbed energy in W/M^2 from a broader spectrum than visible light. Energy falling on a surface.
Kinetic	Of, relating to, or produced by motion.
LED (Light Emitting Diode)/LED Polarity	A diode (semiconductor) that emits visible light when current passes through it and will only allow current to flow in one direction, they are always polarized.
Mobile	A decorative structure that is suspended so as to turn freely in the air and moves with air currents.
Stability	A steady motion to develop forces that restore the original condition.
Variable	A condition that can change or is likely to be changed.
Visible light	The range of the electromagnetic spectrum we can see.

REQUIRED MATERIALS

HANDOUTS/PAPER MATERIALS

- Student's Engineering Notebooks or paper copies of the worksheets
- Lesson 2: Powering UP Solar Planes! Exploring Simple Solar Circuits for a Mobile
- Lesson 4: Exploring Center of Gravity

  Online article: http://www.explainthatstuff.com/center-of-gravity.html

  Hands on activities: http://sciencewithkids.com/Experiments/Physics-experiments/physics-center-of-gravity-experiment.html
- Lesson 5:
- Light Source Efficiency
- Lesson 6: Solar Mobile Engineering Design Challenge
- Lesson 6: Solar Mobile Rubric

TEACHER SUPPLIES

- Vernier LabQuest2
- Vernier Pyranometer
- Various light sources with lamp stand(s) -halogen, incandescent, LED, florescent
- Balancing bird for Center of Gravity activity- https://www.teachersource.com/product/balancing-bird-demo/physics- Additional but not necessary.
- Projection system for outline drawings (a computer and projector work great)

CLASSROOM SUPPLIES

- Exacto knives
- Safety goggles
- Wire cutters/strippers
- Needle nose pliers
- PVC pipe cutter(s)-***used with teacher supervision or teacher only***
- Hot glue gun
- Multimeter
- Clear or masking tape
- Laptops or computers for students (for airplane design research)
- Meter sticks
- 1 box of Modeling Clay

ACTIVITY SUPPLIES (PER GROUP OF 2-4 STUDENTS)

- 2-4 sheets of *lightweight* foam craft board for aircraft- 1per aircraft (in this project cheaper is better)-1 sheet/student
- 2-small DC motors (3-6V) per aircraft
- 2-propellers/aircraft
- A meter stick for each student
- A small ball of clay
- File folder
- ½ meter of string
- Hand held hole punch
- 2-4, 5 mm (1/4”) O rings-1 per student
- 4-6 meters of fishing line
- 2-8 Large paperclips- (2-3/student)
- 1-KidWind hub (from Vernier) drilled (see Teacher Tips)
- 1-10’ section of ½” PVC pipe (to be cut into sections- 4 @ 1.5’, 1 @ 4’)
- 1-1/2” five-way PVC connector
- 2-4, ¼” wooden dowels cut to 2 feet in length each
- 1-arrow
- 1-Vernier Pyranometer
- 1-Vernier LabQuest2
- Variety of light bulbs to test (incandescent, halogen, LED, florescent)
- Lamp stand(s) for the various bulbs

UNIT PROGRESSION

This unit is designed as a kit that can be used year-round in the classroom to study solar power and is not dependent on students going outside for sunlight. There are many variables that can be addressed but the main unit is divided into four parts with the culminating project being an engineering design challenge of designing a desktop solar mobile to achieve the fastest speed.

- **Lesson 1:** Lesson one starts with the phenomenon of powering a solar aircraft with the engaging Solar Impulse Video. Students will read an informational article and then be given the introduction to Children’s Technology Museum Solar Mobile Challenge.

- **Lesson 2:** In an exploratory, students will focus on building simple circuits to power up two motors with propellers using a variety of solar panels that will eventually be placed on their solar mobile aircraft.

- **Lesson 3:** Students will demonstrate their circuits and discuss the energy transfer. This is a teacher led discussion.
- **Lesson 4:** Students explore the concept of Center of Gravity (mass) using various materials. This understanding leads to more success when students come to balancing their aircraft on their mobile.

Lesson 5: Students use a Vernier Pyranometer to measure irradiance of artificial light sources as compared to the Sun's natural irradiance. They use this process to see what the best light is to power solar mobiles indoors.

Lesson 6: As an engineering design challenge, students will combine their new learning and skills in order to make a solar powered mobile.

- **Project Extensions:** Students will calculate the percent of reflectivity of various materials (aluminum foil, space blanket, various mirrors, CD, Mylar balloons of different colors) and draw conclusions about which material will be best for tabletop reflector. Students will also look at the light source and irradiance using various light sources in order to find the optimum combination of material and light source.

LESSON SUMMARIES

ENGAGE/EXPLORE:

LESSON 1: ENGAGE/DEFINING THE PROJECT

First, engage students by showing the short video about the phenomenon of solar powered aircraft, learning that manned and unmanned aircraft CAN be powered by solar: http://www.solarimpulse.com.

Use Solar Impulse video to introduce Guiding Phenomenon: https://aroundtheworld.solarimpulse.com/adventure.

For additional information on solar flight students will read the following article https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-034-DFRC.html) about NASAs Pathfinder Solar Powered Aircraft.

To engage students and give them a focus for the project, introduce students to the "Scenario" and "Design Challenge" paragraphs on the Solar Mobile Engineering Design Challenge. Show YouTube video of the room size solar mobile at the NEMO Museum in Amsterdam.

LESSON 2: POWERING UP CLASSROOM SOLAR AIRPLANES

Next, students explore and learn about building simple circuits in order to power two motors with propellers using solar cells. These motors, propellers and solar cells will eventually be placed on student aircrafts in the final solar mobile engineering challenge.

Students start by exploring simple circuits with solar cells that have a variety of voltages using the ***Powering UP!*** **Exploring Solar Circuits worksheet**. Students test various solar cells with different voltages with varying amounts of motors wired in both series and in parallel. Test using available sunlight or light stands with incandescent bulbs (Different types of light irradiance will be tested and measured at a later point within this Unit).

Once students finish constructing different circuits and feel that they have the best circuit for their aircraft, dedicate time for students to demonstrate their circuits and discuss energy transfers with each other and the room. This gives students an opportunity to investigate and debug unforeseen problems that they might have encountered.

EXPLAIN:

LESSON 3: CENTER OF GRAVITY

Start this lesson with a teacher demo of the discrepant event (https://www.scienceworld.ca/blog/discrepant-events-and-inquiry-based-learning) of a bird that can balance on its beak. Then students explore center of mass with a meter stick and ball of clay, giving them some hands-on experiences.

Additionally, students work with various irregular shapes cut out of file folders and find the center of mass of an irregular shape (**Center of Irregular Things worksheet**).
Following this, students conduct Internet research to find their preferred aircraft blueprint and trace these onto a sheet of foam board (or practice paper). Use drawings to find each aircraft's center of gravity. Having student create their aircraft at this point brings a lot excitement for the final project. Students follow the same process as in Center of Irregular Things and find the initial center of gravity for their aircraft.

This online article can also be used for concept reinforcement: http://www.explainthatstuff.com/center-of-gravity.html

LESSON 4: LIGHT SOURCE EFFICIENCY

This lesson explores the concept of irradiance by having students use a Vernier Pryanometer. Using the "**Light Source Efficiency**" worksheet to guide their work, students measure irradiance of artificial lighting and compare it to the Sun's irradiance to gauge what is most optimal to power their Solar Mobiles indoors. This can be taught as a demonstration if you only have one LabQuest2 and Pyranometer.

LESSON 5: SOLAR MOBILE DESIGN CHALLENGE-CONSTRUCTION

The building of the Solar Mobile follows an engineering design process. Students will start by **Restating the Design Problem** that was introduced to them in the beginning of the project. Next, they will **Brainstorm** ideas and **Plan** out the construction of the mobile. They research an aircraft to draw if this was not accomplished in the Center of Gravity lesson and go on to the building phase. The exciting part is pulling all the parts together to **Build**, **Test, Evaluate** and go through this loop multiple times, making improvements along the way. The final assessment will be students demonstrating how their Solar

Mobiles work and justifying why their design should be chosen for a Children's Technology Museum's Renewable Energy display.

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENTS

This project is designed for students to use a science/engineering notebook to record in as they proceed through the project. As students work through the engineering design process, they will write out a daily reflection.

Some reflection questions might be,

1. What have you learned about (concept) today?
2. How will you apply this to your design work tomorrow?
3. What new learning about (concept) did you use in your design work today?
4. What questions do you still have about your project that you can continue to explore?

There are also numerous worksheets provided to give more guided instruction.

SUMMATIVE ASSESSMENT

The final engineering design of the mobile will be assessed with a grading rubric. The rubric addresses all the separate engineering components of the mobile.

UNIT EXTENSIONS

REFLECTIVE LIGHT AND LIGHT SOURCES LAB

If you want to explore reflected light, students can use a Vernier light sensor attached a lab ring stand to measure reflected light and calculate the percent of reflectivity of various materials (aluminum foil, space blanket, various mirrors, CD, mylar balloons of different colors) using a variety of light sources. This lesson is based on Experiment 7 from the Vernier Middle School Science lab book (https://www.vernier.com/experiments/msv/7/reflectivity_of_light/#standards) with an extension of evaluating different reflective materials with different light sources (incandescent, halogen, LED, florescent) looking for the optimum combination. Students will draw conclusions about which materials will be best for their solar mobile light reflector and what will be the optimum light source in order to reflect light to give their aircraft a power boost.

REFERENCES AND RESOURCES

Solar Impulse Video, https://aroundtheworld.solarimpulse.com/adventure, from the Solar Impulse website.

Pyranometer info. and purchasing information. https://www.vernier.com/products/sensors/solar-radiation-sensors/pyr-bta/

Use Solar Impulse video to introduce Guiding Phenomenon: https://aroundtheworld.solarimpulse.com/adventure.

For additional information on solar flight students will read the following article https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-034-DFRC.html)

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