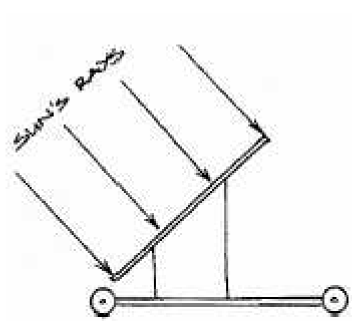
SOLAR RACE CARS
Tips for Educators

Model race cars powered by solar electric modules are an engaging activity through which students learn about solar electricity and design efficiency. In their designs students take into account weight, friction, gear ratios, materials, and building vehicles that are light yet strong. They get to test out their designs through timing how long it takes for their vehicle to travel a set distance. They are given opportunities to improve their design and engage in friendly competition with fellow solar race car builders.

The most expensive piece of equipment for the race cars is the solar module. Fortunately, the 3 watt Pitsco modules that we included in your solar technology kits were originally designed to be used for the Jr. Solar Sprint.

Students may work individually or in **teams** to build their cars. Teams are useful both to teach collaboration in design and execution of design as well as to make limited materials go further. If there are more teams/cars than solar modules, that is not a problem. The students only need the modules when they are sizing, testing, or racing their cars. Design the cars so that the modules are easily connected/disconnected. This is done with a bit of Velcro or using an eye screw to mount the modules (Pitsco's have a small hole on top and bottom of the module). The electrical connection between solar module and car motor is made with alligator clips. In a pinch the modules can be connected to the car with rubber bands or tape. When students believe their car is ready for a test, hook them up with a solar module and let them test it. For simply testing their motor's connection to the axle via gearing or a drive belt (rubber band), they can do this with a battery (ideally two 1.5V AA batteries in series to produce 3 volts). If, when testing the cars there is slippage between the gear on the motor and the gear on the axle, stop the motor immediately by disconnecting the power source because slippage will cause the teeth on the gears to be worn down.

In order to build a successful car, students need to apply engineering/physics principles. They can do this in a directed fashion, intuitively, and/or through trial and error. Key design issues include the following: ideal gear ratios to maximize acceleration and top speed with the amount of power supplied by the solar module, minimize friction, build a car that is both strong and light.



Equipment, Materials, Tools:

Equipment:

Solar Modules: The modules used are rated at 3 Volt x 1 Amp =3 Watt. They each have 6 - 0.5V solar cells wired in series to make the module and provide 3 Volts. Two primary companies provide modules.

- Solar World: www.solar-world.com 719-635-5125 Provided by Shell Solar.
- Pitsco: www.shop-pitsco.com is the source for the lightweight modules ("Ray Catcher") and associated gears, wheels for solar cars.

Accessories- Solar World: www.solar-world.com

- DC motor (solar world JSS-M)
- DC mounting bracket and motor gears (solar worlds Jr. Solar Sprint JSS-B/G)
- Axel gears, wheels, axels (Jr. Solar Sprint Accessory bag JSS-ACC)

Materials:

- 3/16 inch by 3/16 inch by 24 inch lengths of Basswood (hobby building wood) (approximately 4 to 5 per car to build trusswork car body/chassis).
- 1/8 inch by 4 inch by 24 inch lengths of Basswood (for motor platform (approx. 3 x 4 inch piece per car, one sheet will take care of 6-8 cars)
- Small eyehooks (for axels and car guides)
- Paper to create walls for car body.
- Velcro or rubber bands for attaching solar module to car.

Note: if you are using this project to encourage creative use of materials, etc, then students can bring all kinds of materials from home such as plastic containers, parts from broken VCRs, toy cars, etc. We've seen cars built from plastic soda bottles, foam board, CDs, aluminum, etc.

Tools:

- Hot Glue guns
- Glue sticks
- Cordless electric drill
- Drill bits (1/16 inch) (for drilling holes to mount motor brackets, etc)
- Tiny Phillips screwdrivers
- Small hobby saws for cutting basswood, plywood and dowels
- Hobby knives or utility knives for cutting materials, side cutters can also be used for cutting thin dowels.
- Wire cutters strong enough to cut clothes hangers and dowels
- Wire strippers

The dowels are useful for students who wish to build their own car bodies: they can build strong light truss works for the chassis and sides of the cars. The hot glue is a fast and strong way to glue them together. The plywood is a surface to mount the motors. They may want to use tissue paper to put sides on the cars.

We strongly recommend you to encourage your students to be creative about re-using objects and parts from home to build their cars. You may even give an award for the most creative RE-USE of materials. Wheels can be made from such items as CDs,, the innards of old equipment, or retired toy cars. Wire coat hangers work well for axles. Chassis can be made from a variety of materials—

cardboard, Styrofoam, foam board, plastic soda bottles, dowels, balsa wood. However, it is critical that the motor mount and the axel mount surfaces be reasonably strong—use bass wood or some thin plywood, tongue depressors, popsicle sticks, or possibly foam board.

You will also want just a stock of materials from which to fashion needed parts: plastic yogurt container lids come in handy for fashioning small plastic items such as stops to control the sideways movement of the axels so that the motor and axel gears stay lined up.

The thrifty use of thin dowels (1/8 inch in diameter) can create very strong truss work car bodies that are also light weight. Eyelets make great mounting brackets for axles. If you do a truss work car body, you will probably still want to create a small platform for mounting the motor.

Tools: hot glue guns, tiny Phillips screw driver, drill or screw starter, dyke or side cutters for cutting cut hanger and dowels, saw for cutting wood, knife for foam board, plastic.

Transmission: The gearing between the motor and the axle is crucial. This is where students learn about gear ratios to produce balance between rapid acceleration and cruising speed, between power and speed. Hint: small gear on the motor, larger gear on the axel. Students can also use pulleys and drive belts.

> **Teaching Tip**: To teach about how gear ratios work, a 10 speed bike flipped upside down on a table or the floor works great. This will show students the difference between torque and speed. Example: Big gear on pedal sprocket, small gear on rear wheel—high speed, minimal torque (students know this from experience). Small gear on pedal sprocket and Big gear on wheel, lots of torque but can't go fast.

Wheel size: Wheel size also affects the relationship between power (torque) and speed. A big wheel will cause the car to accelerate more slowly, but reach a higher maximum speed. Choosing the optimal wheel size and gear ratios is partly based on the length of the race course. The longer the course, the more distance for a vehicle to accelerate and therefore, a slower start with a faster finish works. On a shorter course, students want to hit a fast speed, but top out earlier. The length for the official sprint is 20 meters.

Students are given a motor, a 3 watt solar module, a few gears, and then they are on their own using materials from home and from a stockpile at school. Their goal is to build a car that is either fast or elegant, or both. Their limitation is the amount of power provided by a 3 watt solar module.

To build a successful car they must take into consideration the following:

- Friction (of wheels)
- Weight of their vehicle
- Strength of their vehicle
- Gear rations (motor to axle)
- Wheel ratios
- Materials
- Orientation of solar module to the Sun.

Friction: They need to design a car that has minimal amount of friction. They can use ball bearings, or steel axels through eyelets, or…

Weight: With a given amount of power, the lighter the vehicle, the faster it will go. Same principle applies with full sized cars. The lighter the car, the smaller the power plant and fuel needed to enable it to go a given speed and to accelerate.

Strength: Need to build a vehicle that can last through several heats. They cannot sacrifice strength in order to reduce weight. They need to use building principles and materials that both are light and strong. For example, a chassis that utilized lightweight plywood sparingly and thin wooden dowels will provide strength and light weight.

Design Problems, Solutions & Recommendations:

- **Gear on motor** needs to line up and engage well with gear on axel. Need to figure out good mounting platform for motor and for eyelets or whatever it is that will hold axel. Also, need to control for side to side movement of the axel gear so that it maintains its contact with motor gear. We often accomplished this with small pieces of plastic that we attach to the axel and glue in place to control side to side movement. I cut these pieces out of such things as yogurt container lids. A simple way to control this motion is to mount the wheels close to the eyelets that the axle goes through. Leave minimum play so that the wheels spin freely but do not travel back and forth.
- **Electric hook up, switch**. Recommend using alligator clips spliced onto leads coming from car motor to attach to the leads coming from the solar module. These can serve as on/off switch. Also, facilitate easy removal of module from car chassis.
- **Velcro** or rubber bands or eyelets: to hold solar module onto car chassis and enable easy removal.
- **Axels**: coat hanger or other straight wire is good diameter. Make sure it is straight. The Solar World accessories also include axels.
- **Wheels.** We can get variety of wheel diameters. Students should experiment here. We found best combination to be 2” diameter wheels on the rear, power axel and 1” wheels on the front. Key here is to get the diameter that creates a ratio that enables rapid acceleration and maximum cruising speed.
- **Glue**: hot glue is great because it hardens quickly so that students can make rapid progress on their projects. Also, it can be pulled apart so that they can make adjustments.
- **Wheel alignment**: encourage students to build cars that will drive straight. Best accomplished by making the two axels parallel to each other. Of course students may not have two axels. Some may opt for three wheeler. Or make the front axel adjustable.
- **Tools:** hot glue guns, wire cutters which can cut both coat hanger and wooden dowels, drills (cordless is easiest), wood saws, scissors. They may try to make car out of cardboard or foam board. Screw drivers. Tiny Phillips for the motor mounts. Water bucket for when students get hot glue on their fingers.

Curriculum resources: http://www.nrel.gov/education/student/natjss.html

Classroom Investigations PDF 500kb http://www.nrel.gov/docs/gen/fy01/30830.pdf)
Teachers, mentors, and their students can use this publication to explore the components of model solar cars. It includes investigations and experiments to improve car performance.

So… You Want to Build a Model Solar Car (PDF 356kb http://www.nrel.gov/docs/gen/fy01/30826.pdf)
Written for teachers and students who want to participate in JSS, this document contains teacher background on photovoltaics, classroom activities for measuring solar cell output and understanding transmission components, tips on the vehicle construction process, hints for transmission design, formulas for calculating vehicle performance, and design considerations.

Inside Tips on Parts and Construction (PDF 192kb http://www.nrel.gov/docs/gen/fy01/30827.pdf)
This booklet helps students identify possible options for obtaining parts to build the vehicle's drive train and chassis and provides formulas for determining appropriate gear ratios and wheel sizes.

An Introduction to Building a Model Solar Car: Student Guide for the Junior Solar Sprint Competition (PDF 555kb http://www.nrel.gov/docs/gen/fy01/30828.pdf)
This guide assists students in the selection of components and materials for creating model solar cars. The publication identifies potential problems based on components chosen for chassis, wheels and bearings, power source, transmission and body shell and discusses possible solutions.

Teacher and Mentor Guide (PDF 232kb http://www.nrel.gov/docs/gen/fy01/30829.pdf)
Suggestions to teachers and mentors for integrating JSS activities into their classroom curriculums are presented here. Useful background information about the role of a technical mentor, recommendations for teaching "hands-on" design in classroom groups, a description of the engineering design process, and an eight-week lesson plan can be gleaned from this guide.

Chimacum Middle School , WA
http://eagle.chimacum.wednet.edu/middle/jss/Course_Materials.htm
A teacher from Washington State developed teacher and student lesson plans.

APPROACHES TO ORGANIZING CLASS/SCHEDULE FOR BUILDING CARS

The challenge here is to maximize learning within time constraints.
Learning opportunities range from design, thrifty use of materials, re-use of materials, tool skills, and efficiency in getting most acceleration and speed from finite power source.

Options:

1. Limited time: Three to four 1.5 to 2 hour work sessions. Teacher provides all the materials needed to build the cars. Students are given 2 work sessions per week. Some teachers actually use a Friday worksession as reward session each week for the several weeks it takes to build the cars. It is good to have a working deadline (with a margin to extend). This leads to more focused, productive engagement.

If there is less class time available, then students can be encouraged to take the cars home to work on them. Problem that can arise is tools.
Set class up like a lab with cutting, measuring, etc tools on group work tables. You should set up glue guns at a couple of work stations.
Given short amount of time, you may need to show students some examples of cars that they can mimic. Encourage them to modify the design. Car decoration can be something they do at home.

Trickiest part of the construction/design is the motor to gears/axle assembly. Have examples for them to look at.

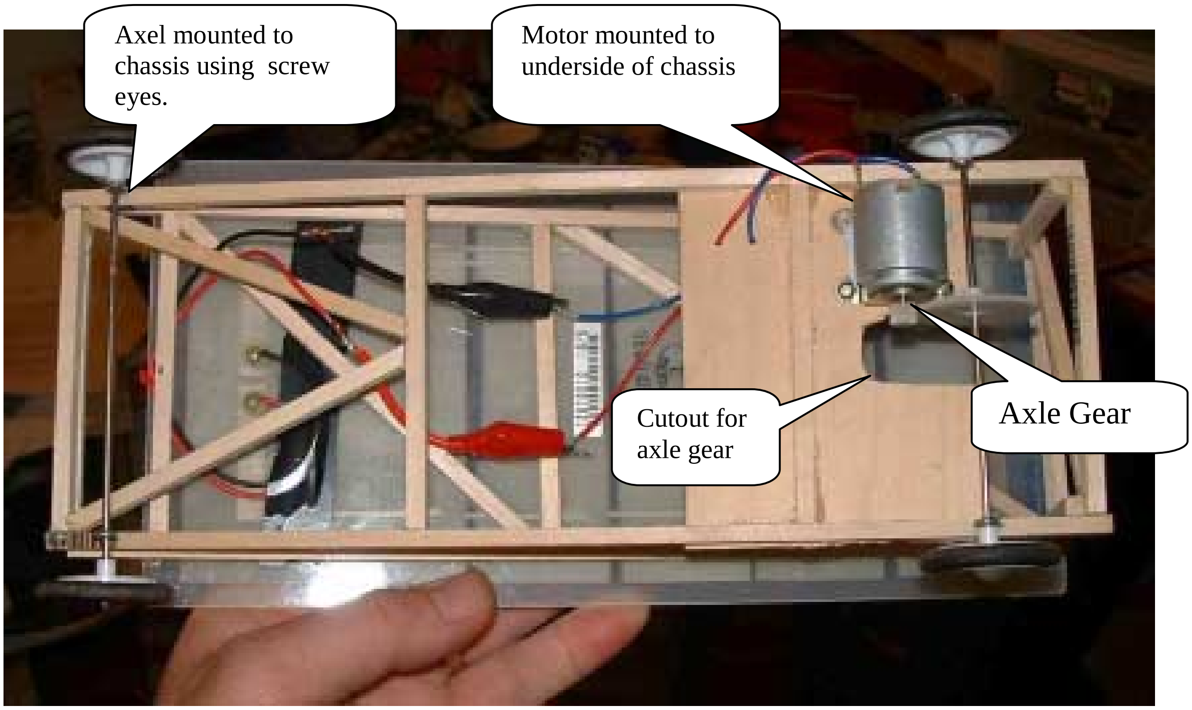
2. More time, desire for students to practice re-use of materials. If you have plenty of time, you may want to give students more time to be inventive, give them less chance to look at examples, offer prize for most creative, aesthetic, best use of recycled materials, etc as well as fastest.
Even consider that students may need to build two cars. The first one will be a clunker but be full of learning, the second one will benefit from all that students learned in the first iteration.
This approach could take 4-8 1.5 hour sessions. Again, students can do some of the work at home.
Materials: students should go home with a note to parents about the project and encourage them to find materials around the house to use. Teacher may also bring in a stock of materials and students can bring in extra for others to use as well.

3. After school. Some teachers run the race car project as a GATE kind of activity in which students can come after school and the teacher will have the materials and tools set up certain days after school for a 6 to 8 week period.

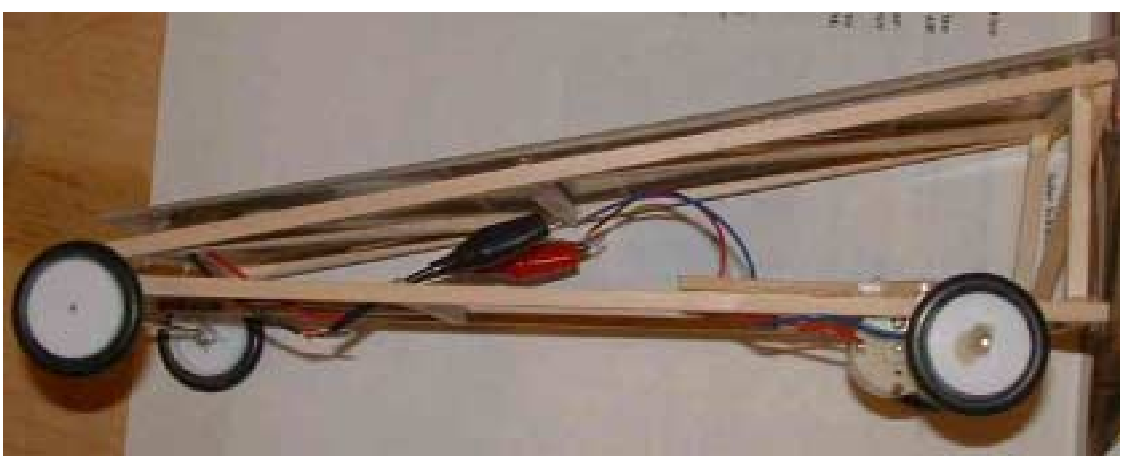
4. Combination of the above. This can include one or two days a week after school in which students can continue working on the cars.

OUTSIDE HELP: Teachers who are apprehensive about their ability to teach solar car building benefit from the skills that an outside person can bring. Outside help that may include people who have model building background from trains and cars to planes. It is a great opportunity to bring in parents, retirees, and other community members into the classroom to assist or teach.

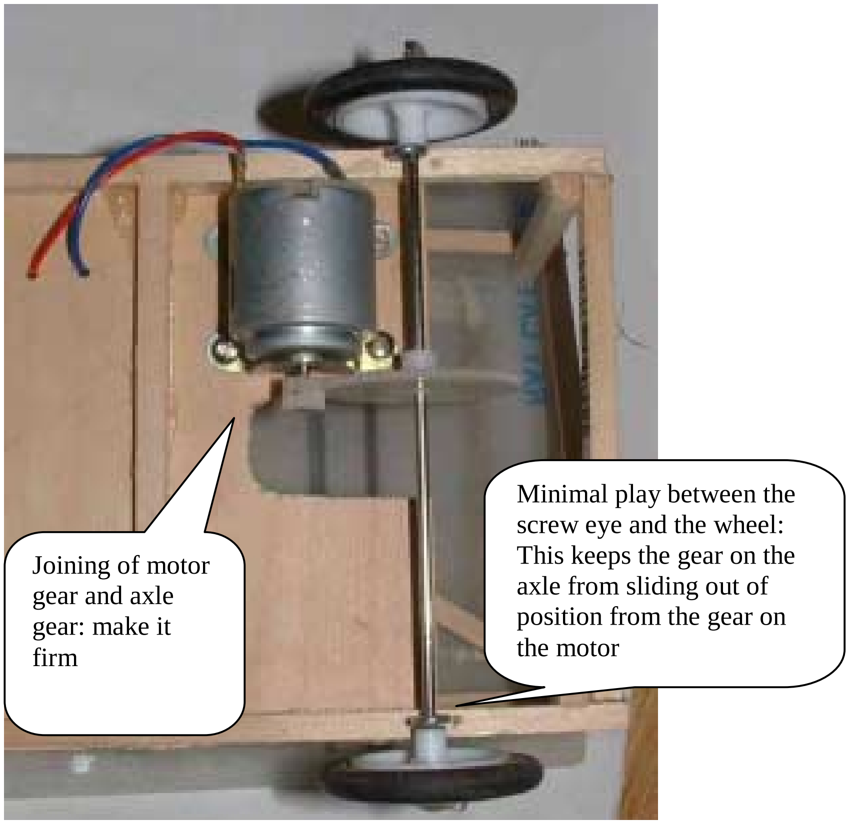
Example of Solar Race Car with Construction Tips



This photo is taken from the bottom of the car. The chassis is built from bass wood sticks and a piece of 4 inch wide bass wood for mounting the motor. Note that in this car the motor is mounted underneath the chassis, though you could also mount the motor above. Note the cutout for the gear that is on the rear axel. Also note that the front and rear axels are mounted to the chassis using screw eyes. It is important to make the front and rear axels parallel to each other. Note the use of alligator clips to attach the motor's electrical wires to the solar module.



Profile of the Solar Race Car. Note the clearance of the motor above the ground; with this size wheel, it barely makes it. This is a minimalist design. Tissue paper can add to look and strength without adding significant weight.



Detail of the power train. In this example, the motor is mounted on the bottom of the chassis. If you do this, make sure the wheels are large enough to allow for clearance of the power train. This photo also provides detail of the use of the screw-eye to wheel placement which is used here to prevent the axle gear from wandering away from the motor gear.
When placing the axle gear onto the axle, be careful not to bend the axle. If the hole in the gear is too snug to slide it onto the axle, you may ever so slightly drill the whole bigger. If in so doing, you make the whole too big, the gear will slip, robbing the wheels of power. If this happens, hot glue in the hole and onto the axle where the gear meets it can remedy this minor tragedy.

This example is built using dowels. While the lights add a nice look, they take away from the power going to the motor.