# SOLAR CARS

In this apprenticeship students will engage in the engineering process to design, build, test, and revise a solar car according to the specifications set forth by the Junior Solar Sprint (JSS). Students will work in teams to apply their knowledge of solar power, vehicle mechanics, mathematics, and engineering to several iterations of a car design. Each iteration will be improved by rigorous testing and redesigned based on data. By the end of the apprenticeship students will be qualified to compete in the JSS. Some students may actually be able to compete in the JSS while others will compete against each other on campus.

<table>
<thead>
<tr>
<th>Unit Standards and Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>21st Century Skill: Innovation</strong></td>
</tr>
</tbody>
</table>

### Innovation Standard #1: Citizen Schools students will generate an idea or product that suits a practical or artistic purpose

**Lesson Objectives:**
- Brainstorm a list of designs
- Compare the advantages and disadvantages of each design
- Select the best design based on the advantages and disadvantages of each

### Standard #2: Citizen Schools students will use a design process to create ideas or products

**Lesson Objectives**
- List the steps in the design process
- Identify the tools and materials needed to realize your idea
- Create a plan for testing your design
- Improve your design based on data from testing

### Standard #3: Citizen Schools students will realize an idea or product that suits a practical or artistic purpose

**Lesson Objectives**
- Build a solar car from a plan
- Rebuild a solar car from a revision plan
- Build your final solar car based on testing data

**Project-specific Lesson Objectives:**
- Trace the transformation of solar energy into kinetic energy in a car
- Explain the purpose and importance of solar car technology
- Display their car design/beginning building in a vlog entry and describe the materials and components using technical vocabulary
- Test your design
- Compile your vlog entries into a final Google Slides/PPT that showcases the design process that they learned throughout the class.

### Essential Questions

- How can I learn from designing, building, and revising a solar car?
- Are there limits to how much I can improve my design?

### Performance Task Assessment (WOW!)

The WOW! will showcase the solar car students created. The car can be showcased to a “panel of experts” and in a race (in JSS if it is available in your region, against each other if not). The solar cars will be powered only by solar energy. Students will demonstrate their knowledge of their cars and their design process to judges in a video log that can be shown on the day of the WOW! or at another time which will show their innovation skills. Students can be evaluated by the judges on creativity, speed, and design quality. Students will have been focusing on one of those three elements which will be weighted heaviest in their judging round.

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Goal: Given limited materials and your understanding of car mechanics, you will use the design process to build a functioning solar car. In the process, you will document your design process using video logs.

Role: You will work as designers on a team to complete the brainstorming, construction, and revision of the car using the design process.

Audience: If competing in Jr. Solar Sprint, your car will be judged by other students and JSS judges. If not, your audience will include school selected judging panel and peers.

Situation: You will showcase your car on a race track in front of judges. Ideally you will be able to compete in a JSS or similar competition.

Product: You will build a solar car that is powered by an attached solar panel, and can complete a course that meets the standards of JSS competition. You will also create a weekly video logs of your process.

Standards: Your design will be assessed using the Innovation rubric and you will showcase each row through a vlog entry. On the day of the competition, you will be assessed based on creativity, speed, and quality (the JSS standards).

This task will be evaluated using the Innovation rubric found here.

Lesson Plans At-A-Glance

Lesson Plans are available here.

<table>
<thead>
<tr>
<th>Week</th>
<th>Lesson Objectives</th>
<th>Agenda</th>
<th>Outcomes &amp; Work Products</th>
</tr>
</thead>
</table>
| 1    | SWBAT trace the transformation of solar energy into kinetic energy in a car | Hook: Design Spotlight-Steps  
Introduction of New Material: What is solar energy?  
Activity 1: Design Process  
Activity 2: Solar Power and Energy  
Activity 3: Vlog  
Assessment: Exit Ticket | First vlog entry explains the purpose and importance of solar car technology; demonstrates students’ ability to use the vlog process  
Exit Ticket questions:  
1. What are the steps of the design process?  
2. In the cars we are going to build, ________ energy is turned into ________ energy. |
| 2    | SWBAT brainstorm a list of designs  
SWBAT compare the advantages and disadvantages of each design; specifically the role of friction and the best gear ratios  
SWBAT select the best design based on the advantages and disadvantages of each | Hook: Hill Racing  
Introduction to New Material: Friction  
Activity 1: Pit Crew  
Activity 2: Brainstorm designs  
Activity 3: Pick Your Path  
Assessment: Vlog Entry | Volg entry to share the design the group will pursue.  
Car Parts: Draft design for first iteration. |
| 3    | SWBAT display their car design/beginning building in a vlog entry and describe the materials and components using technical vocabulary  
SWBAT identify the tools and materials needed to realize your idea | Hook: Design Spotlight-Gears  
Introduction of New Material: Ratios & Gears  
Activity 1: Investigating Ratios  
Activity 2: Reflection  
Activity 3: Redesign with Ratios  
Assessment: Exit Ticket | Vlog entry to share what gear ratio they want to use and why.  
Car Parts: Formal design for first iteration. |
| 4    | SWBAT build a solar car from a plan  
SWBAT create a plan for testing your design | Hook: Design Spotlight- Great Gears!  
Introduction of New Material: Transmission Systems  
Activity 1: Precision & Accuracy-Teamwork  
Activity 2: Build Time  
Activity 3: Testing Plan  
Assessment: Vlog Entry | Vlog to predict car strengths and weaknesses including what data they will look for in tests  
Car Parts: First iteration of car. |
<table>
<thead>
<tr>
<th>Lesson</th>
<th>SWBAT</th>
<th>Hook</th>
<th>Assessment</th>
<th>Car Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>test their designs</td>
<td>What is Data?</td>
<td>Vlog to share the plan for redesign based upon the collected data.</td>
<td>Formal design for second iteration.</td>
</tr>
<tr>
<td>6</td>
<td>improve their design based on data from testing</td>
<td>Introduction of New Material: What Are We Testing?</td>
<td>Car Parts: Second and third iterations of car.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SWBAT rebuild a solar car from a revision plan</td>
<td>Hook: Design Spotlight</td>
<td>Car that meets race criteria and is able to run on solar power</td>
<td>Fourth iteration of car; adding the solar panels.</td>
</tr>
<tr>
<td>8</td>
<td>SWBAT create a mount for the solar panel</td>
<td>Introduction of New Material: Spotlight on Design Process</td>
<td>Vlog Entry: What are the advantages of my new design over my old one?</td>
<td>Car Parts: Formal design for second iteration.</td>
</tr>
<tr>
<td>9</td>
<td>SWBAT create a mount for the solar panel</td>
<td>Activity 1: Redesign 1</td>
<td>Car Parts: Second design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SWBAT create a mount for the solar panel</td>
<td>Activity 2: Test 1</td>
<td>Vlog Entry: What are the advantages of my new design over my old one?</td>
<td>Car Parts: Second and third iterations of car.</td>
</tr>
<tr>
<td>10</td>
<td>SWBAT create a mount for the solar panel</td>
<td>Activity 3: Redesign 2 and Test 2</td>
<td>Vlog to share the plan for redesign based upon the collected data.</td>
<td>Car Parts: Formal design for second iteration.</td>
</tr>
</tbody>
</table>

### Lesson Elements

#### Hook
Opening ritual used each week to build excitement

- Take advantage of student misconceptions to open up questions they can answer for themselves during the lesson.
- Give students a common experience from which the lesson can carry them forward.
- Highlight a specific fact or concept that needs to be explored and/or addressed during the lesson.

#### Assessment
How you will measure student learning (i.e., exit tickets, student writing, student presentations, etc.)

- Exit Tickets will ask students to recall or explain one or two facts or concepts.
- Vlog Entries will ask groups to present or explain a design, iteration, or to describe a concept in a short video.
- Design Specs will be detailed drawings of groups’ latest car designs.

#### Structures
Learning structures, tools or student grouping strategies

- Make student groups as small as possible given the amount of materials you can provide given your budget and access to existing materials. Ideally, student will not work alone nor will the work in groups larger than 4.
Build Time and Redesign Time are included in most lessons to direct student work at the stations. The emphasis of Redesign Time is to plan or build a new or different way of accomplishing the design task, even if it worked the first time!

The Design Spotlight each week features with new materials or a sketch in their notebook. During this time you can showcase successful design solutions from students in the class or previous solar cars.

Procedures

In every lesson there are specific roles and responsibilities for working with building materials at stations. One student from each group may travel to a station. Because there are materials that require safe handling, students should be reminded of expectations before using tools.

Station Set Up: Generally, the seating arrangement should involve students working at desks and satellite building stations. You will want to include sets of materials at the stations, not at the student desks unless otherwise described. Discuss ways to make this effective at your particular site with your TL. For more on stations, see the last page of this plan.

Materials procedures are critical for this class: In managing material, expect students to have a specific goal before they begin to do the building. This will keep them on task and help control crowding in the materials area.

Implementation Notes

The class is materials-heavy and more expensive. Check with your regional team about solar panels and motors but this is the basic set:


Additional materials like voltage meters, wheels, extension wires, smaller alligator clips, hot glue, wood/other base materials can be purchased from Amazon or your local hardware store.

Budget will dictate how many students will need to be in a group, groups can be done by choice or by assignment. Ideally this happens during Lesson 1 but can happen during Lesson 2 if you want to poll students about preferences before making groups.

PLEASE BUDGET for a kit for you as a teaching team so that you can build and play ahead of class starting. It is recommended that you build it together in training if possible to find sticking points that students will face.

Below is a list of materials with prices found on the internet. Better deals are possible with a little time spent searching.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Quantity (Assuming 8 groups)</th>
<th>Supplier</th>
<th>Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carolina STEM Challenge Solar</td>
<td>$144.25</td>
<td>Provides materials for 8</td>
<td>Carolina</td>
<td>You need all the materials in this</td>
</tr>
</tbody>
</table>
### Core Apprenticeship Library

**Apprenticeship Sector:** STEM

**Unit Guide:** Solar Cars

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Kit</td>
<td></td>
<td></td>
<td>kit, but any kit that provides them will do.</td>
</tr>
<tr>
<td>DC Motors 1.5 - 3 V</td>
<td>Included</td>
<td>8 provided</td>
<td>Carolina</td>
</tr>
<tr>
<td>Solar Cell, 1 V with leads</td>
<td>Included</td>
<td>8 provided</td>
<td>Carolina</td>
</tr>
<tr>
<td>Wheel, Gear, and Axle Pack</td>
<td>Included</td>
<td>8 provided</td>
<td>Carolina</td>
</tr>
<tr>
<td>Cardboard Pad</td>
<td>Included</td>
<td>8 provided</td>
<td>Carolina</td>
</tr>
<tr>
<td>Drinking Straws (Axles)</td>
<td>Included</td>
<td>16 provided</td>
<td>Carolina, Easy to obtain elsewhere, sometimes at no cost</td>
</tr>
<tr>
<td>Teacher's Manual</td>
<td>Included</td>
<td>1 provided</td>
<td>Carolina, Useful for images and design ideas, but not necessary</td>
</tr>
<tr>
<td>Digital Multimeter</td>
<td>$37.00</td>
<td>8</td>
<td>Carolina, Necessary, but widely available; can share</td>
</tr>
<tr>
<td>Wires with Alligator Clips</td>
<td>$11.35</td>
<td>2</td>
<td>Carolina, Necessary, but widely available</td>
</tr>
<tr>
<td>Rulers</td>
<td>$1.00</td>
<td>8</td>
<td>Carolina, Necessary, but widely available</td>
</tr>
<tr>
<td>Scissors</td>
<td>$5.00 (3 pack)</td>
<td>3</td>
<td>Staples.com, Necessary, but widely available</td>
</tr>
<tr>
<td>Transparent Tape</td>
<td>$10.00 (10 pack)</td>
<td>1</td>
<td>Staples.com, Necessary, but widely available</td>
</tr>
<tr>
<td>Protractors</td>
<td>$0.49</td>
<td>8</td>
<td>Staples.com, Necessary, but widely available</td>
</tr>
<tr>
<td>Flashlight</td>
<td>$7.99</td>
<td>8</td>
<td>Staples.com, Necessary, but widely available</td>
</tr>
<tr>
<td>Hammers</td>
<td>$10.99</td>
<td>4</td>
<td>Staples.com, Necessary, but widely available; can share</td>
</tr>
<tr>
<td>Pliers</td>
<td>$7.98</td>
<td>8</td>
<td>Lowes.com, Necessary, but widely available; can be shared</td>
</tr>
<tr>
<td>Stopwatches</td>
<td>$10.15</td>
<td>2</td>
<td>Carolina, Necessary, but widely available; can be shared</td>
</tr>
<tr>
<td>Construction</td>
<td>$6.79</td>
<td>1 pack of 200</td>
<td>Staples.com, Necessary, but widely available</td>
</tr>
</tbody>
</table>
### Supporting Materials & Resources

- **Handouts, books, materials**
- Slides for each lesson that you can customize are available [here](#).
- If you are working with JSS, please refer to their official website and rules for additional information: [http://www.usaep.com/programs/competitions/jss/](http://www.usaep.com/programs/competitions/jss/)
- If your teaching team is not well versed in this content you might want to consider purchasing the curriculum from here ($35): [https://www.teachengineering.org/view_activity.php?url=collection/duk_/activities/duk_solarcar_tech_act/duk_solarcar_tech_act.xml](https://www.teachengineering.org/view_activity.php?url=collection/duk_/activities/duk_solarcar_tech_act/duk_solarcar_tech_act.xml)
- A great, free resource to help guide the process: [http://www.nrel.gov/docs/gen/fy01/30828.pdf](http://www.nrel.gov/docs/gen/fy01/30828.pdf)

### Location

- **Tables/desks, or classroom, gym, kitchen, outside, etc.**
- You will need to determine the surface that students are going to race on (indoor/outdoor, smooth, rough, etc.) and plan for access on testing days.

### Choice and Voice

- **Key decisions students make**
- Students will make choices around design and improvements which may alter the materials you need for this apprenticeship. The course of the lessons should not change, however.

### Modifications for Student Needs

- **Supports and changes to help meet the needs of all learners**
- For students with processing difficulties, watch their trials closely so that you can help them make connections between what they see and any improvements they can make.
- Students with physical impediments to fine-motor skills should be allowed extra time. Avoid “doing it for them” whenever possible. It will be better that these students get to do the physical work themselves even if it costs them one cycle of trial and revision.
- If there are students with acute behavioral challenges consider keeping them close together (even if they are not in the same group) and adjust your co-teaching strategy so that one of you is working closely with them, keeping them on task, and redirecting them when necessary. Every effort should be made to give these students the same experience as typical students.
- If there are ELL students in your class and either you or your co-teacher have experience with ELL and/or speak the same language, adjust co-teaching to take advantage. If neither of you have experience with ELL or speak other home languages, consider taking the time to provide written instructions translated via online translator and where possible checked by a native speaker of the translated language.
## Core Apprenticeship Library

### Apprenticeship Sector: STEM

### Unit Guide: Solar Cars

<table>
<thead>
<tr>
<th><strong>Student Background</strong></th>
<th><strong>Knowledge and Skills Needed</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Students should have positive experience working in groups and be able to problem solve.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>College and Career Readiness</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Connections to college and career</td>
</tr>
<tr>
<td>This is an introduction to the kinds of problem solving students will encounter in STEM college courses.</td>
</tr>
<tr>
<td>In addition to careers in the automotive industry, this apprenticeship introduces students to the type of work done by mechanical engineers and by the energy industry.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Co-Teaching Roles</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommendations for co-teaching and planning</td>
</tr>
<tr>
<td>This apprenticeship will rely heavily on the Stations co-teaching model, though there will be some Parallel Teaching and One Teach, One Assist.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Special Resources</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Field trips, excursions, guest speakers</td>
</tr>
<tr>
<td>The need for field trips or guest speakers for this unit is not urgent, and it will take away from the number of iterations students can make with their cars. However, if an mechanical or solar engineer is available and can help students in a way that is specific to making their cars better, consider reaching out and asking them to do so as a guest.</td>
</tr>
<tr>
<td>Keep in mind, having someone who works in a related field come in and “give a talk” may not be the best use of students’ time - having someone come in to talk about installing solar panels on houses, for example.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Road Map to WOW!</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual overview for students of their 10 week apprenticeship:</td>
</tr>
<tr>
<td>Note to CT/TL: Create a poster-sized visual of the information listed below, display and reference weekly in your classroom.</td>
</tr>
<tr>
<td>Week 1: Meet the group, learn about solar power, and explore different car designs.</td>
</tr>
<tr>
<td>Week 2: Decide on one design from your own list of choices.</td>
</tr>
<tr>
<td>Week 3: Design the car and plan how you’ll build it.</td>
</tr>
<tr>
<td>Week 4: BUILD DAY – motor, gears, base, and wheels together to get a car that can move with a battery; plan how you’ll test it.</td>
</tr>
<tr>
<td>Week 5: TEST DAY – run the cars and collect data on: sturdiness, distance, speed, and straightness. Decide on adjustments.</td>
</tr>
<tr>
<td>Week 6: Rebuild and re-test your car.</td>
</tr>
<tr>
<td>Week 7: Solar Panel and payload attachment</td>
</tr>
<tr>
<td>Week 8: Test cars using their solar panel structure</td>
</tr>
<tr>
<td>Week 9: Final adjustments and making sure cars meet intended focus</td>
</tr>
<tr>
<td>Week 10: Create process vlog using PPT template</td>
</tr>
<tr>
<td>WOW!</td>
</tr>
</tbody>
</table>

Poster Examples:
- [Example 1](#)
- [Example 2](#)
- [Example 3](#)
### Co-Teaching Structures Guide

<table>
<thead>
<tr>
<th>Teaching Model</th>
<th>Description</th>
<th>Why should we use it?</th>
<th>When should we use it?</th>
</tr>
</thead>
</table>
| Parallel Teaching    | Class is split into two (or more) small teams. **Same** content is taught to each team. | - Low student-teacher ratio  
- Greater proximity to high-risk students  
- Co-teachers have equal presence and responsibility in the classroom | - When we can plan effectively together to ensure we teach the same content to each group well.  
- Classroom’s physical structure permits it.  
- For lessons with heavy independent work  
- Need to provide a lot of individual attention |
| Station Teaching     | Class is split into two (or more) small teams. **Different** material taught to each group simultaneously and then teams switch or teachers switch. | - Low student-teacher ratio  
- Co-teachers have equal presence and responsibility in the classroom  
- More variety in teaching methods for teachers and students | - When a lesson can be split into two mutually exclusive and equally timed parts (e.g. using a camera/critiquing a photo, chopping vegetables/measuring ingredients)  
- When the classroom’s physical structure permits it  
- For lessons with a lot of knowledge or skill-building |
| Team Teaching        | Both teachers actively teach the material taking turns during the lesson to lead teach. While one teacher is lead teaching the other goes around to groups or individual students. | - One teacher can pay attention to high-risk students while one teacher leads the full class.  
- Co-teachers have equal presence and responsibility in the classroom. | - When it’s difficult to effectively split a lesson into two stations  
- When a lesson has lectures and independent practice time  
- If most SPED students can follow whole-group instruction  
- Best used with well-developed co-teaching relationship  
- For lessons with a lot of group work |
| Alternative Teaching | One teacher remediates a small group of students (pre-teach, re-teach, supplement, or enrich) and catches them up for the main lesson being taught by the other teacher. | - Low student-teacher ratio  
- To remediate in class for a small group of students.  
- To catch students up who may not have understood/missed previous lessons | - When the benefits from a few minutes of remediation/pre-teaching will pre-empt greater misunderstandings for the lesson.  
- When the classroom’s physical structure permits small group in one part of the room. (CTs should not be left alone in the classroom with students.) |
| One Teach, One Assist | One teacher leads the whole lesson and the other teacher works with individual students. | - To redirect behavior from an especially low functioning student.  
- To pay greater attention to a student who needs one-on-one interaction in order to keep up | - If there is a particularly high-needs student(s) in the classroom that need specific support.  
- During direct-teach sections of the lesson |
The Pitch

Come prepared with two charged solar cars. The two should be identical except for the gear sizes which should be hidden from sight on the car. Ask students which car they think will win (perhaps paint numbers on them to differentiate). The car with the better gear ratio will win, but students will not see the gears. Ask them why they think that car won. Get them excited with a fast pace peppering of questions “Why do you think this one won? Why do YOU think it won? How about you? And you? You? YOU?” Don’t give any hints. Hook them in by closing with “This car won because it was designed better. If you want to know how, you will probably LOVE this apprenticeship!”

Materials Needed for Pitch Day

2. Identical solar car with a 2:1 gear ratio.
3. Finish Line (consider constructing some kind of checkered flag overhang).

Apprenticeship in Action
Students in Salem prepare to test their car
Collins Middle School student works on his team’s car at the glue station

Students test their cars
"Students from the Trotter Innovation School this semester created solar powered cars with their volunteers. While most students just focus on getting the car to move across the race track, this group of students created "the beast" as it was nicknamed at their WOW! The group created aerodynamic wings to help the car move faster and ended up getting to the final round of their race!" - Citizen Teacher, 2016

Apprenticeship Description for WOW! Communications

In this apprenticeship students will engage in the engineering process to design, build, test, and revise a solar car according to the specifications set forth by the Junior Solar Sprint (JSS). Students will work in teams to apply their knowledge of solar power, vehicle mechanics, mathematics, and engineering to several iterations of a car design. Each iteration will be improved by rigorous testing and redesigned based on data. By the end of the apprenticeship students will be qualified to compete in the JSS. Some students may actually be able to compete in the JSS while others will compete against each other on campus.

Apprenticeship Acknowledgements

Solar Cars was written by Rob LoPiccolo and edited by Amy Hoffmaster and includes feedback from several Citizen Teachers including Kelly Deans-Birmingham, Gregg DeVolder, Charles Emple, Lizandro Garcia, Kasia Gibson, Barbara Harrison, Maroua Jabouri, Alex Julien, Hsin-Chiao Lin, Sybry Luma, Natalie Maslow, Erin Nfonoyim, Monsurat Olaosebikan. We were also fortunate to have feedback and inspiration from the following Teaching Fellows and Citizen Schools Regional team members: Eric Saindon, Crysta Song, David Blinn, Katherine Applegate and Rose Barrett. This unit was developed with support from the Lemelson Foundation.
Resource: Station Descriptions

**Reference station:** provides examples of different kinds of cars and transmissions.

**Cutting station:** all cutting takes place at the cutting station. Note- Knives are not to be removed. All cutting must occur on top of cardboard, with the object lying flat. Blades must be retracted when finished.

**Sawing station:** Note: apprentices will wear safety goggles when sawing. The clamp must be used at all times. Apprentices who abuse this station will be asked to go to the “pit stop” station.

**Pit stop station:** (time out) with puzzles and reference materials.

**Gluing station:** where all gluing will happen. Use glue gun with caution.

**Painting station:** all paint stay here.

**Pliers and Rulers station:** Tools for measuring and bending.

**Bearings and Wheels station:** tools for building and redesigning wheels and attachments.

**Chassis materials station:** Includes tools for building and restructuring chassis (except glue).

**Sample Set Up:**

![Sample Set Up Diagram]