Clark Public Utilities

Solar Car Challenge

Activity and Judging Guides

Clark Public Utilities POWER ZONE™

green lights Clark Public Utilities

Clark Public Utilities

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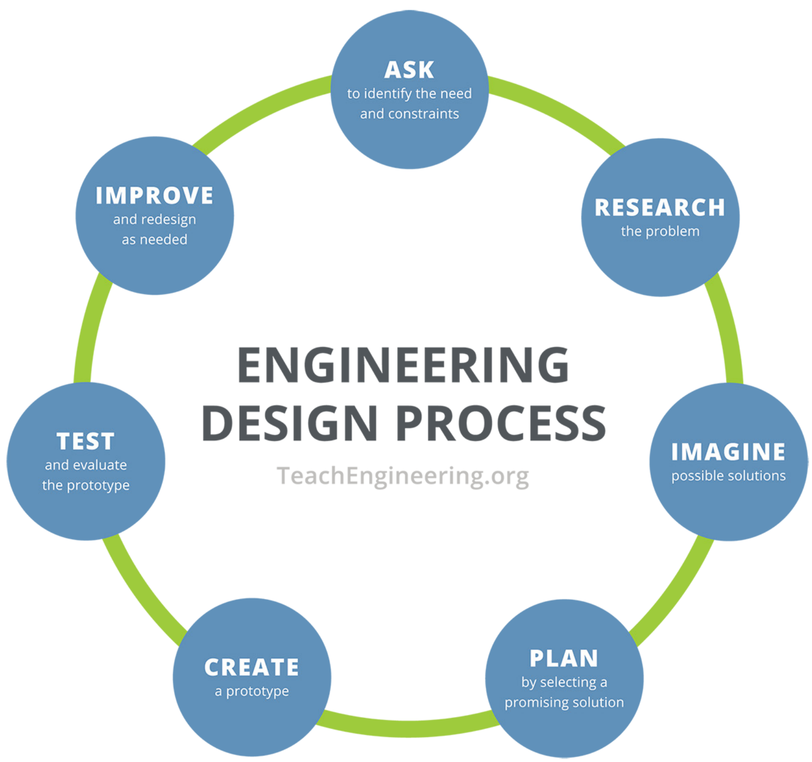
TEACHER GUIDE

Overview

Welcome to the Clark Public Utilities Solar Car Challenge and thank you for taking the driver's seat with your students! This challenge, including student resources and teacher workshops, are funded by the Clark Public Utilities Green Lights program – a voluntary utility customer contribution in support of renewable energy education.

The classroom activities included in this curriculum are designed to facilitate Solar Car Challenge preparation and correspond to the engineering notebook teams will produce and submit at the competition. Each activity has a simple lesson progression aligned with the provided materials and solar car kits.

Though the lessons are primarily geared towards middle school students, the provided lessons and activities are flexible and can be used as appropriate with your students at any grade level. Teams from elementary to high school are invited to participate in the challenge. Modules can be scaled up or down depending on class level and needs, and each activity is intended to align with NGSS Performance Expectations, grouped according to the Engineering Design Process model below.



Teach Engineering
https://www.teachengineering.org/k12engineering/designprocess

The Clark Public Utilities Solar Car Challenge is based on other successful engineering challenges around the region. Here in Clark County, Washington the challenge has been modified to include "boost" lighting at the beginning of the race and batteries for supplemental power in the cars to accommodate an indoor race format. This allows students to focus on the engineering process and increases the likelihood that cars will work on race day.

The Clark Public Utilities Solar Car Challenge will be held indoors at Hudson's Bay High School on a Saturday in March each year. Dates will be announced on PowerZone in the Educator Resources section.

Best Practices for Engineering Notebooks

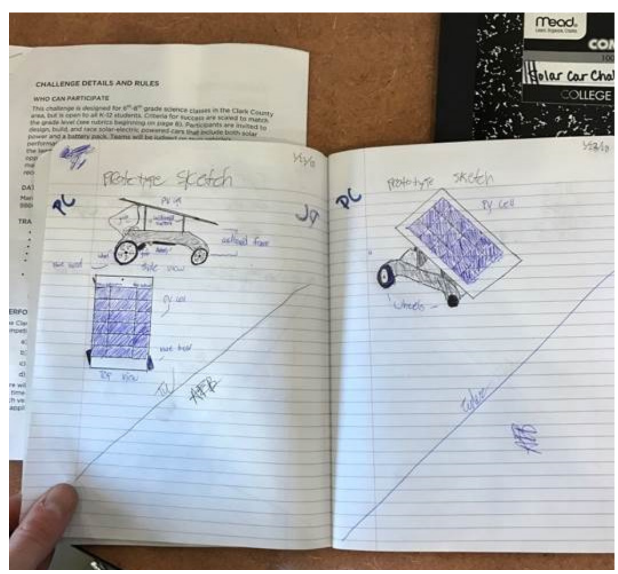
All students must use some form of small notebook, preferably college ruled composition books, to maintain as an "Engineering Notebook." Engineering notebooks are intended as a way for students to track the progress on their engineering project and provide themselves a reference point for the continued development of their solar car. Students should view this as their personal record and space for development, not necessarily a worksheet or something solely used for academic grading. However, they should recognize that they will be held accountable for keeping thoughtful, useful records in the notebook, much like they would in the "real world." Teachers may want to use these for formatively assessing their students and can note their process to their students ahead of time for tracking a particular grading process.

Students should also be aware that in addition to their car performing well in the challenge races, they should also make the effort to keep good records and practice good teamwork skills to be successful in the full engineering challenge. One of the key factors for being successful in the "real world" is to be able perform well, communicate well, and work well with others.

Note that 55% of the team's overall score will depend on their documentation and performance in an interview.

The activities in this guide will provide specific instructions for components to create in student notebooks. We've provided a set of best practices for all students to keep in mind when building out these notebooks. Some of these practices for students include:

- **Date** your entries, creating new sections for different time frames, to reference when you completed or thought about different pieces of your design process.
- Keep your notebook **clean**. Ensure that it is **legible** and organizes your thoughts in a coherent way.
- While keeping it clean, also **avoid erasing or making changes to previous thought processes** as much as possible. All thoughts, regardless of whether they have been later disproved, hold valuable information from your engineering design process. Being able to piece together your design story is vital to the challenge. If a change is needed, note that change in the notebook rather than simply erasing that information.
- Use **color or writing styles** to point out specific components of your work. This could be used with dates, vocabulary, "a-ha!" moments, things you want to communicate to judges at the challenge, or questions you may have.
- Include **updates and revisions** to prior models. These can be notes explaining changes implemented in your design process. **Comments in older models** that explain what you are learning, and simple reflections.
- Be sure to create as much of a balance as possible **between text, pictures, and numerical data**. This will make it even easier for you to remember why certain decisions were made and where you learned specific things. Feel free to cut and tape images from other locations!
- **Make it yours**. This is your personal space to make important decisions that will impact the success of your team's vehicle. Do not view this as a worksheet that must be completed a specific way for a grade. A successful engineering notebook is a reflection of your **personality through design** and will look very different from your peers' notebooks.
- If a student team wishes to create **electronic notebooks**, we will request a **printed version to bring to the challenge event** as we have limited capacity to review electronic notebooks during the event.



Engineering Challenge Specs (Materials Summary)

TRACK NOTES

- Surface: Gym Floor
- Each lane, bounded by ½” PVC pipe is 12 inches wide
- 20 feet long

LIGHTING NOTES

- The light reaches only the first 24 inches of track
- (3) 500W halogen light 32 inches above track (center, left, and right)
- 200-300W of irradiance at floor level

CAR REQUIREMENTS SUMMARY

- 1 DC Motor (small motor for elementary and middle School, larger 5V motor for high School)
- 1 Photo Voltaic module (2.76V)
- 1 Switch (any type, team must create/provide)
- 2 AA Batteries
- 1 AA Battery holder
- 1 6.2 OHM Resistor (high school only)
- 1 LED (middle and high school only)
- Review the Judging Guide for specific details on each item!

TEAM KIT CONTENTS (ELEMENTARY SCHOOL)

- 1 Photo Voltaic Module (Pitsco Ray Catcher Solar Module, 2.76V, 1A)
- 1 small DC motor (Pitsco Motor 280)
- 1 2-AA battery holder
- 2 rechargeable AA batteries
- 2 metal axles
- 4 rubber bands (2 thick, 2 thin)
- 8 gears (2 mm hole)
- 8 gears (1/8” hole)
- 4 nylon spacers
- 4 wheels (2 large, 2 small)
- 2 balsa wood sheets
- 1 solar panel blank (cardstock)
- 12 pack mini alligator clip leads
- 2 small metal alligator clips
- 2 screw eyes

TEAM KIT CONTENTS (MIDDLE SCHOOL)

- 1 Photo Voltaic Module (Pitsco Ray Catcher Solar Module, 2.76V, 1A)
- 1 small DC motor (Pitsco Motor 280)
- 1 2-AA battery holder
- 2 rechargeable AA batteries
- 2 metal axles
- 4 rubber bands (2 thick, 2 thin)
- 8 gears (2 mm hole)
- 8 gears (1/8” hole)
- 4 nylon spacers
- 4 wheels (2 large, 2 small)
- 2 balsa wood sheets
- 1 solar panel blank (cardstock)
- 12 pack mini alligator clip leads
- 2 small metal alligator clips
- 2 screw eyes
- 3 red LEDs (Specific to MS/HS)

TEAM KIT CONTENTS (HIGH SCHOOL)

- 1 Photo Voltaic Module (Pitsco Ray Catcher Solar Module, 2.76V, 1A)
- 1 5V DC motor (Specific to HS only)
- 1 2-AA battery holder
- 2 rechargeable AA batteries
- 2 metal axles
- 4 rubber bands (2 thick, 2 thin)
- 8 gears (2 mm hole)
- 8 gears (1/8” hole)
- 4 nylon spacers
- 4 wheels (2 large, 2 small)
- 2 balsa wood sheets
- 1 solar panel blank (cardstock)
- 12 pack mini alligator clip leads
- 2 small metal alligator clips
- 2 screw eyes
- 1 6.2 OHM resistor (Specific to HS Only)
- 3 LEDs (specific to MS/HS)

SUGGESTED TOOLS AND OTHER SUPPLIES

These items are not included in the kits but may be necessary to construct the solar cars.

- Glue Gun and hot glue
- Hobby knife to cut balsa wood
- Sandpaper
- Needle nose pliers
- Ruler
- Clamps
- Soldering Iron and solder
- Material from which to construct a switch mechanism

Additional materials to add an original touch to cars for aesthetics or performance (in accordance with information provided in the Judging Guide.)

Content Background

There are several locations to research content background information, such as circuitry and solar vehicles. Below are suggested resources:

- CE created wikis available towards the back of the workbook.
- Junior Solar Sprint's "An Introduction to Building a Solar Car": https://www.nrel.gov/docs/gen/fy01/30828.pdf.
- CE's Educator Library Activities: http://cebrightfutures.org/teach/teacher-activity-center. Activities relevant for this project could include the following:
  - "Understanding Science and Engineering Through Solar Power" by Mike Hellis (ES/MS).
  - "Mini Solar Homes" by Beverly Satterwhite (ES/MS).
  - "Solar Cars" by Carol Patrick (ES).
  - "Solar Transportation" by Clayton Hudiberg (HS).
- Pitsco Education (solar car vendor) resources:
  - Instruction sheet (for teachers!): https://asset.pitsco.com/sharedimages/resources/userguide/ray_catcher_sprint_deluxe_student_ug_21211.pdf.
  - Video: Building the Ray Catcher solar car https://video.pitsco.com/default.aspx?vID=586&p=1.
- Ray Catcher Solar Car: https://www.pitsco.com/Shop/Ray-Catcher-Sprint-Deluxe-Solar-Vehicle.

Support for Team Coaches (Teachers)

Please reach out to Amber Hall at Clark Public Utilities for support throughout the process:

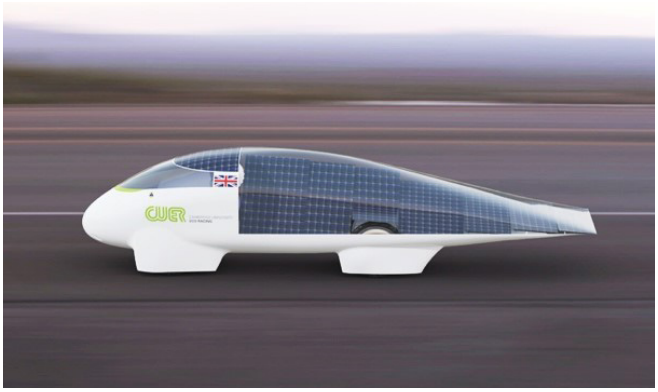
Amber Hall
Education Engagement Specialist at Clark Public Utilities

- 360-992-3550
- ahall@clarkpud.com

Two Tech Support Clinics will be held leading up to the main Solar Car Challenge to provide guidance and hands-on expertise to support coaches and teams. Each clinic will be held on one Saturday in January and February from 8 a.m. to Noon. The dates will be announced at the coach's clinics and on PowerZone, in the Educator Resources section. These clinics will be held at the Clark Public Utilities community room at 1200 Fort Vancouver Way.

ACTIVITY GUIDE: ASK/IDENTIFY

Student Introduction to Challenge



OVERVIEW

This is the first opportunity that students will have to address the challenge at hand. One of the primary important pieces of this section is to elicit as many student questions as possible and provide them with the overall guiding questions as well. This can serve as a reflection tool throughout the duration of the solar car unit, thus it is important to establish norms for students to revisit questions following investigation.

INTRODUCTION

This is a great opportunity to provide students with an innovation-based phenomenon to spark interest. One example could be to watch videos on the Solar Impulse solar plane, discussing the journey that these individuals had in their quest to circumnavigate the globe. The World Solar Challenge, a solar car race in Australia, is an additional interesting place for students to begin learning about advancements in technology for solar vehicles.

During these initial observations of cool technology, ask students questions to spark discussion on challenges overcome in this design, as well as big-picture thinking. For example:

- What obstacles would be faced in these individuals completing this design challenge?
- How do you think they overcame these obstacles?
    - Why are solar vehicles important to design?
    - Why is it important that society works to solve these types of design challenges?

Another interesting strategy to elicit initial ideas, especially for younger students, is “Novel Ideas Only.” In this activity, students write down a list (usually limited to 8) of concepts attached to a particular idea or question, in this case it could be solar power. After a given amount of time, they share out their responses, by group, one by one. If other groups have the same idea or concept written down, they cross it out. This continues until all ideas have been listed across the room. This is a great strategy to give students a sense of all the ideas in the room, providing them gratification for ideas they share with others and additionally highlight unique ideas.

FRAMING THE CHALLENGE

- After providing some sort of hook to draw student thinking to the topic of vehicles, introduce students to the Clark Public Utilities Solar Car Challenge. The provision of this information should come in two parts: the actual challenge students will be competing in, as well as a guiding question for them to address in their development process and reflect on throughout the unit.
- When introducing the challenge, refer to the judging guide and rubrics that students will be scored using. This is an excellent opportunity to discuss constraints in engineering challenges, and what they will be using.
- The following is a suggested guided/essential question for the unit; however, this can be modified depending on student needs:
    - **“What role does solar energy play in the future of transportation?”**

- After providing students this initial guiding question, ask students to write as many additional questions they believe will help them to answer this in their engineering notebooks. Have them share these out as well, tracking both the main guiding question as well as their additional questions; somewhere visible such as a poster. Note: having space for students to write ideas around these visible questions as they work through the project is advised. This can be completed as part of a journaling or reflection activity.

MATERIALS AND EXAMPLE

- Go over the materials list that students will be working with (noted above in the judging guide).
- Discuss what students' initial thoughts are regarding materials they could supplement these with from home.
- It may be useful as well to show students the model solar car built by the coach previously to the lessons/activities with students. This can serve as a demonstration of what their car could be based on. Allow for some time for students to test this car on the classroom track and ask any other additional questions that may arise from this introduction.

ACTIVITY GUIDE: RESEARCH

Exploring Photovoltaics

ACTIVITY LIST

- Photovoltaic Challenges
- Simple Solar Tracker (Extension)

SUMMARY OF PROGRESSION

This section is intended as a precursor to students building solar cars. These activities can be moved around according to the needs of the teacher or the availability of supplies. Should any of the activities not fit your class' needs or have already been done in some fashion, please refer to the Educator Library under the "Teach" tab on the CE website (http://cebrightfutures.org/) for more lesson ideas involving photovoltaics.

Exploring Photovoltaics Activity 1: PV Challenge Quest

OVERVIEW/PREP

In this activity, students will be asked to complete a number of challenges involving solar circuits. Students can use the circuitry materials that come with their solar car challenge supplies in order to complete these tasks. However, they can be expanded using additional solar circuitry supplies should they be available to your school.

LESSON SEQUENCE

- Prep:
  - Pass out solar modules, gears, LED's, and any other loads you want to incorporate into this activity should you have access. Note: any small battery powered device can be powered with these modules and exploring their requirements and getting them to work with these tools is a great exploration for students!
  - Have students create a three-column KWL Chart in their notes in order to categorize what they know about solar panels, what they wonder about solar panels, and what they have learned about solar panels.
  - Have students fill out the first two columns, leaving the "L" column for after the activity is completed.
- Should students not have extensive background in circuitry, try several simple activities to acquaint them with this type of functionality. Steve Spangler Energy Sticks are a great way to introduce the idea of completing a circuit and allowing electricity to flow (also, forming group circuits using one battery and several loads works similarly). After an initial introduction to its structure, students can be asked:
  - What does it need to function properly?
  - What prevented it from working properly?
  - How might it be similar to a solar panel?
  - Where else do we see systems like this?
- If you don't have an energy stick, other simple activities to prep them using the solar car materials can be used. These could include:
  - Have them connect a battery to an LED to turn it on, eliciting student questions about directionality.
  - Provide them the objective of creating a circuit with two modules and a load, discussing the implications if circuits look different from one another.

- When you feel that students have had adequate time to be exposed to the basics of solar panel function and at least a surface-level understanding of circuits, introduce them to the following challenges:

Challenge 1

"**Get a motor and gear to spin in two different directions in addition to making it spin faster and slower.** How did you do it? Draw or write your solution(s) in your engineering notebook so that others can do it, too."

Challenge 2

"**Light up three LEDs using one solar panel.** What did you try? What didn't work? Did you get something that did? Draw the different configurations you tested, below. Note which worked and which didn't and explain your process for determining the solution. Create a table (similar to the one below) in your notebook and list the as many similarities and differences as you can at this point between an LED and the motor you previously tested."

Configurations and Process	
Similarities	**Differences**

Challenge 3

"**Figure out what is wrong with the non-functioning circuits in the room.** Explain, for each, what prevented them from working. Use drawings to help your explanation if needed."

- Instructors will need to set up several different non-functioning circuits. Problem could be simple or scaled up in complexity. Examples could include:
    - Incorrect polarity either module-to-module or module-to-load. (Use two solar panels and one motor. Hook up the solar panels in a series circuit but with black connected to black or red-to-red between the two solar panels. Or, connect black-to-red between the solar panel and a load, such as a Vernier Sound and Light Board).
    - Creating a short circuit by having opposite polarity wires touching (Use one solar panel and one motor, Connect the two alligator clips to the motor terminals so the metal of the alligator clips overlap).
    - Connect an LED light into a circuit backwards.
    - See the table on the next page from Beverly Satterwhite's "Mini Solar Homes" unit for detailed photos and descriptions of faulty circuits:

Station 1: The LED is placed in the wrong direction (in these circuits, current flows in one direction. LEDs are diodes, which means they have a polarity and current can only flow in one direction).	
Station 2: An alligator clip lead is damaged (the clip is dislodged and isn't always contacting the wire).	
Station 3: The positive ends of the solar modules are touching.	
Station 4: The voltage requirements of the LED were not met (note: "fixing" this circuit and understanding why it isn't working are two separate tasks – if students know the voltage requirements of the LED and then measure the voltage across the LED in this circuit, they may realize the true problem).	
Station 5: The motor is running the LED is not (LED leads are touching).	
Station 6: The attachments to the switch are placed incorrectly (the bottom lead is not fully attached).	

Challenge 4

"**Create a circuit that has a battery and a solar module in it connected to a motor and gear.** Write down observations about what happens when you add this battery to your circuit as opposed to having simply a module connected to your load. Additionally, write down observations about what advantages this might give to a device, such as a car, should it have these types of components."

WRAP-UP

- Have students revisit their KWL Chart, filling in the final column for what they have learned during the process of completing these challenges.
- As a class, share out these findings to assess where student understanding of circuitry falls as it related to solar car needs.
- Additionally, bring students back to the initial guiding question and the student-generated questions they posited at the beginning of the unit.

(Extension) Exploring Photovoltaics Activity 2: Solar Trackers

DETAILS

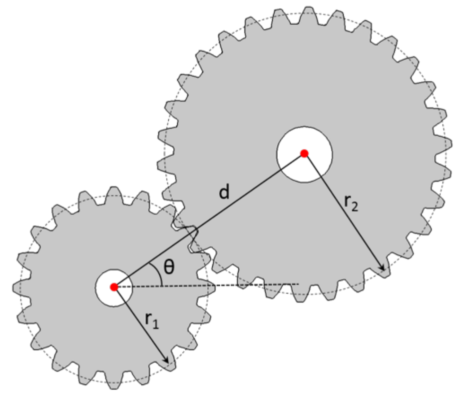
- On our website, there are several lesson plans to create a simple solar tracking device. These lessons are great ways to engage students in an activity that will further acquaint them with the interaction between motors and solar modules. Follow the steps below to find these lessons:
  - Go to http://cebrightfutures.org/.
  - Under the "Teach" tab, select "Search the Online educator library."
  - On the top left of the search page where it says "Search Keyword or Phrase," type "Solar Tracker" with quotes around the text to find "Solar Tracker" and "Simple Solar Tracker" activities by Pat Blount and Jamie Repasky.
- The motors used in these activities are geared, but this activity can be modified to use the car motors by using smaller solar modules and using a gear to hold.
- In addition, smaller modules like those in the solar car kit would work best in order to keep the size down.

ACTIVITY NOTEBOOK: RESEARCH

Exploring Vehicle Mechanics

ACTIVITY LIST:

- Wheels
- Gears



SUMMARY OF PROGRESSION:

This section is intended as a precursor to students exploring the usage of all of their car parts together. While the suggested activities scratch the surface of wheel and gear mechanics, these can be expanded upon however much the instructor feels is necessary. **One suggested area for more background information is the Junior Solar Sprint materials noted in the Teacher Guide at the front of this handbook.**

Exploring Vehicles Activity 1: Wheels

OVERVIEW/PREP

This is a quick activity that could be used to discuss wheel size with students and how it factors into overall success of a vehicle's design. This is mostly an organization and categorization-based activity that will be expanded upon through student investigation with their solar cars later on. This activity will also help build group rapport and prepare them for different phases of the engineering design cycle during their actual car development.

LESSON SEQUENCE

- **Intro**
  - Open up discussion with your students using the following scenario or a similar scenario: "You have been challenged by your friend to a unicycle race. There are two unicycles available to you and your friend, one unicycle with a single 15" wheel, and one with a single 30" wheel. Everything else, such as the seat, tires, pedal, etc. is the same. Which unicycle do you choose and why?"
  - Students can answer this question in a Think-Pair-Share in their engineering notebooks.
  - Discussion during this section can wrap up without a concrete answer, noting that they should add on to their answer or modify it throughout their course of investigation with wheels.
- **Categorization**
  - This section could go in one of two directions. Students can either be given six different types of vehicle wheels or be asked to find six different types of wheels through research online. Examples:
    - Mountain bike
    - Road bike
    - Caterpillar/heavy machinery
    - Roller blade
    - Tire with chains/without chains
    - Steamroller wheel
    - Combination of wheels (big in the back, small in the front)
    - Penny farthing bicycle
  - For each wheel type given or selected, have them write pros and cons to their design.
- **Sketch/Wheel creation**
  - Students are given another scenario in which they will be asked to design a wheel system for a car. This scenario could go in a number of directions, however, one way to keep it open would be to ask them to "Design the perfect wheels to have on your truck/vehicle during the zombie apocalypse." Students can be given many or few constraints.

- Have students sketch their designs, using color and labels to help explain why they chose certain characteristics.
- When they are done, have them share in groups or as a whole class.

- **Extension**
  - Should time allow, students can decide in teams what model wheel design they would like to build, and use scrap materials to build this visual tool.

Exploring Vehicles Activity 2: Gears

OVERVIEW/PREP

This activity will allow students to work hands on with tools they will experience in their solar car design, practicing taking gears on and off and connecting their solar module to the motor. Before beginning this activity, teachers will need to use the car parts available to them to set up stations where students can try different gear combinations on the same motor, axle, and wheel set up. This can be accomplished through having a simple base chassis set up with an axle attached and wheels that hang off the edge of the table, perhaps one for each group of students. Students will need to be able to count the number of times that the wheel turns for different gear combinations, without the wheel on a surface. A small mark or piece of tape attached to the wheel can help with this.

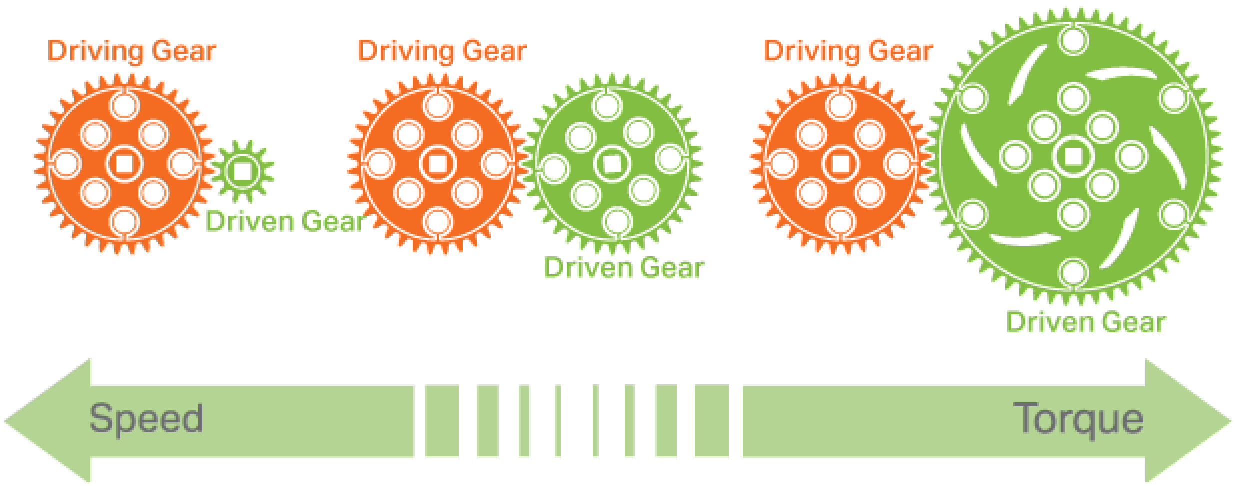
LESSON SEQUENCE

- **Intro**
  - In their engineering notebooks, have students list as many things as they can that have gears, or places they have seen gears. Ask them if there is anything that these have in common.
  - Optional: Bring in a bicycle or have students use a geared bicycle at home for a homework project. Ask them to find the easiest gear to ride on, the most difficult gear to ride on, and the most comfortable gear to ride on while on a flat surface. If in class, one or two students could be test subjects for the class. Have students sketch visual representations of what the gear combinations look like. This can just be done with their relative size to each other. Collect student questions and observations.
- **Exploration Prep**
  - Direct students to the stations that you have set up, noted in the Prep section.
  - Go over the components used to connect motors to axles in a solar car set up. Note the different sizes of gears available to them and differentiate between the **drive gear (the one connected to the motor, where effort is located) and the driven gear (connected to the axle, where load is located).**
  - Ask students to make predictions about what they think will be the best combination of gears to use in their final designs.
  - Have students create tables in their engineering notebooks where they can record data from testing different variations. Students can either be testing the same drive gear on three different driven gears in each table, or vice versa. They should measure the number of turns achieved in five or ten seconds. Make sure that their module connected to the motor is in the same place relative to the light source each time. It may be useful to have one taped to the table that students can bring their model over to when they are ready to test. See example table below:

DRIVE GEAR SIZE: SMALL

Driven Gear Size	# Turns in 5 Seconds
Small	
Medium	
Large	

- **Discussion**
  - After students have created three tables, discuss their findings as a class. If they are able, students should count the teeth on each gear, or have them counted for them, so that they can calculate the gear ratios for each of their tests in a third column of their table.
  - Students should notice that when you increase the size of the drive gear to the driven gear, the car slows down. That is because in this situation, the power (from the module) is constant and more force is required to keep it going the same speed.
    - **Torque** can be defined as the force used to twist an object. When you increase the size of the gear on which force is being applied (drive gear) you are increasing the torque because more force is needed to turn a larger gear.
    - If the size of the drive gear is smaller than the driven gear, there is less torque and less force required for a full gear rotation. With power being constant, less toque means more speed.
    - More advanced students can look into the following formula as a rule to follow for a deeper explanation: power= (torque) (speed). Torque and speed are inversely related. Increasing one will decrease the other.

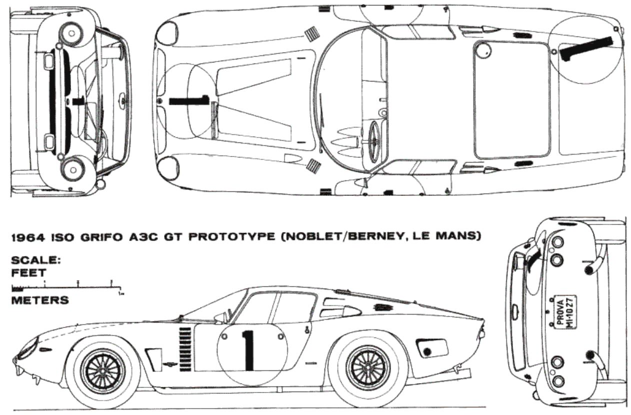


https://www.vexrobotics.com/vexiq/education/iq-curriculum/mechanisms/gear-ratio/

  - It is also important to note that effectiveness of gear ratios will vary depending on car design and reminding students that gear selection may play a role in the continued redesign of their car is important.
- **Wrap Up**
  - Following their final exposure to background content, it is important to address their initial questions once more.
  - Ask students to use new material that they have learned in how they approach the questions. Potential questions to prompt discussion could include:
    - What are the limits of solar energy when applied to vehicles?
  - What combination of gears resulted in a faster car?
  - In what situations would you design a car with more speed?
  - In what situations would you design a car with more torque?
  - What other applications of solar energy exist outside of vehicles?

ACTIVITY GUIDE: IMAGINE/PLAN

Initial Prototype Models



ACTIVITY LIST

- Individual Design
- Team Decision

SUMMARY OF PROGRESSION

During this section, students will work on creating visual models of their first designs of their car. This is split into two short activities, one where students will be creating designs on their own, and another where they come together as a group.

Initial Models Activity 1: Individual Design

OVERVIEW AND PREP

Students will be creating their first iterations of solar cars individually. Depending on the class understanding of various aspects of car design, you may want to emphasize their focus on specific pieces, such as gears, motors, wheels, etc. By having certain pieces pre-selected to display for them, it may scaffold the process for them to help them visualize more clearly what their car can look like. **In addition to pinpointing these specific components, it may also be useful to have a pre-built simple model to display how they can fit together.** This is also an effective section to go over the term "model" with them and provide examples of useful visual models. At its simplest, a model is a representation of a scientific principle, system, or concept that helps us to make predictions about how it works. Showing students, the difference between simple and more complex models of the same idea is a great way to elicit feedback on what makes them successful. Lastly, being transparent about model revision with students helps to set a culture of reflection and growth-mindsets as students recognize these changes as what they are learning in their process, not what they got "wrong." It is critical to include areas where students circle back to initial models and revise their work.

LESSON PROGRESSION

- By this point, students should be familiar with the engineering challenge. However, make sure to have them reference the challenge and some potential questions they may still have before entering this planning stage.
- **Constraints**
    - Students will additionally be familiar with many of the components that will be used in the solar car construction as well, through their previous investigations. However, provide each group with their materials in one location to give them a sense of everything they will be using in the construction of their vehicle.
    - In their engineering notebooks, have them create two columns: "Competition Tasks" and "Constraints."
    - Under the "Tasks" section, have them explain in their own words as many pieces of the overall challenge that they can. It is important for them to break it down if possible, using different language.
    - To discuss "Constraints," explain to students that these are the limitations or conditions that must be satisfied by a design. If students have never been introduced to this term, start of by discussing a totally different innovation, such as the Solar Impulse plane or moon landing mission. Ask students, "What made this challenge difficult?" or "What smaller problems would they have to solve?" Next have them list out similar constraints with their solar cars given the materials at hand.

- **Individual Sketch Prep**
  - Depending on how prepared your students are to visualize an operating vehicle, starting with some or all of the questions below could be helpful before sketches are created. Have students write their responses to the questions below with as much detail as possible and references to previous investigations:
    - **How could a solar car work?**
    - **Are there real-world solutions or existing models that you can use design solutions from?** (This will vary depending on whether you choose to have a model pre-made for your students to observe).
    - **What materials or tools were used by engineers to solve problems in the solution above?**
  - **Optional:** If your students have been observing a pre-designed model of car (such as your classroom model) or vehicle close in design, they can fill out a SCAMPER table before their initial design drawing that references this initial design.

SCAMPER Table	Questions to ask about your pre-existing design	What is your modification?	How does the modification improve the pre-existing design?
Substitute	What kind of alternate materials can I use?		
Combine	What could be added?		
Adapt	How can it be adjusted to fit another purpose?		
Magnify or Minimize	What happens if I exaggerate a component?		
Put to other uses	Can you change a component to be used for another purpose?		
Eliminate or Elaborate	What can be removed or taken away from it? What can be developed more?		
Reverse or Rearrange	Can I interchange any components? What can be turned around or placed in an opposite direction?		

- **Creating a Sketch**
  - Following initial prep and investigation of parts and previously built models, students will then create their own individual visual models.
  - In their engineering notebooks, have students create a "Front View," "Side View," and "Top View" section to contain different depictions of their vehicle ideas.
  - Below this, have them list the "Pros" and "Cons" to their initial design.
  - Make sure that students are asked to be as specific as possible in their sketches, especially when selecting gear sizes, wheel types, and any other modifications that they would like to change based on their previous investigations.
  - If time allows, have students create more than one sketch on their own, coming up with different design ideas for a potential second car.

Initial Models Activity 2: Group Design

OVERVIEW AND PREP

During this section, students will come back together in their groups to share their individual ideas for their solar car design. Groups should be pre-chosen at this point, with norms reminded for the collaborative process. It is especially critical to remind students of how to properly provide constructive feedback, as their peers will be vulnerable in the sharing of their initial plans.

LESSON PROGRESSION

- **Team Sharing Process**
  - Tell students that they will be required to take detailed notes while their peers are discussing their car design. Additionally, tell them that they should hold their questions until the end of their peer's presentation unless they are instructed otherwise.
  - Students will have specific instructions, depending on whether they are in a "presenter" or "audience" role in their groups. Ensure that all students are aware of this process before groups begin the process.
  - Presenter Role: Students that are discussing their individual design must answer the following questions to their group, using their drawing as a visual aid:
    - How does the car work and what makes you confident it will complete the challenge?
    - How did what you know about vehicle design influence your prototype?
    - How did your knowledge of solar panels influence your prototype?
    - What are you most excited about with your prototype?
    - What questions do you still have about your prototype's function?
  - Audience Role: Students will create a "+'s" and "?'s" chart in their engineering notebook:
    - On the "+'s" side, they are required to list all aspects of the car they like or thought were positive in the completion of the design challenge.
    - On the "?'s" side, they are required to list any questions they have about why the student chose particular design aspects OR questions they want the designer to consider moving forward in their process.
- **Team Decision**
  - As a class, have each group share out design aspects that their peers shared that they enjoyed. Try to have them be as specific as possible.
  - In teams instruct students to work together, combining ideas they liked into one initial team prototype. Have this team prototype created on a larger poster for the whole team to contribute to if possible and have hanging close to their workstation.

- Again, ensure that they are as detailed as possible, noting gear ratios, module placement, wheel selection, etc. in their prototypes.
- Have them refer to initial discussions of models and what made them successful.

- **Materials**
  - In their notebooks, have students create a chart that lists the materials and quantities they will need, clearly, to move forward. Students can divide these by what they have in the classroom vs. what they would like from outside the classroom.
  - Make sure they refer to the rules of the challenge before selecting outside materials.

ACTIVITY GUIDE: CREATE

Building Your Initial Prototype

OVERVIEW AND PREP

The primary objective for this section is for students to construct a working prototype to use in their initial testing phase. While students will be making small adjustments to their design throughout this process to make it "testable," this phase of their workflow remains separate from more calculated design changes later down the line. Essentially, they should be oriented toward getting a car they feel confident to test on the track. It may be useful to set a specific time limit for all students to work toward, at which point you can come together and discuss how to move into the testing and redesign steps.

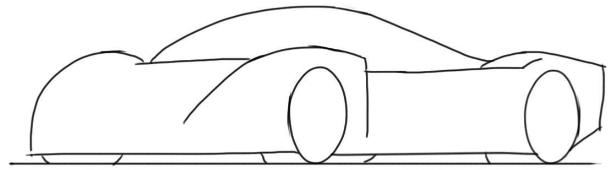
LESSON PROGRESSION

- Students work together in groups to build a "testable" initial prototype.
- This prototype should work to some degree in order for students to make initial observations on the strengths/weaknesses of their design.
- As noted in the prep section above, setting a timeline based on your knowledge of student workflow would be useful in terms of students having reached this "testable" point. It is important to emphasize that they first complete a working car, and that their more creative and intensive ideas can be incorporated down the road.
- Relay the following best practices/norms to your students to keep in mind while they work:
  - **Keep a clean workstation.**
  - **Read the Challenge Guidelines, Rules and Constraints.**
  - **Plan before you build.**
  - **Write everything down.**
  - **Use tools safely.**
  - **"Measure twice, cut once."**
  - **Manage your time well.**
  - **Enjoy the challenge!**
- In their engineering notebooks, have students list questions/wonderings they have relating to the completion and testing of their prototype while they are in the midst of constructing it. This may require reminders or having them write these down as they approach an instructor with questions.
- Even though a more in-depth process of redesign has not yet been reached, have students create a table to track small changes made to their initial prototype idea outlined in their sketch, similar to the one below:

Adjustments	Reasoning
What did you change about your design that was initially planned out by your group? This could be materials or structure.	Why did you make these changes? What impact do you hope they will have?

ACTIVITY GUIDE: TEST/IMPROVE

Determining Success and Redesign



ACTIVITY LIST

- Independent vs. Dependent Variables
- Thoughtful Redesign

PROGRESSION OF SEQUENCE

During this phase of student work, it is critical to realize and explain to students that the perfection of their car and completion of different phases may not happen the same way for everyone and may not follow a concrete structure. The activities that are outlined below can be thought of as a guide for students to follow and they may need to move back and forth between testing and redesign many times before they reach a decision. It is up to the instructor as to how students represent their work, however, it is critical that all students work through the following processes explicitly at least once in order to determine aspects of thoughtful redesign in engineering projects. This will additionally ensure that they are able to answer judges' questions and present their project clearly.

Lesson 1: Independent vs. Dependent Variables

OVERVIEW AND PREP

Students will focus the attention of their group onto determining the most successful design of their solar car through the manipulation of single variables at a time. This discussion will require students to have a certain level of background knowledge about independent variables, dependent variables, and controls. Some students may be able to complete this section faster than others, depending on how well the initial test goes with their first prototype design.

LESSON PROGRESSION

- **Initial Test**
  - Students' primary objective will be for their initial prototype to reach the end of the track. This should have been initially completed by the end of the Create phase, although some students may still have testing issues.
  - **All changes they make to their initial prototype drawing in order to make their physical model complete the first test should be noted in their engineering notebook, along with reasoning for making these changes.** See table for example:

Adjustments	Reasoning
What did you change about your design that was initially planned out by your group? This could be materials or structure.	Why did you make these changes? What impact do you hope they will have?

- **Variable Manipulation Discussion**
  - Once students have completed their initial tests and reached the end of the track, they will begin to focus on more fine details associated with the development of their car. This will pull from their background knowledge of different types of variables and their exploration of content before building a car.

- As a class, discuss all the details that they could change about their car. Work with students to move from broad changes to more specific ones. Try to reach a list that contains specific variables. You may want to provide some of these for students to start with.
- Once these changes are listed, ask students to list what these changes will affect about their car, working toward variables such as speed, load bearing, completion time, etc.
- Finally, using the list created as a class, have student determine which of these variables are most feasible to change and test in their design process.

- **Independent vs. Dependent Variables**
  - Provide the definitions for the following, or use your own from previous classes:
    - **Independent variables are variables that cause something to change and are manipulated directly by the engineer.**
    - **Dependent variables react to changes in independent variables; they “depend” on them.**
    - **Controls are variables that are unchanged to make sure you only see the effect of one variable are a time.**
  - As a class, have students select a variable in their cars they can all manipulate easily in their groups. This may be wheel size, gear ratios, angle of their module, etc. Ensure that all groups agree to the first variable to manipulate.
  - Discuss this variable as the independent variable that they will be working to change it and monitor the effect on an independent variable, most likely the time to complete the track.
- **Team Testing**
  - In their groups, students will be determining at least three variations of the independent variable to manipulate. It will be up to them to make decisions about the exact direction they will go with this variable manipulation.
  - Although the first variable will be determined together, make sure students test at least three different variables on their cars. Some variables include:
    - Drive gear
    - Driven gear
    - Module angle
    - Front wheel size
    - Back wheel size
    - Wheel grip
    - Body length
    - Body width
  - In their engineering notebooks, students will need to track data from their testing phases, creating a table before they even begin testing that outlines which variations they will test, noting their controls on their car and predictions they have for success. Note: with gear ratios, they must change either the drive or driven gear, not both, to avoid confusion. Their table could look something like example on the next page:

Independent Variable: Drive Gear Size	**Dependent Variable:** Completion Time
Trial 1: 16 teeth	______________ seconds
Trial 2: 32 teeth	______________ seconds
Trial 3: 54 teeth	______________ seconds
Controls:	
Initial Predictions:	
Were they true?	

Lesson 2: Thoughtful Redesign

OVERVIEW AND PREP

During this process, students will reference their initial prototype and take into account everything they have learned through careful variable manipulation. It is important that students take a step back from their work process and consciously engage in redesign, rather than making quick changes without monitoring progress. There are several tools, both specific and more general, that they can use to do this in their engineering notebook and have as a formative assessment of their understanding of the challenge.

LESSON PROGRESSION

- **Reflecting on Initial Prototype**
  - Students will use their observations from the manipulation of several variables to make more changes to their prototype, tracking each change as they are incorporated into their overall design.
  - The best redesign occurs when students are being thoughtful before they go back to testing and keep a log of their results.
  - Have students complete a SCAMPER table that references the iteration of their car that was used to complete the Initial Test.

SCAMPER Table	Questions to ask about your pre-existing design	What is your modification?	How does the modification improve the pre-existing design?
Substitute	What kind of alternate materials can I use?		
Combine	What could be added?		
Adapt	How can it be adjusted to fit another purpose?		
Magnify or Minimize	What happens if I exaggerate a component?		
Put to other uses	Can you change a component to be used for another purpose?		
Eliminate or Elaborate	What can be removed or taken away from it? What can be developed more?		
Reverse or Rearrange	Can I interchange any components? What can be turned around or placed in an opposite direction?		

- **Continued Testing**
  - As students continue to make changes and test them, it is important to have them tracking their progress along the way.
  - Determine some form of quick table for them to create and use in their engineering notebook that will allow them to take information back from the testing area to their group and log it quickly before making any more changes.
  - The table below is one example of how students can independently track redesign results:

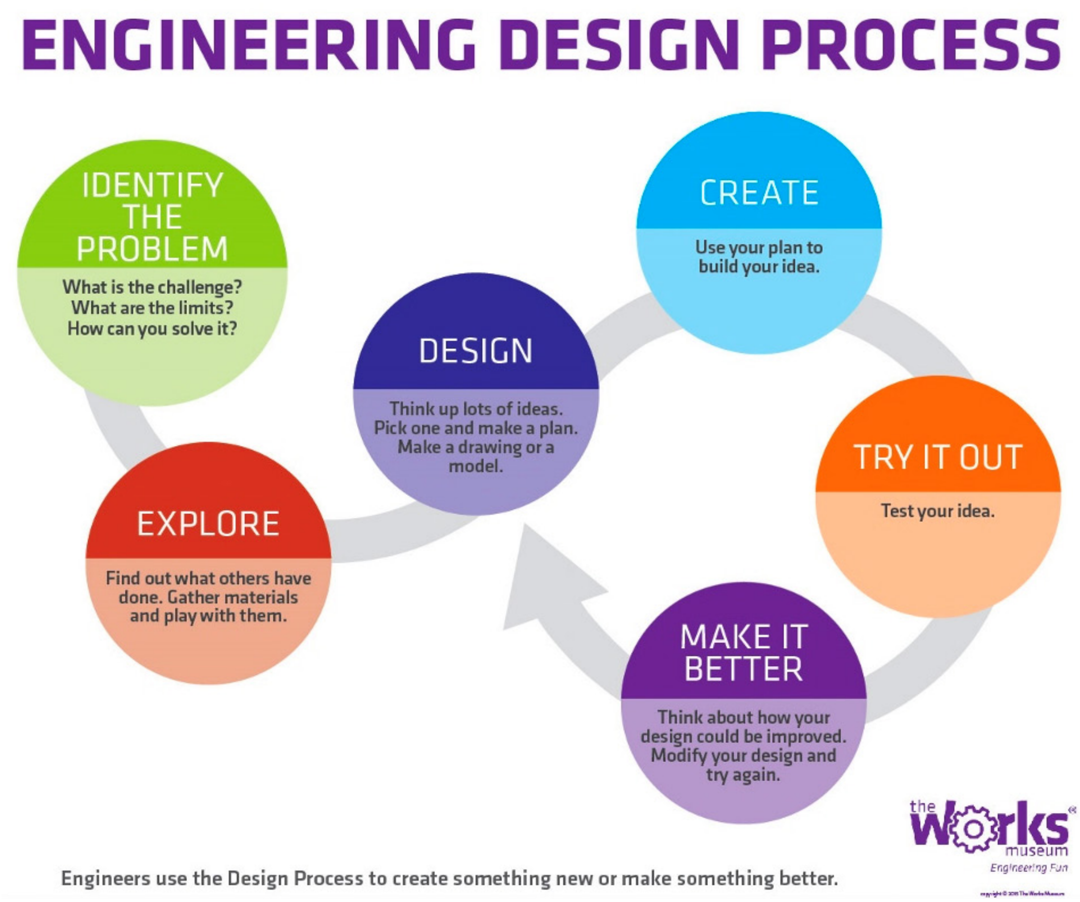
Redesign Changes	Results
What specific aspects of your car design did you change? What variables?	Did you notice any significant changes to your vehicle's performance? What were they?

- **Checking-In**
  - Students can continue the above processes countless times to determine the best iterations of their design process. Should they want to start over with a new car entirely, condensed versions of the same previous steps can be used.
  - There are several strategies that can be used to check in with students should it appear that they are not nearing completion. It is important before leaving each day to have them provide themselves with some next steps to return to on the following day.
  - One method to have students self-assess is a Claim-Evidence-Reasoning. This strategy can be used to determine how they can continue to improve their design. See below:

CLAIM What aspects of your car's design are successful? What aspects can be improved?
EVIDENCE What evidence can you point to from testing your car to support the above claims?
REASONING What background content knowledge do you have that supports this? What have you learned about how solar cars work?

- **Optional Addition: Design Consulting**
  - As students work through their own process of redesign, a concerted effort to utilize the ideas of other students circulating around the room not only helps them to increase their team's creativity, but also increases the rigor and level of competition amongst groups in the room as everyone is lifted up to a higher caliber.
  - Creating student "consultants" is one way to facilitate a process of idea exchange. Obviously, students may not want to give away their best ideas to remain competitive but will enjoy providing insights to teams based on their own findings.
  - For each group, designate students that will act as consultants, circulating the room and noting ideas for other teams to incorporate into their cars. Designate other students to stay with their car and discuss these changes with the consultants.
  - As this process is underway, require that both consultants and the stationary students track listed changes as well as the desired effects and/or purpose of these changes.

Always remember, Engineering Design is not a perfect cycle, and oftentimes looks more like a web as students move between different stages depending on what redesign necessitates. The image below depicts a closer-to-reality scenario:



ACTIVITY GUIDE: COMMUNICATE

Prepare for Clark Public Utilities Solar Car Challenge

OVERVIEW/PREP

As the date of the Solar Car Challenge approaches, students should focus their efforts on the presentation of their car design to judges at the solar car challenge. Communication of results and readdressing initial questions is the final, and most critical, stage of the engineering design cycle. Remind teams that while 45% of their score depends on the car's performance in the races, 55% of the team's overall score will depend on their documentation and performance in an interview with a utility professional.

LESSON SEQUENCE

- Engaging students in the rubric that will be used to score them will be a central piece to their preparation for the event. They should be familiar with the judging guide as much as their teacher is, so that they are not surprised on the day of the event.
- Before creating posters and preparing for interview questions, readdress the initial guiding and unit questions one last time. Regarding their overall guiding question, facilitate a conversation about the progress toward an answer. These initial guiding questions oftentimes do not have a single answer, and many times will lead to more questions on the part of the students. Students will be required to include some of their big takeaways both into the interview as well as their poster.
- While students are creating their poster for the event, encourage the inclusion of engineering notebook sketches, tables, and notes into this piece. Additionally, they should be encouraged to use their engineering notebooks in their interview portion as well to help them answer questions and show things to the judges.
- If your school has a high number of interested teams, intramural competitions will be necessary to determine finalists who will advance to the main event at Hudson's Bay High School. See next lesson for details.

ACTIVITY GUIDE: REFERENCES

NGSS Performance Expectations

Note: The following performance expectations are to serve as suggested targets for alignment. This activity guide is designed to allow teachers from different grade levels and subject areas to make modifications to more strongly align the activities to appropriate standards.

Elementary

3-5-ETS1-1.	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2.	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3.	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
3-PS2-2.	Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.
3-PS2-3.	Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.
4-PS3-1.	Use evidence to construct an explanation relating the speed of an object to the energy of that object.
4-PS3-2.	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
4-PS3-4.	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.
5-ESS3-1.	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
4-ESS3-2.	Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

Middle School

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.
MS-PS2-3.	Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
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.
MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3.	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4.	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

High School

HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-3.	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-ESS3-4.	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ETS1-1.	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-2.	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3.	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
HS-ETS1-4.	Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

ACTIVITY GUIDE: WIKIS

The Fundamentals of Electricity

Electric charge (conventionally denoted Q) is a property of matter that describes the force experienced (and exerted) in the presence of other electrically charged matter. An electrically charged particle will therefore perform work on another electrically charged particle, which is an example of energy by definition. Electricity is defined as the collection of phenomena associated with the presence of electrically charged particles. These particles can either be static, representing an accumulation of charge, or flowing as an electric current.

ELECTRIC CHARGE

There are two types of electric charge: positive and negative. Alike charges will repel one another, and opposite charges will attract. For the most part we deal with protons and electrons as the fundamental charged particles, and each carries an "elementary charge," which describes its magnitude. In other words, protons carry one positive elementary charge (denoted +1 e), while electrons carry -1 e.

Although the elementary charge is a unit unto itself, in the context of energy and electricity it is often impractically small. In fact, while all charge is composed of individual charged particles carrying 1 (or -1) e, it is often more convenient to think of charge in terms of the force exerted by its movement or by its potential when static. When discussing electricity, the Coulomb (C) is the preferred unit of measurement. One Coulomb is roughly equal to 6.241×1018 e.

As previously touched on, a particle or material with a net positive charge will repel another positively charged material and attract one with a negative charge. In other words, electrically charged materials exert force on other electrically charged materials. For instance, if you were to take a proton and physically separate it from an electron, there would be a force of attraction between them. If allowed to move freely, these two oppositely charged particles would recombine, transforming the potential energy that existed between them due to their attraction into the kinetic energy of their motion toward one another. This is analogous to the transformation of gravitational potential energy into kinetic energy when an object is dropped from some distance above the ground. In this case, rather than gravitational potential energy created by the distance of the object above the ground, we have electric potential energy, created by the separation of two oppositely charged materials.

VOLTAGE

Voltage (denoted V), sometimes referred to as "electrical potential difference" or "electro-motive force" is the difference in the electrical potential energy per unit of charge between two positions in space. It tells us the amount of energy (again per unit of charge) that is required to separate two charged materials some distance. To give an example, if it requires 9 Joules (J) of energy to separate 3 Coulombs (C) of electrical charge, the resulting electrical potential difference (which is to say voltage) would be 3 Volts (V). Accordingly, the equation for voltage is:

$$V = \frac{w}{Q}$$

Where:

V: Voltage
w: Energy (or Work)
Q: Charge

By the same token, voltage is also the amount of electrical potential energy per unit of charge contained by the charges once they have been separated. Therefore, if 3 C of charge travels across the 3 V of electrical potential difference, that represents 9 J of electrical kinetic energy available to do work on some other system. This decrease in voltage as charge moves from a position of higher electrical potential energy to a position of lower electrical potential energy is referred to as a "voltage drop."

Voltage is also (synonymously) the motive force that drives the movement of charge across the electrical potential difference. Gravity is once again an apt if somewhat imperfect analogy here. The force of gravity causes both the difference in potential energy of a mass as it's raised above the Earth and the motion of the object once it's released.

Current

Current (denoted I) is the rate at which charge is flowing. It is defined as the amount of charge that passes a point in a second. For example, if 3 Coulombs of charge pass a single point in a wire over the course of 2 seconds, there exists a current of 1.5 Amperes (A) in the system.

$$I = \frac{Q}{t}$$

Where:

I: Current
Q: Charge
t: Time

The relationship between current and voltage is integral in understanding how much power is "developed" in a system, that is to say, how much electrical power is generated and dissipated. It is important to understand that in a circuit, current is a conserved quantity. At each junction in the circuit, the sum of the current entering a node must be equal to the sum of the current leaving it. Therefore, in a circuit with one single loop, the current would be the same across each electrical element. Current doesn't "drop" in the same way that voltage does, but in fact remains constant.

POWER

The standard unit for measuring electrical power is the Watt, which is equal to 1 Joule/second. In the context of electricity, power is often used to describe an electrical device or generation system. In the first case, the power rating of a device gives its instantaneous electrical demand. For instance, in order to remain lit, a 10-Watt compact fluorescent light bulb would continuously require 10 Watts of electrical power. In the second case, the power rating of a generation system describes its capacity. For example, a 200-Watt photovoltaic module is capable of producing 200 Watts of electrical power when in peak sun conditions. Power is a conserved quantity, meaning that the amount of electrical power provided to a circuit (for instance, by a battery or a photovoltaic module) is equal to the amount of power dissipated (or used) in the circuit by resistors or devices.

ENERGY VS. POWER

Though the terms are often used interchangeably in everyday speech, energy and power are two different things. Power is the rate at which energy is transferred, used or transformed. When lit, a 100-Watt incandescent light bulb is continuously converting 100 Watts of electrical power into light and heat. As already discussed, energy is the ability to do work, but it can also be quantified as the amount of power consumed or generated over a period of time. The unit Watt is equivalent to one joule of energy per second. That 100-Watt light bulb will transform 100 Watt-hours or 360 kilojoules of electrical energy into thermal and electromagnetic energy every hour that it's lit. Therefore, if power is not changing over time, the relationship between energy and power can be explicitly described by the equation:

$$w = Pt$$

Where:

w: Energy (or Work)
P: Power
t: Time

If power varies as a function of time, then energy is the integral of power with respect to time:

$$w = \int P dt$$

In other words, Energy (or "Work") (W) is equal to the integration of power (P) over a specified time interval.

THE POWER EQUATION

The power equation describes the relationship between voltage, current and power. Recalling that power is the amount of energy transformed or transferred per second, it then makes sense that power would be the amount of energy per unit of charge multiplied by the amount of charge that is passing per second. Therefore, power is equal to the product of voltage and current.

$$P = IV$$

Where:

P: Power
I: Current
V: Voltage

RESISTANCE

Resistance is the opposition to electrical current in a material. To put it another way, resistance is the inverse of a material's ability to conduct electricity. Resistance is an important concept to understand when discussing electricity because it dictates how quickly charge will flow through a circuit and therefore how much current will exist.

OHM'S LAW

Ohm's Law gives us the mathematical relationship between voltage, current and resistance and is one of the most fundamental tenants in understanding electricity:

$$V = IR$$

Where:

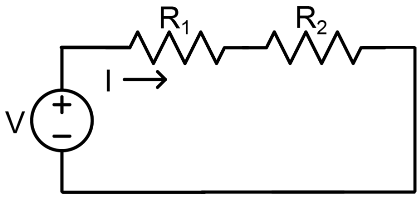
V: Voltage
I: Current
R: Resistance

Circuits

An electric circuit is simply a connection of electrical elements. A light bulb connected to a battery is a basic circuit. The battery provides voltage to the circuit, and the light bulb introduces resistance. If the circuit is closed, meaning that it creates a complete and unbroken loop between the two terminals of the battery, the voltage will "push" charge through the circuit, creating a current, and the light bulb will be illuminated. Energy is therefore transformed by the circuit from electrical potential energy in the battery into electrical kinetic energy flowing through the conductors, which is then transformed into light and heat in the light bulb. In essence, the goal of every circuit is transform electrical energy into some other useful form of energy.

SERIES CIRCUIT WIRING

A circuit that is wired completely in series is just a single loop, which means that there is only one path through which current can flow. The current across each element is therefore the same because it never gets split across two different paths. In this circuit diagram, two resistors are wired in series:

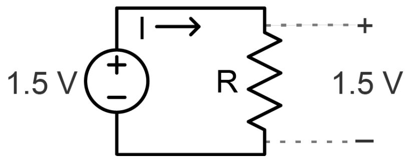


Where:

R1 & R2: Resistors
V: Voltage Source
I: Current

VOLTAGE IN SERIES WIRING

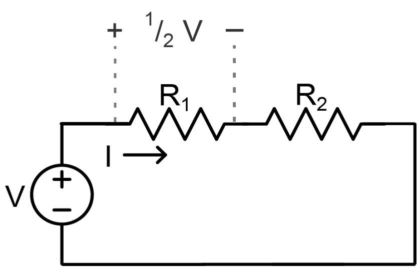
Voltage is the electric potential difference between two points. Therefore, when we talk about voltage, we are always talking about the voltage in one location relative to another. In a circuit, the reference point is always zero. For instance, in the series circuit drawing above, if the voltage source were a 1.5 V battery, the voltage at the positive terminal would be 1.5 volts relative to the negative terminal, where the voltage would be 0 volts. Therefore, the voltage supplied by the battery will drop over the circuit. In the case of a light bulb connected to the battery, essentially the entire voltage drop occurs across the terminals of the light bulb since it represents the only meaningful resistance in the circuit.



Where:

R: Light bulb
I: Current

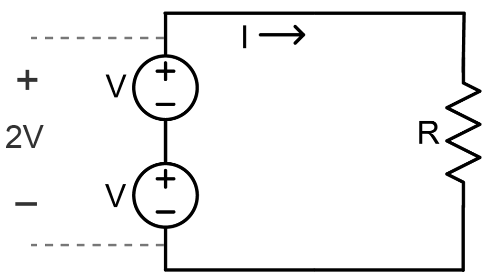
In a circuit with multiple resistors in series, the voltage will drop incrementally across each. For instance, if two resistors of the same resistance are wired together in series, then the voltage drop across each resistor will be the same - and will be equal to half the total voltage drop across the circuit.



Where:

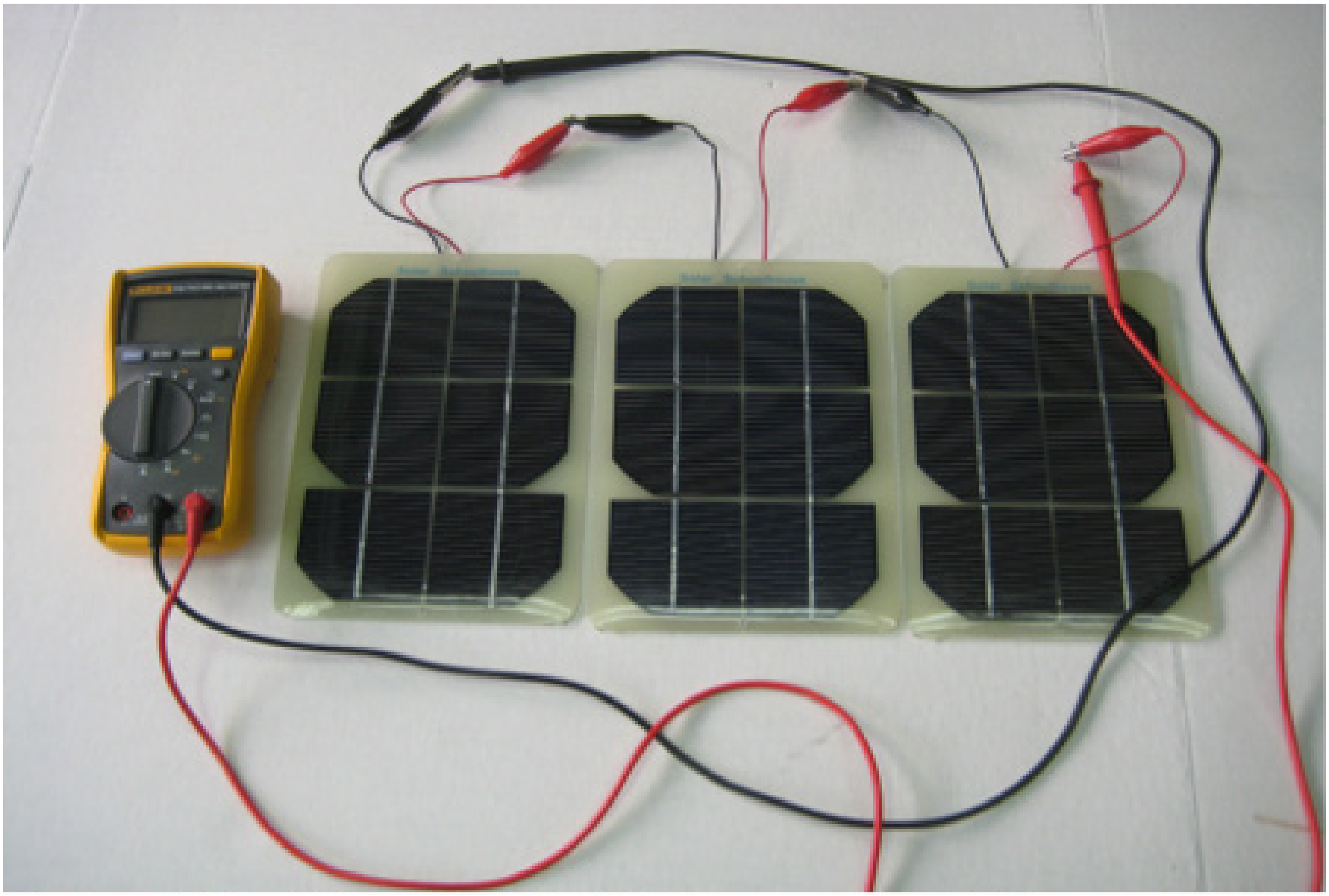
$R_1 = R_2$
V: Voltage
I: Current

When two voltage sources are wired in series, the two voltages are added, creating a larger electric potential difference over the entire circuit.



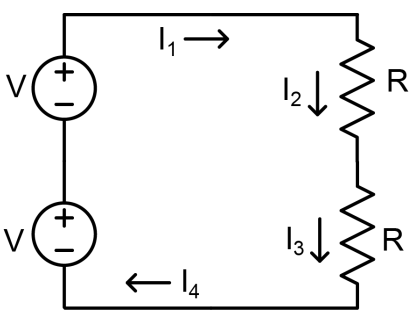
$$V_{total} = V1 + V2 + V3 + ... + Vn$$

If the two voltage sources in the series above are 3-Volt photovoltaic modules, the total voltage across the resistor would be 6 Volts. In this configuration the positive (red) lead of one module would be wired to the negative (black) lead of the next. This is shown in the schematic above where the two voltage sources are connected negative side to positive - essentially stacked. In this instance, since both voltage sources have the same voltage (3 Volts) the overall potential difference between the topmost positive terminal and the bottommost negative terminal is twice as large - making it 6 Volts. Below are three 3-Volt photovoltaic modules wired in series, making the total voltage drop in the circuit 9 Volts.



CURRENT IN SERIES WIRING

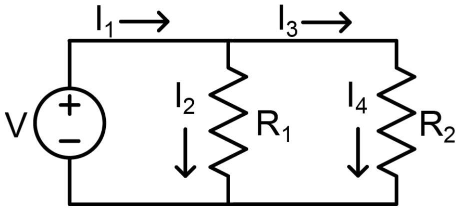
As previously mentioned, in a series circuit there is only one path through which current can flow. Current will be conserved in a circuit because charge must be conserved. Electrons move through a circuit, but they don't disappear, and as each electron propels the next forward, a current is created. If you imagine the electrons moving through a wire as a traffic jam on the highway, the rate at which traffic moves is the current. A car can't move faster than the car in front of it, and so the speed of each car is the same as every other car. Obviously, this is an imperfect metaphor, but the key point is that if there is only one loop through which electrons can flow, the rate at which they flow - the current - will be the same at every point in the circuit.



$$I_{total} = I_1 = I_2 = I_3 = \ldots = I_n$$

PARALLEL CIRCUIT WIRING

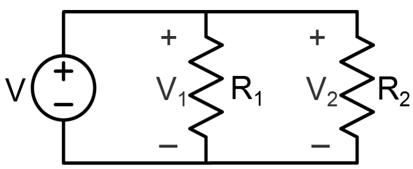
Wiring electrical elements in parallel means that each will have its own distinct loop. Therefore, there are multiple paths through which current can flow.



Where:
R_1 & R_2: Resistors
V: Voltage Source
I_1, I_2, I_3 & I_4: Current Values

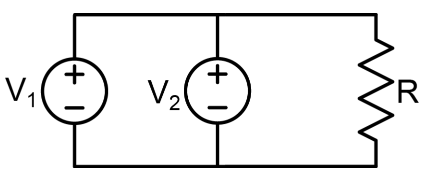
VOLTAGE IN PARALLEL WIRING

In the circuit diagram below, each resistor is wired directly and independently to the voltage source. If either resistor was removed - thereby creating an open circuit across one of the loops - current would still be able to flow across the other resistor. The total voltage drop in each loop must be equal to the voltage supplied to the loop. Therefore, in a circuit like the one displayed below where a single voltage source delivers voltage to several loads wired in parallel, the voltage drop across each will be the same.



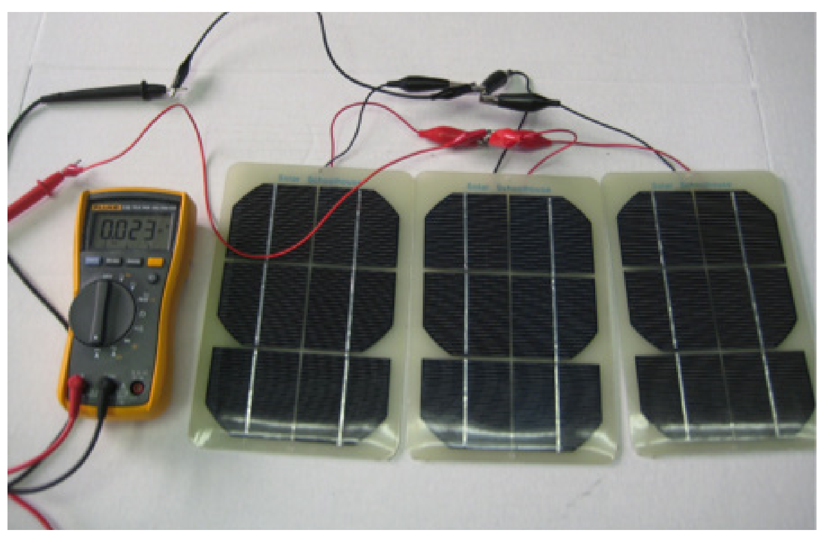
Where:
V: Voltage Source
R_1 & R_2: Resistors
V_1 & V_2: Voltage drop across each resistor
$V = V_1 = V_2$

When two voltage sources are wired in parallel, the positive terminal of one source is wired to the positive terminal of the other. The voltages provided by each source are not added to one another - the voltage delivered to the circuit is equal to the voltage of the individual sources. Therefore, parallel voltage sources should have the same voltage.



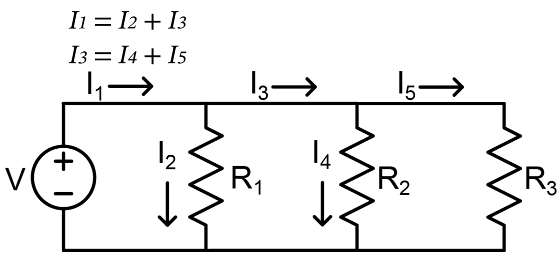
$$V_{total} = V_1 = V_2 = V_3 = ... = V_n$$

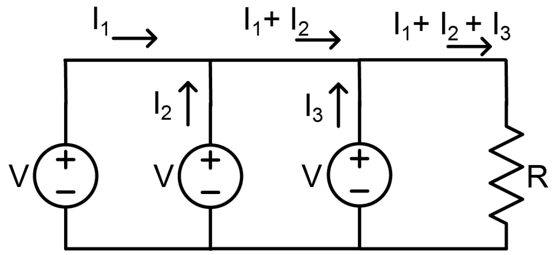
If the two voltage sources wired in parallel as shown above are 3-Volt photovoltaic modules, the total voltage across the resistor would be 3 Volts. In this configuration the positive (red) lead of the first module is wired to the positive lead of the next and the negative (black) lead of the first to the negative lead of next. Notice that in the schematic there is a connection between the positive side of the two sources and between the negative side. No matter how many 3-Volt photovoltaic modules are wired together in this configuration, the voltage delivered to the resistor will always be 3-Volts.



CURRENT IN PARALLEL WIRING

In a parallel circuit there are multiple paths through which current can flow, and it will divide according to the resistance in each branch. The total current in the circuit must still be conserved, and so when it divides (or combines) at a junction, the sum of the currents entering that junction will be equal to the sum of currents leaving it.





Therefore, when several voltage sources are wired together in parallel, the voltage will not add, but the currents delivered by each of those voltage sources will.

SOLAR ENERGY

Solar energy is the radiant electromagnetic energy - or light - received from the Sun by the Earth. While the solar radiation received by the Earth's atmosphere is relatively constant, the amount of sunlight incident on the Earth's surface varies widely due to:

- Atmospheric effects, including absorption and scattering;
- Local variations in the atmosphere, such as water vapor, clouds, and pollution;
- Latitude of the location; and
- The season of the year and the time of day.

The above effects have several impacts on the amount and quality of the solar energy that we actually receive, including variation in the amount of power, the specific wavelengths of light and the angle at which sunlight strikes the Earth's surface. In addition, the variability of the solar radiation at a particular location will be affected by the above considerations. For instance, desert regions tend to have lower variations due to local atmospheric phenomena such as clouds. Equatorial regions have low variability between seasons.

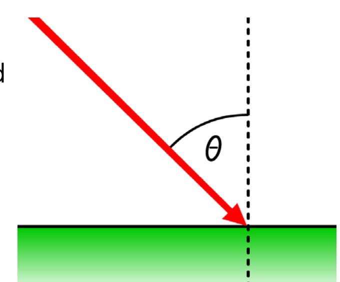
IRRADIANCE & INSOLATION

To quantify solar resource, we measure the amount of **power** received from Sun over a given area of earth. This value is called irradiance and measured in kilowatts per square-meter, where 1 kW/m2 = 1,000 W/m2. Over the course of a day, the **irradiance** will go from 0 kW/m2 at night when there is no sunlight to about 1 kW/m2, which is sometimes called "peak sun." Photovoltaic modules are rated based on the amount of electrical power they will produce under these peak sun conditions. A 200-Watt photovoltaic module will therefore produce 200 Watts of electrical power when receiving1,000 W/m2 of solar power.

Cumulative irradiance or **insolation** is the amount of energy received from the Sun over a given area of earth and is measured in kilowatt-hours per square-meter.

INCIDENT ANGLE OF SUNLIGHT

When the Sun's rays are perpendicular to an absorbing surface, the irradiance incident on that surface has the highest possible power density. As the angle between the sun and the absorbing surface changes, the intensity of light on the surface is reduced. When the surface is parallel to the sun's rays (making the angle from perpendicular to the surface 90°) the intensity of light falls to zero because the light does not strike the surface. For intermediate angles, the relative power density is cos(θ) where θ is the angle between the Sun's rays and direct normal (or perpendicular) to the surface. The irradiance absorbed by the surface can be found by multiplying the total irradiance by cos(θ).



$$I_i = I_t \cos(\theta)$$

Where:
I_i: Irradiance absorbed by the surface
I_t: Total irradiance
θ: Incident angle

Therefore under peak sun conditions (1,000 Watts/meter2) if the angle of the sun's rays strike a surface 15° off from perpendicular, the irradiance absorbed the surface would be:

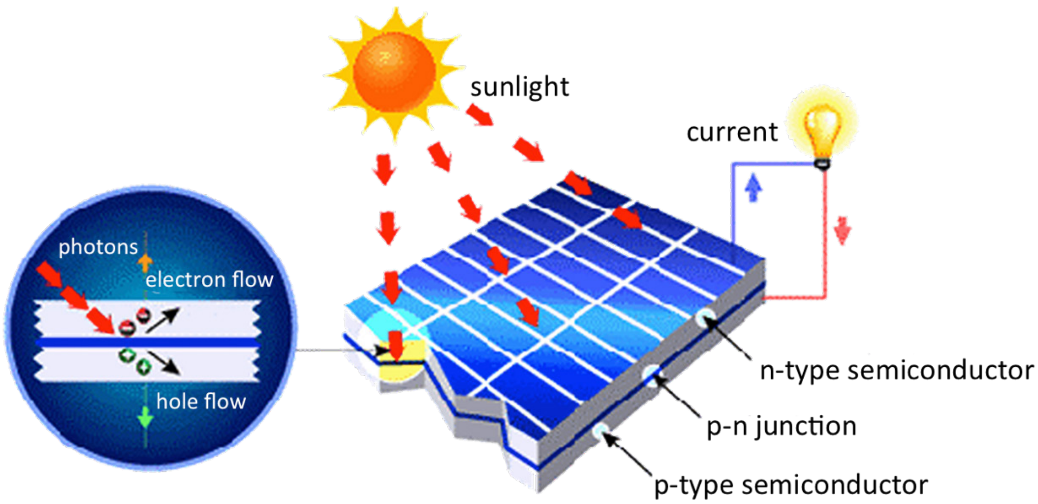
$$I_i = 1{,}000\ W/m2\ x\ \cos(15°) = (1{,}000)(\sim .966) \approx 966\ W/m2$$

In designing photovoltaic (PV) systems, this question of how much available irradiance is absorbed by the photovoltaic modules is very important, since the amount of energy the system is able to produce is directly proportional to the amount of energy it absorbs from the Sun. Some systems are therefore designed with trackers on them, which cause the photovoltaic modules to follow the Sun's movement across the sky, maximizing the amount of time that the PV modules are directly facing the Sun.

ACTIVITY GUIDE: WIKIS

Photovoltaic Technology

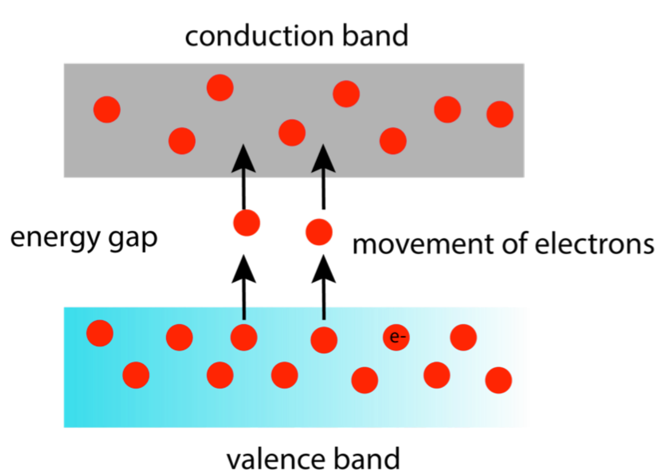
The term photovoltaic (often shortened to "PV") is used to describe materials that are capable of converting electromagnetic energy - or light - into electrical energy. The photovoltaic effect is a phenomenon whereby a voltage is created in a material when the material is exposed to light. This voltage will then cause charge to flow if the circuit connecting the two terminals of the photovoltaic material is closed. The amount of current that flows is directly proportional to the amount of light that strikes the photovoltaic surface.



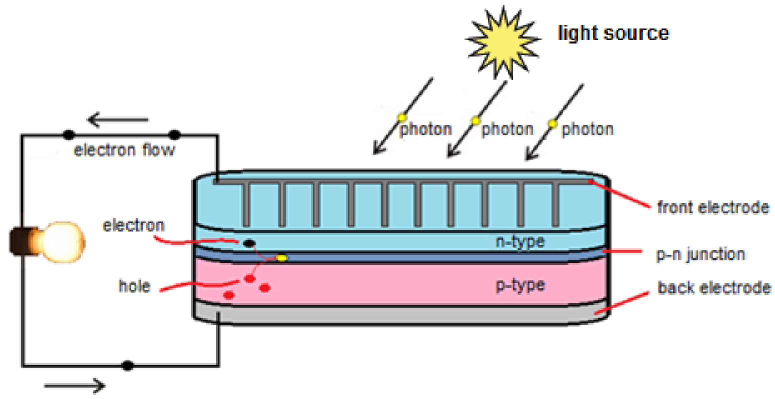
PHOTOVOLTAIC MATERIALS

The most fundamental component of a photovoltaic module is its individual photovoltaic cells. They are made up of a semiconductor material that exhibits the photovoltaic effect. The material most commonly used in PV technology is silicon because of its abundance and affordability, but other semiconductors are sometimes used for particular applications. By doping the silicon with other elements, two oppositely charged layers are created in the cell, a positive (p) layer and a negative (n) layer, which meet at a p-n junction. The p-n junction is essentially a diode, meaning that current can only flow in one direction through the junction. Therefore, a voltage exists between the two layers of the PV cell.

When photons strike the cell, this will give electrons the energy they need to move from the valence band to the conduction band, making them available to move through the circuit.



The voltage across the cell will then cause these electrons to flow if there is a closed circuit connecting the negative layer at the top cell to the positive layer at the bottom. This is the electric current, which corresponds directly to the amount of solar energy available to elevate electrons into the conduction band. Once these electrons have traveled through the circuit to the bottom p-layer, they will then travel back through the p-n junction and return to the n-layer. This cycle will continue as long as the circuit is closed and the cell is exposed to light.



DOPING

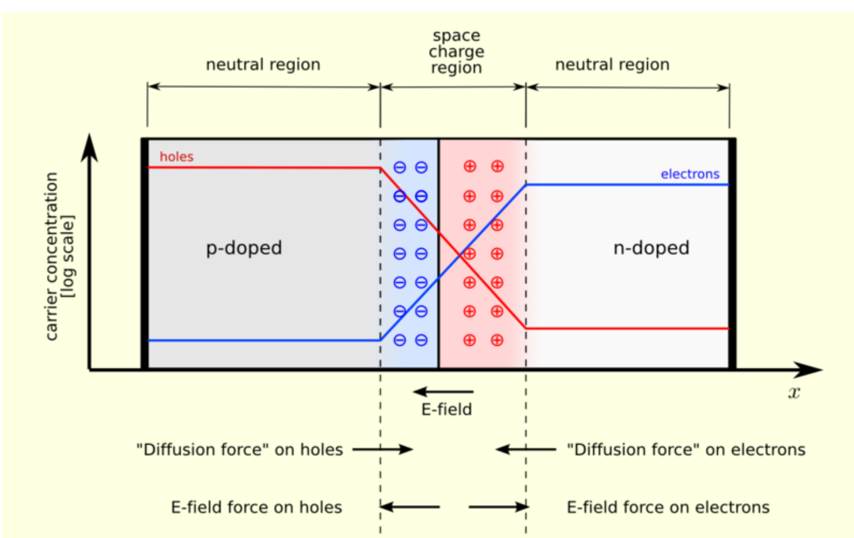
In order to create the positive and negative layers in the semiconductor material, other elements are added to the silicon. This process is known as doping. Silicon (Si) has 14 electrons in its electron shells, and therefore 4 valence electrons in its outermost shell.

In order to create the n-type layer of the PV cell, an element with 5 valence electrons is added to the upper layer. Phosphorus (P), which has 15 electrons, is a common choice for this. When the silicon and the phosphorous bond in the n-type layer, there are a total of 9 valence electrons, which is one more than will fit in the valence shell, meaning that there is one available electron.

Similarly, doping the bottom layer of the silicon cell with an element containing only 3 valence electrons in its outer shell creates the p-type layer. Boron (B), which has a total of 5 electrons, is often used in the p-type layer. When the Silicon atoms bond with these atoms, a hole is effectively created because the resulting covalent bond lacks an 8th electron.

DEPLETION REGION

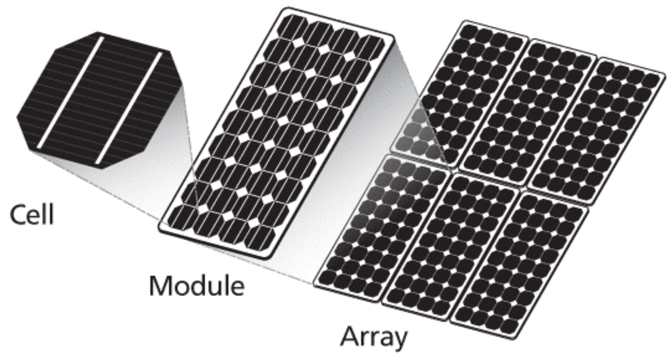
When the n-type and p-type materials meet at the p-n junction, electrons from the n-type layer tend to migrate into the p-type layer where they fill the “holes” in the outer valence shell created by the silicon-boron covalent bonding. The area at the edge of the junction from which the electrons migrated on the n-type side becomes positively charged because now there are positive ions that have given up an electron. Similarly, the area at the edge of the junction on the p-type side that accepted these electrons now has a net negative charge. This region is known as the “depletion region” because following the electron migration there are no longer any charge carriers available to move, and the junction is in a state of equilibrium. Additionally, these ions on each side of the junction create an electric field across it, which prevents any other electrons from crossing the junction from the n-type layer to the p-type layer.



However, if a circuit is created connecting the top and the bottom layer of a photovoltaic cell, electrons from the n-type layer that cannot travel across the p-n junction because of the depletion region can now travel through the circuit to reach the p-type circuit. Once the electrons arrive at the bottom contact of the PV cell, the same electric field that prevented them from traveling across the depletion region in the downward direction will now draw them back up to the n-type layer.

PHOTOVOLTAIC SYSTEM

Discrete pieces of photovoltaic material are known as photovoltaic cells and have an inherent voltage of roughly 0.5V, regardless of their size. However, the amount of current that a cell is capable of producing is directly proportional to the area of its photovoltaic surface. Therefore, recalling that power is the product of voltage and current, the amount of power that a cell is capable of producing is proportional to its surface area.



A photovoltaic module (or colloquially a "solar panel") is an assembly of wired together PV cells that have been packaged between a rigid backing and a transparent material to provide protection and ease of installation. The material covering the PV cells can be glass, plastic or an epoxy - something lightweight that is strong enough to protect the fragile photovoltaic cells from hail and other environmental hazards while admitting all of the desirable portion of the light spectrum to the photovoltaic material. Very high-energy electromagnetic energy such as UV light is actually not desirable because it can overheat the photovoltaic cells, decreasing their efficiency.

Each PV module is rated based on the amount of DC power it is capable of producing under Standard Test Conditions (STC), which are 1,000 W/m2 (or "Peak Sun") at 25 °C module temperature. The modules are then typically wired together into strings, which are then wired together into the complete photovoltaic array.

Photovoltaic modules produce direct current (DC) electricity. This is convenient if the goal is to charge a battery for energy storage in an off-grid system, but our electrical grid and most of our day to day to electrical devices operate on alternating current (AC) electricity. Therefore, in order to convert the DC electricity into AC electricity, a device called an inverter is installed as a part of the photovoltaic system. In addition to converting the direct current power into alternating current power, a grid-tied inverter also matches the phase and frequency of the inverted power from the photovoltaic system to the power on the grid, thus allowing the photovoltaic system to safely and effectively feed into the grid and to interact with the power already supplied to facility on which its installed.

ACTIVITY GUIDE: WIKIS

Using a Multimeter "Cheat Sheet"

MEASURING VOLTAGE:

- Voltage is the difference in electrical potential between two places in a circuit.
- We therefore measure voltage **across** an element, meaning that we connect the multimeter in **parallel** with the element of interest.
- To prevent the multimeter from changing the circuit, we want **very little current** to flow through the meter, so the meter needs to have a **very high resistance**.

MEASURING CURRENT:

- Current is the measure of how fast electrical charges move through a branch of the circuit.
- We therefore need all of the current passing through an element to pass through the multimeter, meaning that we connect the multimeter in series with the element of interest.
- To prevent the multimeter from changing the circuit, we want **as small a voltage drop** across the meter as possible, so the meter needs to have a **very low resistance**.

SETTING THE DIAL:

- There are four settings on the multimeter. In general, we will be using DC voltage (V⎓) measured in "Volts" and DC current (A⎓) measured in "Amps," hence the "V" and "A" designations on the multimeter.
- The numbers on along the dial represent ranges of measurement. For instance, the first range of measurement on the voltage side of the meter in the images above is from 200mV to 2V. If your expected reading is less than 200mV, you should set the dial to 200m. If it's greater than 200mV, but less than 2V, you should set the dial to 2, etc. The values get larger in the clockwise direction around the dial.

JUDGING GUIDE

Challenge Details and Rules

WHO CAN PARTICIPATE?

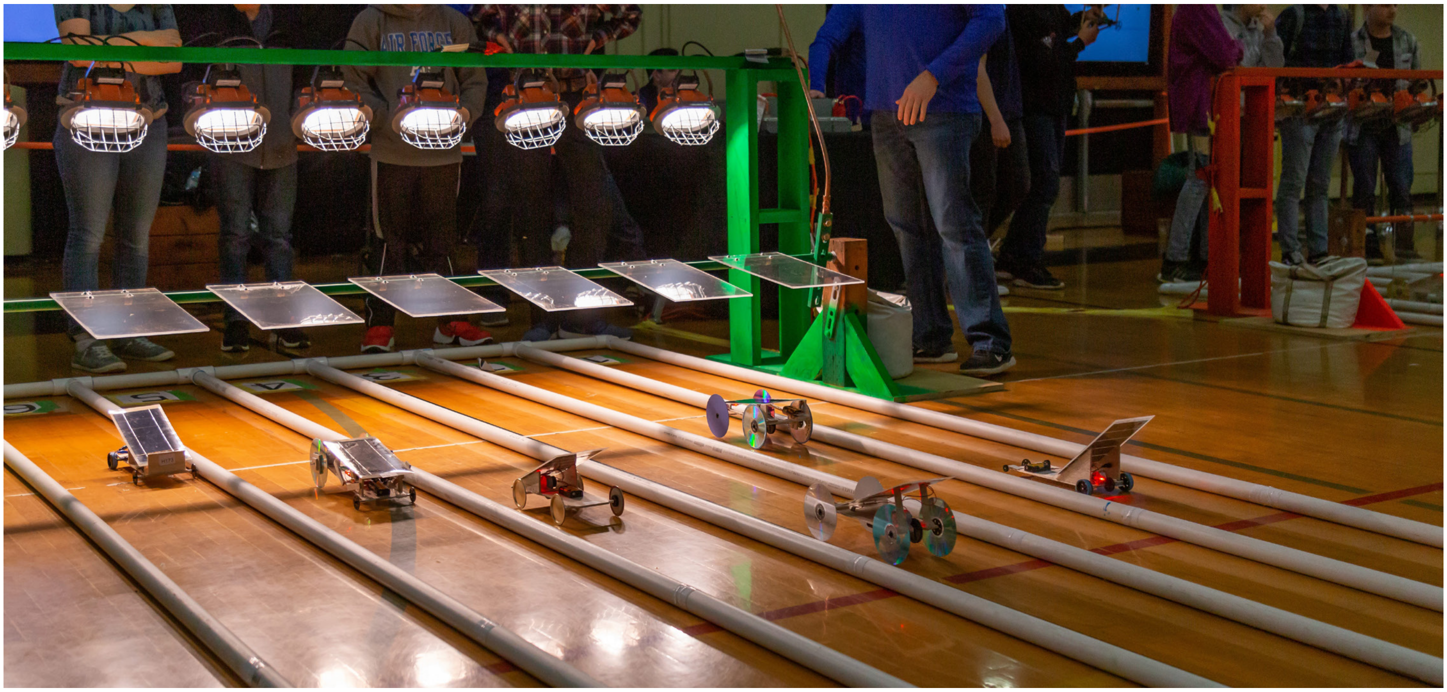
This challenge is designed for elementary, middle and high school students. Criteria for success are scaled to match the grade level (see rubrics beginning on page 52).

Students (with guidance from teachers/coaches) will design, build, and race hybrid solar battery-powered electric powered cars that include both a solar module and a battery pack. Teams will be judged on their vehicle's performance in a race (45%) and performance in a team interview with supporting engineering process documentation (55%). We recommend team sizes of 2 – 4 students per team for the most meaningful experience.

2019 Clark Public Utilities Solar Car Challenge Winners

TRACK SPECIFICATIONS

- Track Length: ~20'.
- Lane Width: ~12".
- Number of lanes: 6 lanes.
- Starting Gate: about 16 inches from the beginning of the track.
- Track Surface: Track sides/lanes are comprised of 1/2" PVC pipe, the surface of the track is the gym floor.
- Lighting: (3) 500W halogen light 32" above track (center, left, and right).
- Each lane will have one halogen light located at about ~32" above the track, illuminating the first ~24" of the track. Altogether, students should expect an irradiance of ~200-300 W/m2.



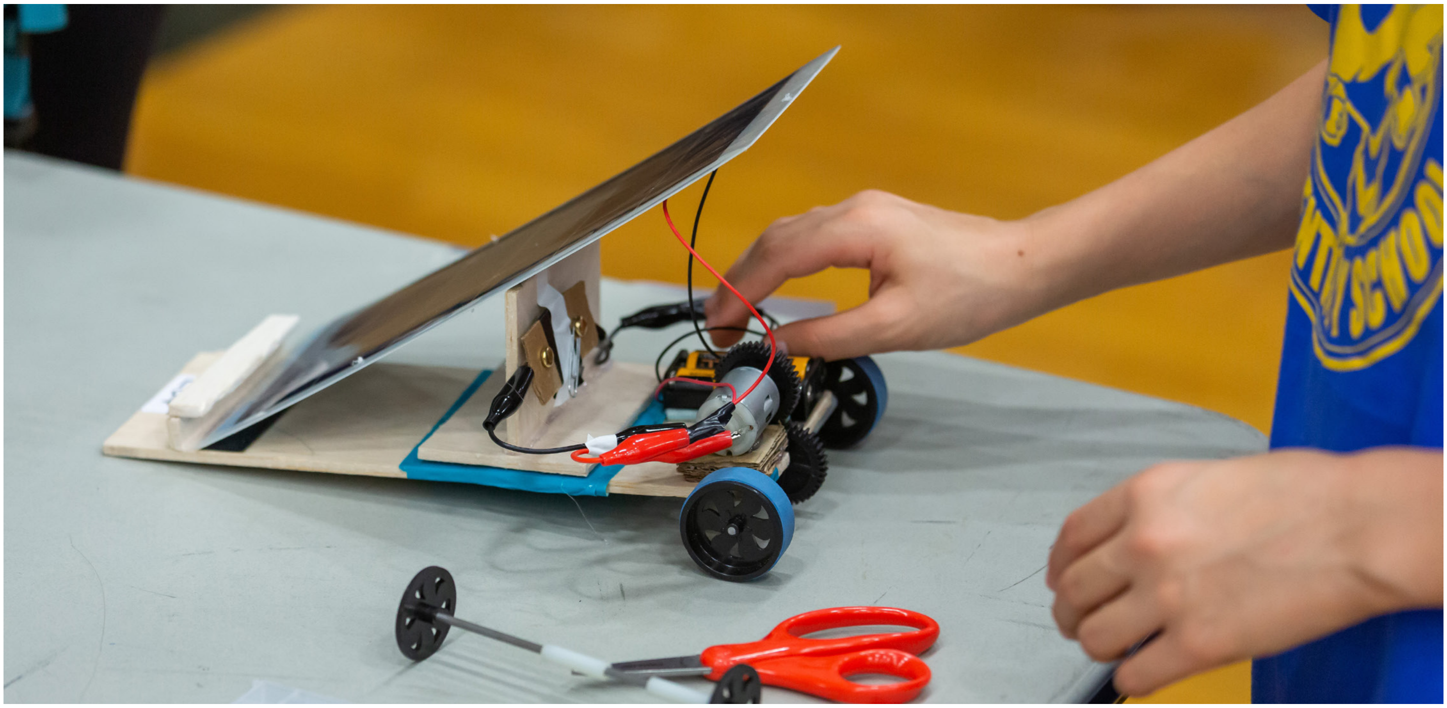
2019 Clark Public Utilities Solar Car Challenge Track (Track Subject to Change)

PERFORMANCE DETAILS

The 2020 Clark Public Utilities Solar Car Challenge is a holistic engineering competition. This means that teams will be judged on a number of factors:

a. Speed (45%).
b. Documentation of engineering design process AND team interview (55%).

The format of the solar car races will be double elimination, meaning that each vehicle will race at least two times. Judging Guidelines begin on page 46 and applicable rubrics start on page 52.



Speed: Students' Innovative Designs Raced During the 2019 Solar Car Challenge

Overview

QUALIFYING CHECKLIST

Each car will be examined on the day of the challenge to ensure the car meets the vehicle specifications outlined for the challenge.

RACE (45% WEIGHTED SCORE)

The format of the speed trial will be double elimination meaning that each vehicle will race at least two times. There will be a bracket system developed and bracket movement will be tracked through the Solar Car Challenge app. This app will be available to download and track your team's progress through the race brackets.

DOCUMENTATION OF ENGINEERING DESIGN PROCESS AND TEAM INTERVIEW (55% WEIGHTED SCORE)

TEAM POSTER

Each team must provide comprehensive documentation that reflects the engineering and design process. Knowledge should be demonstrated through a culminating team poster with supporting evidence from individual engineering notebooks. **A rubric will be used to assign points for the following steps in the engineer and design process:**

Ask, Research, Imagine/Plan, Create, Test and Evaluate, and Improve.

The purpose of the engineering notebook is to document each individual team member's process and notes. The team poster is the summation of the group's collaborative effort and should be a comprehensive snapshot.

TEAM INTERVIEW

Each team will be interviewed by a volunteer and may be asked questions related to the engineering design process or renewable energy. Sample questions are on page 65.

A rubric will be used to assign points for the following categories:

- Content
- Clarity
- Teamwork
- Preparedness/Research

The judges will require more detailed documentation from the high school level, and less formal from the elementary school level students.

Materials List and Specs

REQUIRED MATERIALS	PROHIBITED MATERIALS/PRACTICES
• Provided Motor (see appropriate motor for ES/MS or HS) • Provided PV Module – Pitsco Ray Catcher 2.76V module • Switch (any that is safe – not provided) • Battery holder • 2 AA Batteries • Provided resistor – 6.2 Ω (*HS only) • 1 red LED (*MS and HS only)	• Any vehicle deemed unsafe by any judge (Note: utilities are experts in electrical safety!) • Additional power sources beyond what's included (required) • Modifying power sources (solar panel and batteries) • Tampering with motor (re-wound or disassembled) • Additional purchased materials beyond $10 in cost (receipts for purchased materials must be included in documentation of design in notebooks)

IN THE KIT – ES	IN THE KIT – MS	IN THE KIT – HS
• 1 PV Module (Pitsco Ray Catcher Solar Module, 2.76V, 1A) • 1 small DC motor (Pitsco Motor 280) • 1 2-AA battery holder • 2 rechargeable AA batteries • 2 metal axles • 4 rubber bands (2 thick, 2 thin) • 8 gears (2 mm hole) • 8 gears (1/8" hole) • 4 nylon spacers • 4 wheels (2 large, 2 small) • 2 balsa wood sheets • 1 solar panel blank (cardstock) • 12 pack mini alligator clip leads • 2 small metal alligator clips • 2 screw eyes	• 1 PV Module (Pitsco Ray Catcher Solar Module, 2.76V, 1A) • 1 small DC motor (Pitsco Motor 280) • 1 2-AA battery holder • 2 rechargeable AA batteries • 2 metal axles • 4 rubber bands (2 thick, 2 thin) • 8 gears (2 mm hole) • 8 gears (1/8" hole) • 4 nylon spacers • 4 wheels (2 large, 2 small) • 2 balsa wood sheets • 1 solar panel blank (cardstock) • 12 pack mini alligator clip leads • 2 small metal alligator clips • 2 screw eyes • **3 red LEDs**	• 1 PV Module (Pitsco Ray Catcher • 1 2-AA battery holder • 2 rechargeable AA batteries • 2 metal axles • 4 rubber bands (2 thick, 2 thin) • 8 gears (2 mm hole) • 8 gears (1/8" hole) • 4 nylon spacers • 4 wheels (2 large, 2 small) • 2 balsa wood sheets • 1 solar panel blank (cardstock) • 12 pack mini alligator clip leads • 2 small metal alligator clips • 2 screw eyes • **3 red LEDs** • **1 5V DC Motor** • **1 6.2 OHM Resistor**

VEHICLE SPECIFICATIONS FOR QUALIFICATION

- Vehicle size: maximum length of 38 cm, width of 30 cm, and height of 30 cm.
- The solar panel cannot be used as the body of the vehicle.
- The solar panel cannot be altered (e.g. drilled, sanded, or cut).
- Vehicles must be powered by 2 AA batteries provided during the day of the challenge. The batteries must be connected to a working switch that can be turned off. (Note for high school teams: batteries should be connected in series with the provided resistor.)
- The solar panel is not required to be connected to the on/off switch.
- There must be an available 5 cm square of free space for team number sticker.
- Middle school and high school teams must include a minimum of one red LED in their design that lights up when vehicle is running.
- High school teams must also include the resistor and use the 5V DC motor.

Score Breakdown

TOTAL CHALLENGE POINTS	% SCORE	POINT STRUCTURE
Race Trials (Team Heat Races, modified double elimination)	**45%**	1st place: **5 points** 2nd place: **3 points** 3rd place: **1 point** DQ* or DNC**: **0 points**
Documentation of Engineering Design Process	**30%**	Poster and engineering notebook **500 maximum points**
Team Interview	**25%**	Content, clarity, teamwork, preparedness/research, final product **400 maximum points**

* DQ – Disqualified
** DNC – Did Not Complete race/length of the track

You may want to create a spreadsheet to compile all results by team for races and the interview, and design/documentation challenges to determine the winner of the intramural challenges. For instance, columns could include the following:

- Team Number/Name
- Race points earned for each heat
- Total Race Raw Points
- Design/Documentation Raw Points
- Interview Raw Points
- Total Raw Score
- Final weight adjusted Total Score

Ways to Win

The scores will be weighted by each team's race performance, design, and interview. The following tables indicate the categories in which teams can win an award.

RACING COMPETITION

Division	Awards
Elementary School	1st, 2nd, 3rd
Middle School	1st, 2nd, 3rd
High School	1st, 2nd, 3rd

INTERVIEW AND ENGINEERING DESIGN DOCUMENTATION

Division	Awards
Elementary School	1st, 2nd, 3rd
Middle School	1st, 2nd, 3rd
High School	1st, 2nd, 3rd

JUDGES CHOICE

Division	Awards
Elementary School	1st
Middle School	1st
High School	1st

OVERALL POINTS

Division	Awards
Elementary School	1st, 2nd, 3rd
Middle School	1st, 2nd, 3rd
High School	1st, 2nd, 3rd

JUDGING GUIDE: QUALIFICATIONS

Qualification Checklist: Elementary School

Before racing in intramurals and at the main event, cars must pass inspection.

SIZING

- ❑ 38 cm or less in length.
- ❑ 30 cm or less in width.
- ❑ 30 cm or less in height.

CIRCUITRY

- ❑ Circuits have solar panel and battery packs wired on separate parallel branches (see spec sheet).
- ❑ No additional power sources aside from 2 x AA battery pack and 2.76V Pitsco Ray Catcher solar module.
- ❑ Switch integrated into circuit (see spec sheet) either in series with batteries or in series with motor. **Not in series with panel**.

MATERIALS

- ❑ Motors from original team kit used (Pitsco Motor 280).
- ❑ Solar panel is not used as chassis.
- ❑ Outside (found or created) materials are less than $10 in value. This will need to be determined through questioning and volunteer discretion.

ADDITIONAL

- ❑ No damage done to solar panel rendering it unable to be reused.
- ❑ Visible 5 cm square for registration sticker.

Qualification Checklist: Middle School

Before racing in intramurals and at the main event, cars must pass inspection.

SIZING

- ❑ 38 cm or less in length.
- ❑ 30 cm or less in width.
- ❑ 30 cm or less in height.

CIRCUITRY

- ❑ Circuits have solar panel and battery packs wired on separate parallel branches (see spec sheet).
- ❑ No additional power sources aside from 2 x AA battery pack and 2.76V Pitsco Ray Catcher solar module.
- ❑ Switch integrated into circuit (see spec sheet) either in series with batteries or in series with motor. **Not in series with panel**.

MATERIALS

- ❑ Motors from original team kit used (Pitsco Motor 280).
- ❑ Solar panel is not used as chassis.
- ❑ Outside (found or created) materials are less than $10 in value. This will need to be determined through questioning and volunteer discretion.

ADDITIONAL

- ❑ No damage done to solar panel rendering it unable to be reused.
- ❑ Visible 5 cm square for registration sticker.

Qualification Checklist: High School

Before racing in intramurals and at the main event, cars must pass inspection.

SIZING

- ❑ 38 cm or less in length.
- ❑ 30 cm or less in width.
- ❑ 30 cm or less in height.

CIRCUITRY

- ❑ Circuits have solar panel and battery packs wired on separate parallel branches (see spec sheet).
- ❑ No additional power sources aside from 2 x AA battery pack and 2.76V Pitsco Ray Catcher solar module.
- ❑ Switch integrated into circuit (see spec sheet) either in series with batteries or in series with motor. **Not in series with panel**.
- ❑ Resistor **in series with batteries (see spec sheets) (HIGH SCHOOL ONLY)**.
- ❑ Working LED included in circuit **(HIGH SCHOOL ONLY)**.

MATERIALS

- ❑ Motors from original team kit used (5V DC motor).
- ❑ Solar panel is not used as chassis.
- ❑ Outside (found or created) materials are less than $10 in value. This will need to be determined through questioning and volunteer discretion.

ADDITIONAL

- ❑ No damage done to solar panel rendering it unable to be reused.
- ❑ Visible 5 cm square for registration sticker.

JUDGING GUIDE: RUBRICS/SCORING

Rubric Example: Elementary

ELEMENTARY SCORING SHEET: POSTER & NOTEBOOK		
School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Ask: Research the Problem			Score:
1 Students did not conduct research.	**50** Students conducted research about car materials.	**100** Students conducted research about car materials and content. Students used research to address questions.	
Imagine/Plan: Develop Possible Solutions			**Score:**
1 Students selected plan for prototype design at the outset of their design process.	**50** Students selected design and listed components.	**100** Students selected design and listed components. Students explored wheel size, gear ratio, friction, etc.	
Create: Build a Prototype			**Score:**
1 Students built a prototype.	**50** Students built a prototype with pictures included.	**100** Students built a prototype, with detailed notes about adjustments made.	
Test, Evaluate, and Improve			**Score:**
1 Students tested prototype, but did not redesign.	**50** Students tested prototype, listed results and developed a second design.	**100** Students tested prototype, listed results, made a second design, and retested, taking careful notes.	
Final Design: Innovation			**Score:**
1 Vehicle is not decorated and students did not document its usefulness.	**50** Vehicle is somewhat innovative in nature, but team did not document ways in which their car is innovative.	**100** Student creativity and innovation is clearly present in vehicle material testing or selection. Vehicle uses recycled materials or team creativity is documented.	

Judges Choice Nominee?	❑ Yes	❑ No
Notes:		
Judge Name:		

Rubric Example: Elementary

ELEMENTARY SCORING SHEET: INTERVIEW		
School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Content			Score:
1	**50**	**100**	
Students demonstrated little knowledge of science and engineering content.	Students demonstrated knowledge of science and engineering content.	Students mastered science and engineering content as they relate to renewable energy.	
Clarity			**Score:**
1	**50**	**100**	
Students selected plan for prototype design at the outset of their design process.	Students answered questions and supported their claims with evidence and reasoning.	Students answered questions with comprehensive support and communicated ideas with real world application.	
Teamwork			**Score:**
1	**50**	**100**	
1 student answered all questions.	More than 1 student answered questions.	Many members of the team answered questions and worked collaboratively.	
Research/Preparedness			**Score:**
1	**50**	**100**	
Students shared their approach to the challenge, but with little detail.	Students demonstrated familiarity with components and asked initial questions before they began the design process.	Students demonstrated familiarity with components, asked questions, and mentioned multiple sources to support their decisions throughout the process.	

Judges Choice Nominee?	❑ Yes	❑ No
Notes:		
Judge Name:		

Rubric Example: Middle School

MIDDLE SCHOOL SCORING SHEET: POSTER & NOTEBOOK		
School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Ask: Research the Problem			Score:
1 Students did not conduct research.	**50** Students conducted research about car materials.	**100** Students conducted research about car materials and content. Students used research to address questions.	
Imagine/Plan: Develop Possible Solutions			**Score:**
1 Students selected plan for prototype design at the outset of their design process.	**50** Students selected design and listed components.	**100** Students selected design and listed components. Students explored wheel size, gear ratio, friction, etc.	
Create: Build a Prototype			**Score:**
1 Students built a prototype.	**50** Students built a prototype with pictures included.	**100** Students built a prototype, with detailed notes about adjustments made.	
Test, Evaluate, and Improve			**Score:**
1 Students tested prototype, but did not redesign.	**50** Students tested prototype, listed results and developed a second design.	**100** Students tested prototype, listed results, made a second design, and retested, taking careful notes.	
Final Design: Innovation			**Score:**
1 Vehicle is not decorated and students did not document its usefulness.	**50** Vehicle is somewhat innovative in nature, but team did not document ways in which their car is innovative.	**100** Student creativity and innovation is clearly present in vehicle material testing or selection. Vehicle uses recycled materials or team creativity is documented.	

Judges Choice Nominee?	❑ Yes	❑ No
Notes:		
Judge Name:		

Rubric Example: Middle School

MIDDLE SCHOOL SCORING SHEET: INTERVIEW		
School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Content			**Score:**
1 Students demonstrated little knowledge of science and engineering content.	**50** Students demonstrated knowledge of science and engineering content.	**100** Students mastered science and engineering content as they relate to renewable energy.	
Clarity			**Score:**
1 Students answered all questions.	**50** Students answered questions and supported their claims with evidence and reasoning.	**100** Students answered questions with comprehensive support and communicated ideas with real world application.	
Teamwork			**Score:**
1 1 student answered all questions.	**50** More than 1 student answered questions.	**100** Many members of the team answered questions and worked collaboratively.	
Research/Preparedness			**Score:**
1 Students shared their approach to the challenge, but with little detail.	**50** Students demonstrated familiarity with components and asked initial questions before they began the design process.	**100** Students demonstrated familiarity with components, asked questions, and mentioned multiple sources to support their decisions throughout the process.	

Judges Choice Nominee?	❑ **Yes**	❑ **No**
Notes:		
Judge Name:		

Rubric Example: High School

HIGH SCHOOL SCORING SHEET: POSTER & NOTEBOOK		
School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Ask: Research the Problem			Score:
1 Students asked no questions at the outset of their design process and did not conduct research.	**50** Students presented questions about and conducted research on car materials.	**100** Students conducted research about car materials and content to address criteria and constraints in their design. Students used research to address questions in their documentation.	
Imagine/Plan: Develop Possible Solutions			**Score:**
1 Students selected plan for prototype design.	**50** Students selected design and listed components.	**100** Students selected design and listed components. Students explored wheel size, gear ratio, friction, etc. The final design was collaborative.	
Create: Build a Prototype			**Score:**
1 Students built a prototype.	**50** Students built a prototype with pictures included.	**100** Students built a prototype, with detailed notes about adjustments made.	
Test, Evaluate, and Improve			**Score:**
1 Students tested prototype, listed results, but did not redesign.	**50** Students tested prototype, listed results, developed a second design and noted the process.	**100** Students tested prototype. Students identified independent and dependent variables to manipulate and made multiple designs, clearly communicated their reasoning and discussed trade-offs.	
Final Design: Innovation			**Score:**
1 Vehicle uses only materials provided in kit and looks like it was built from instructions.	**50** Vehicle is somewhat innovative in nature, but primarily relies on materials provided in team kit. Vehicle might include lights.	**100** Student creativity and innovation is clearly present in vehicle material testing or selection and vehicle consists of recycled materials. Vehicle includes lights or other innovation that goes above and beyond the requirements for the competition.	

Judges Choice Nominee?	❑ **Yes**	❑ **No**
Notes:		
Judge Name:		

Rubric Example: High School

HIGH SCHOOL SCORING SHEET: INTERVIEW

School:	Team Name:	Team Number:

Please assign teams a score between 1 and 100 for each of the following five criteria:

Content			Score:
1	**50**	**100**	
Students demonstrated little knowledge of science and engineering content.	Students demonstrated knowledge of science and engineering content.	Students mastered science and engineering content as they relate to renewable energy.	
Clarity			**Score:**
1	**50**	**100**	
Students answered the questions.	Students answered questions and supported their claims with evidence and reasoning.	Students answered questions with comprehensive support and communicated ideas with real world application.	
Teamwork			**Score:**
1	**50**	**100**	
1 student answered all questions.	More than 1 student answered questions.	Many members of the team answered questions and worked collaboratively.	
Research/Preparedness			**Score:**
1	**50**	**100**	
Students shared their approach to the challenge, but with little detail.	Students demonstrated familiarity with components and asked initial questions before they began the design process.	Students demonstrated familiarity with components, asked questions, and mentioned multiple sources to support their decisions throughout the process.	

Judges Choice Nominee? ❑ **Yes** ❑ **No**

Notes:

Judge Name:

JUDGING GUIDE: INTERVIEW QUESTIONS

Interview Example: Elementary

Team Name:	Team ID:

1.	(Briefly Introduce Yourself) Icebreaker: Why is renewable energy important to you? What are you most excited about at the competition today?
2.	What kind of research did you your team do to prepare for the challenge?
3.	How did you choose the components for your solar car vehicle?
4.	What additional materials did you use to make your car? Why?
5.	Did you have any issues with friction? How did you reduce friction?
6.	When building your car, what kind of obstacles or challenges did you face?
7.	What trade-offs did you make when designing your car and selecting components?
8.	What changes did you make to your car that led to the most performance gains?
9.	Describe any redesign processes your team went through before deciding on the final model.
10.	How did the team divide up the tasks needed to make the car run smoothly?

Interview Example: Middle School

Team Name:		Team ID:
1.	(Briefly Introduce Yourself) Icebreaker: Why is renewable energy important to you? What are you most excited about at the competition today?	
2.	What kind of research did you your team do to prepare for the challenge?	
3.	How did you choose the components for your solar car vehicle?	
4.	What additional materials did you use to make your car? Why?	
5.	Did you have any issues with friction? How did you reduce friction?	
6.	When building your car, what kind of obstacles or challenges did you face?	
7.	What trade-offs did you make when designing your car and selecting components?	
8.	What changes did you make to your car that led to the most performance gains?	
9.	Describe any redesign processes your team went through before deciding on the final model.	
10.	How did the team divide up the tasks needed to make the car run smoothly?	

Interview Example: High School

Team Name:	Team ID:

1.	(Briefly Introduce Yourself) Icebreaker: Why is renewable energy important to you? What are you most excited about at the competition today?
2.	What kind of research did you your team do to prepare for the challenge?
3.	How did you choose the components for your solar car vehicle?
4.	What additional materials did you use to make your car? Why?
5.	Did you have any issues with friction? How did you reduce friction?
6.	When building your car, what kind of obstacles or challenges did you face?
7.	What trade-offs did you make when designing your car and selecting components?
8.	What changes did you make to your car that led to the most performance gains?
9.	Describe any redesign processes your team went through before deciding on the final model.
10.	How did the team divide up the tasks needed to make the car run smoothly?