Solar Racing (Lesson Plan)

(The Design, Construction and Evaluation of a Solar-Powered Car)

Suggested Grade Level **6-8**

Overview

In this design challenge, students will harness the power of the sun to design, construct and evaluate a solar-powered model car of their creation. Students will utilize the design process and undergo review by their peers to select an optimal gear ratio and components for their car. As a culminating activity, students compete in a "Solar Sprint" race modeled after the National Renewable Energy Laboratory's Junior Solar Sprint competition. Depending upon the depth of investigation, the suggested time frame for this lesson is four to ten (4-10) 50-minute class periods.

Standard Statements

2.1.8. D	Apply ratio and proportion to mathematical problem situations involving distance, rate, time and similar triangles.
3.1.7 A	Explain the parts of a simple system and their relationship to each other.
3.2.7 C	Apply the elements of scientific inquiry to solve problems.
3.2.7 D	Identify and apply the technological design process to solve problems.
3.4.7 B	Analyze energy sources and transfers of heat.
3.4.7 C	Identify and explain the principles of force and motion.
3.8.7 C	Identify the pros and cons of applying technological and scientific solutions to address problems and the effect upon society.

Content Objectives

Students will know that

1. Solar energy is a renewable energy source, and its utilization has numerous benefits for our environment.
2. The angle at which a solar cell is positioned in relation to the sun affects its power output.
3. The amount of current produced by a photovoltaic cell is proportional to the amount of the light hitting the cell; therefore, increasing light intensity or increasing the size of the cell itself will increase the power output of the cell.
4. In order to construct a solar powered system that will work at maximum efficiency, numerous factors pertaining to the design, such as gear ratio and power output, must be considered.

Process Objectives

Students will be able to

1. Describe three factors influencing a solar car's power needs: friction, air drag, and acceleration.
2. Calculate the gear ratio used in the drive system of their solar powered car.
3. Describe the motion of their solar car based upon its position, direction, and speed.
4. Explain how the solar car design was optimized based upon gear ratio and materials used.
5. Utilize the design process to construct a solar-powered car.

Assessment Strategies

1. Evaluation of the completed student handouts and of the student's participation in class discussions.
2. Observation of student's participation throughout the process of designing a solar car.
3. Student participation in a team presentation of their solar-powered car design.
4. Completion of the student's solar car design evaluation.

Materials

Per Group:

- Solar Sprint kit (from the Junior Solar Sprint website)
  - Solar panel
  - Motor with lead wires and clips
  - Motor mounting bracket with screws
  - Gears for motor shaft
- Solar Sprint accessories kit (from the Junior Solar Sprint website)*
  - 2 shafts
  - 4 wheels with tires
  - 2 spur gears

  * Instead of purchasing Solar Sprint kits, many accessories can be extracted from old toys, VCRs, tape recorders, old "Spirograph" gears and reused as shafts, wheels and gears
- Various reused materials to construct a body for the car (foam core, Blue board, wood, corrugated cardboard)
- Stopwatch

Teacher Tools:

- Soldering Iron
- Sharp Utility Knife or Coping Saw
- Cool-Melt Glue Gun
- Needle-Nose Pliers
- 1/8" Drill Bit or Electric Drill with Bit
- 2 C-Clamps
- Rulers
- Pencils
- Wire Strippers and Wire Cutters

Multimedia:

- "Solar and Car Fundamentals" PowerPoint presentation[1] (Part 2)
- Junior Solar Sprint PowerPoint presentation, titled, "Build_Junior_Sprint_Car" (optional)

Procedure

<u>*Part 1: The Design Process*</u> *(1, 50 minute Class Period)*

1. Introduce students to the U.S. Department of Energy's contest, Junior Solar Sprint using background information and rules from this website: http://www.nrel.gov/education/jss_hfc.html. (An optional introductory video produced by

[1] Created in 2005 by Andy Lau and Dale and Toby Short for the Penn State University (PSU)/Middle Schools Solar Racers Workshop.

the National Renewable Energy Laboratory is available for $10 and is listed in the additional Resources section.)

2. Allow them to get into teams and select a name, colors and number, etc.
3. Briefly describe the components of the solar car (Solar panel, Chassis; Wheels, Axles & Bearings; Transmissions; Body Shells) about which students will be able to make design choices. If your students have not worked with solar panels previously, you may need to spend more time discussing and exploring how a solar panel works.
4. Share the Design Process diagram (Figure 1 in Teacher Notes and on page 1 of the Student Handout) with students and give them a general overview of where and when they will apply the steps of the process in making their cars. The Chimacum School Junior Solar Sprint website has an excellent description of how each step of the design process is connected to building successful solar cars and it can be accessed at: http://eagle.csd49.org/middle/jss/Course_DsgnProc.htm.
5. Allow teams to work together to get their initial car concepts onto paper and prompt them to generate a list of questions they have before they can select a design.
6. Be sure that your students are clear about the task before them. Make sure that you articulate that the students should be thinking about the design of the chassis, wheels and bearing, body and the solar energy source.

Part 2: Experiment with Principles and Prototypes *1 or 2-50 minute Class Periods*

1. Field any questions students have generated and share the "Solar and Car Fundamentals" PowerPoint presentation with your students, highlighting the concepts that direct the goals of the solar-powered car project.
2. Focus specifically on how to calculate gear ratio and give students team-time to make decisions about their transmissions and work through the Gear Ratio calculations section beginning on page 4 of the student handout.
3. Allow students to return to teams to further time to conceptualize their design and prepare for their class presentation.

Parts 3 & 4: Design Review and Solar-Powered Car Construction *Multiple Class Periods*

1. Allow teams to complete page 9 of the student handout and make presentations of their designs to their classmates that explain their decisions regarding the four major car components (transmission, chassis, wheels and bearings, body and Photovoltaic array) with a rationale for each.
2. After teams have taken time to revisit the "drawing board" on page 10 of the student handout, set them off to construct their cars. (A materials list for tools is also included. If students will be using any tools, instruct them to make safety a priority.)
3. Encourage and allow time for some test runs. If you are lacking sun, halogen lamps work well to power cars in a short distance test-track area.

Part 5: Design Test: Solar Racing! *1-50 minute Class Period*

1. Get ready to race. Spend some time prior to race day looking at the following website: http://eagle.chimacum.wednet.edu/middle/jss/Course_Rules.htm for information on official rules for the contest. The Chimacum School District Junior Solar Sprint website is a wonderful all-around resource. If you are interested in spending a full two weeks on the project, an extensive model program for creating solar-powered cars with embedded investigations on each stage of the design process is available.
2. Celebrate the teams' design successes with a solar-power awards ceremony.

Part 6: Make Connections: What other applications can the sun power? *20 minutes*

1. Debrief the project and allow teams to work together to complete Part 5 of the student handout.
2. Spend time as a class sharing ideas and reflecting upon how technology and science solutions impact our society.

Extension

1. Apply solar-powered car knowledge to designing a component for a home such as a solar water heater using a 16-ounce bottle of water.

Additional Resources

Video:

- A video on Junior Solar Sprint is available for $10 from the Northeast Sustainable Energy Association (NESEA)
  http://www.nesea.org/education/jssvideo.html

Websites:

- National Renewable Energy Laboratory (NREL) Education page on Junior Solar Sprint Competition:
  http://www.nrel.gov/education/jss_hfc.html
- National Junior Solar Sprint (JSS) Web site with six lesson packets:
  http://www.nrel.gov/education/natjss.html
- Suggested JSS lessons and background information on solar power:
  http://eagle.chimacum.wednet.edu/middle/jss/index.htm
  - For more information on Using the Design Process:
    http://eagle.csd49.org/middle/jss/Course_DsgnProc.htm
- An on-line elementary/middle school instruction set on solar energy:
  http://www.fsec.ucf.edu/ed/teachers/
- Two interdisciplinary middle school units on transportation:
  - Getting Around Clean and Green
    http://www.nesea.org/education/CandG.html
  - Getting Around Without Gasoline:
    http://www.nesea.org/education/GAWG.html

Solar Racing (Teacher Notes)

(The Design, Construction, and Evaluation of a Solar-Powered Car)

<u>*Notes on Part 1: The Design Process*</u>

- In this activity, your students will experience first-hand the process of design. When they design their car, they will conceptualize and then turn their ideas into real-life models that work. Remind them that design is different than normal problem-solving because:
  - You don't know what problems are going to arise. (You discover and solve problems as you go along. Everyone's challenges will be different.)
  - There is never one right answer.

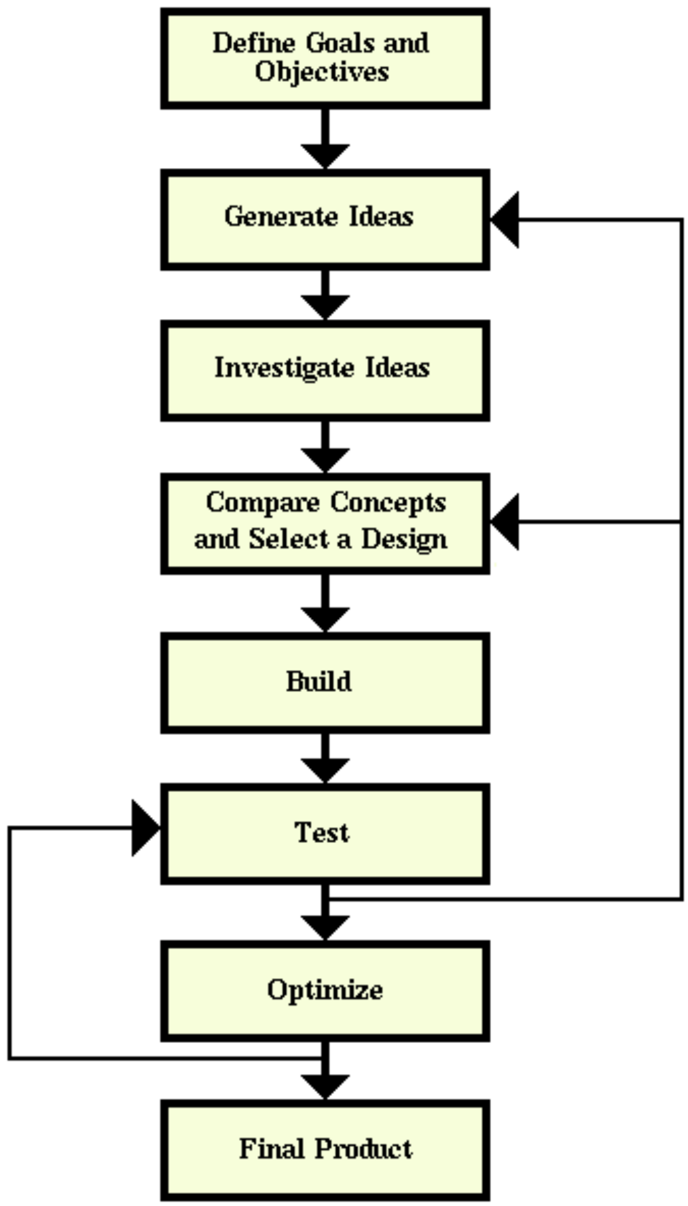


Figure 1. The Design Process
Source: http://eagle.chimacum.wednet.edu/middle/jss/Course_DsgnProc.htm

- It is important to note that the process presented here may be used at any and all levels of model car design, from the design of individual components to the complete car as a system. The key principle in the process is to start all designs with many ideas, then investigate and evaluate several of them before locking into a design.
- Part of the challenge is learning to combine good ideas from several people into a winning design. Students should be encouraged or required to use a notebook to record their ideas and sketches. Ideas not written down or sketched are quickly forgotten. In addition to providing a means to store and communicate ideas, putting thoughts down on paper often aids in idea generation and clarity.[2]

Notes on Part 2: Experiment with Principles and Prototypes

- Another important point to make to students is that designers have to deal with tradeoffs. For example, when a car designer uses a larger engine for greater performance, it usually sacrifices fuel efficiency. In a sports car, performance and speed are very important. But in a city car, fuel efficiency is more important. The students are the designers and it is up to them to decide which goals are the most important and that is their first step.
- Even though there is no one right answer, some answers may be better than others for a particular application. Obviously, in Junior Solar Sprint, the faster cars will win. But remember strategy can be a big factor - there are variables like the amount of sunshine that may influence your decisions.

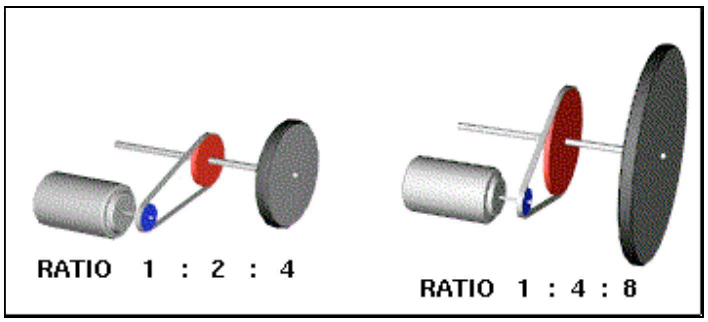


Figure 1: Transmission wheel combinations
Source: http://eagle.chimacum.wednet.edu/middle/jss/Course_GearCalc.htm

- The source site for the figure above is also the source for the gear ratio exercise included in the Student Handout. Reviewing the materials available at this site and sharing the PowerPoint presentation are suggested for preparing students to calculate the gear ratios for their own cars.

[2] http://eagle.chimacum.wednet.edu/middle/jss/Course_DsgnProc.htm, accessed 16 January 2006.

- ***Notes on how a solar panel operates.*** When you look at the diagram above, you might ask, "How does the solar panel turn the sun's energy into electric energy?" The solar panel is made of a sandwich of two materials called *semiconductors*. Each material is made of millions of atoms. As you might already know, atoms have a positively charged *nucleus*, and negatively charged *electrons* which spin around the nucleus. When these two materials are put together in a sandwich, an interesting thing happens: electrons become pulled from the bottom half. But there's a problem. The electrons are all attached to atoms, and the atoms won't let go very easily. This is where the sun's energy helps out. If we shine sunlight on these materials, the sunlight has enough energy to knock the electrons off of the atoms. The electrons will then be free to be pulled to the top of the sandwich.

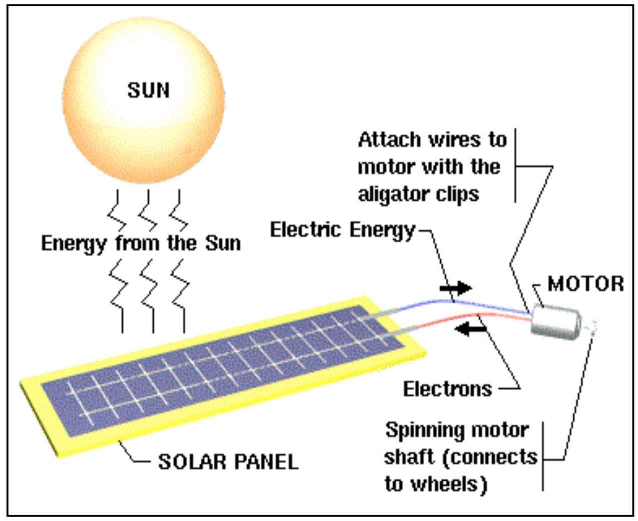


Figure 2: Solar Panel Motor Configuration

Now if we connect wires to a motor, electrons will flow through the wire into the motor (making it spin) and back through another wire to the solar panel where they can fill the "holes" left in the atoms that lost their electrons.

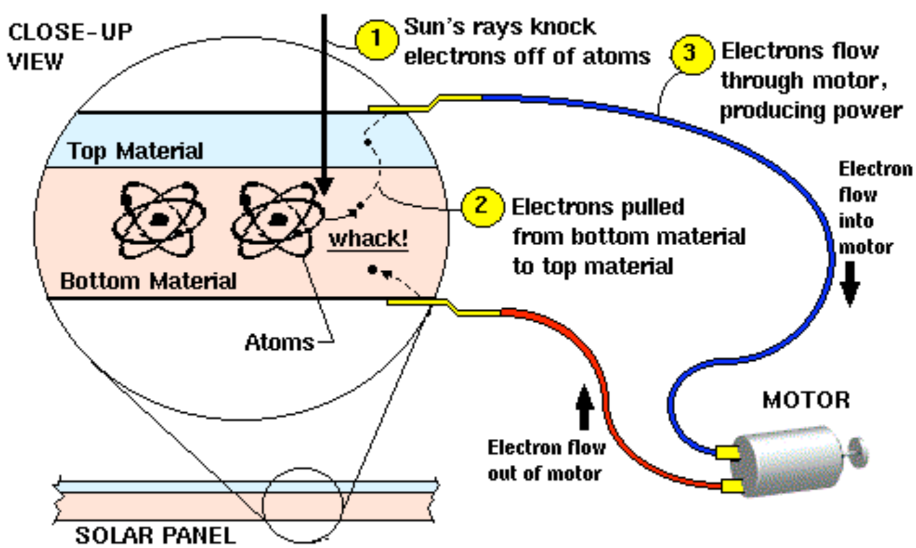


Figure 3: How a Solar Panel Works

For additional information and great visuals to use in a lecture on how the solar cell produces power from a molecular level, please visit:

http://eagle.chimacum.wednet.edu/middle/jss/Course_SolarPanel.htm

Team Name / (Students):____

Solar Racing (Student Handout)

(The Design, Construction, and Evaluation of a Solar-Powered Car)

PART 1 (DESIGN YOUR OWN SOLAR-POWERED VEHICLE)

1) It is time for you to become an engineer. You have the knowledge to build your very own solar powered car! You and a partner(s) will be supplied with a motor, wheels, axles, and a solar cell. It is your job to design the car.

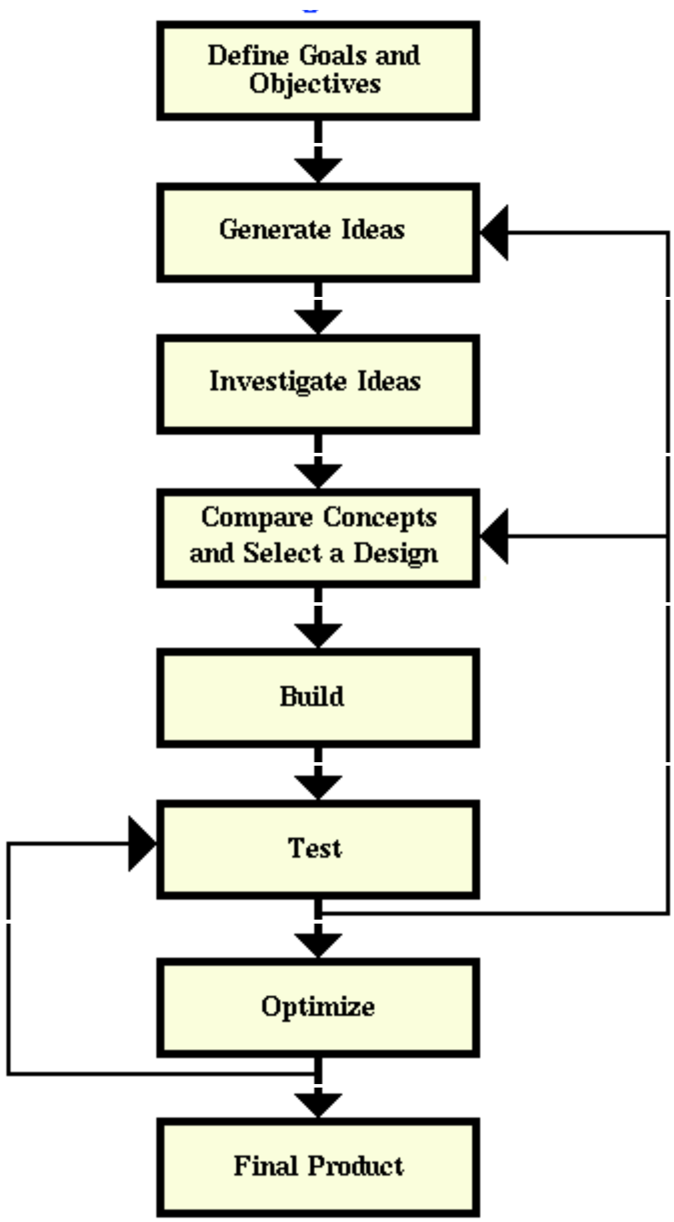
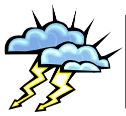


Figure 1. The Design Process

Source: http://eagle.chimacum.wednet.edu/middle/jss/Course_DsgnProc.htm

a) Talk with your partner and answer the following questions. What are some of the features you think your car should have to maximize the energy produced by the solar panel? What kind of materials should be used for the body?

Record what you think in the box provided.



Brainstorming Session

What features should our car have? What materials should we use to make it?

b) Draw a diagram of your car's design below. Please use a separate page if you need more room. Think about strategic placement of the various necessary components in order to create the fastest car possible. Think about how you will go about securing the wheels and axles, as well as the motor and the solar cell.

Car Design #1:

Front View:

Top View:

Side View:

PART 2: IMPORTANT ASPECTS OF THE CAR'S DESIGN

1) In this section you will be working through a series of calculations to make choices about your car's gear ratio, wheel size and transmission. Use the text examples and figures to help you work through the calculations.

GEAR RATIO[3]:

The complete requirements for gearing ratios include the wheel size since it affects the speed versus force conditions. The two transmission ratios and wheel size combinations shown below will produce cars with similar performance in terms of acceleration and top speed.

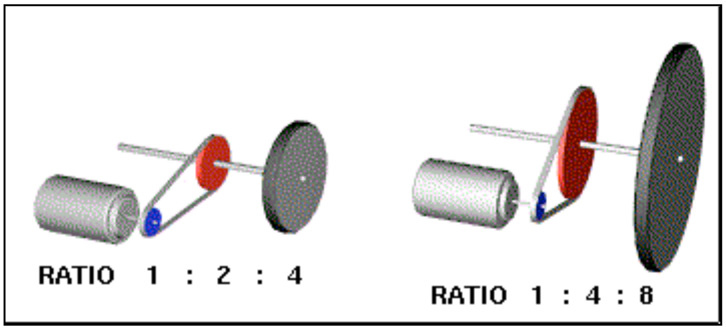


Figure 1: Transmission wheel combinations

The faster the axle rotates in the bearing the more friction and drag it will have. A large wheel will allow the axle to rotate more slowly (if the car is to go at the same speed), and will waste less power in the bearings. In nature, an analogy for wheel size would be leg length. Just as a horse and hamster will travel different distances if each takes one step per second, cars with large and small wheels will travel different distances with each wheel rotation.

If you already know your gear ratio:

If we have a set of pulleys or a couple of mating gears then we already have the gear ratio. Now we just need to find out what size drive wheel(s) we need to be competitive. Figure 2 shows how a pulley or gear system might look.

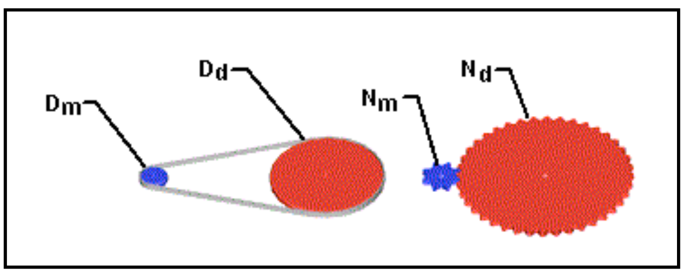


Figure 2: Pulley and Gear Systems

The variable **D** is the diameter of the pulley, and variable **N** is the number of teeth on the gear. The subscript **d** refers to the gear or pulley attached to the drive axle and the subscript **m** refers to gear or pulley attached to the motor.

[3] Chimacum School District Junior Solar Sprint program. http://eagle.chimacum.wednet.edu/middle/jss/Course_GearCalc.htm, accessed 11 January 2006.

For sample purposes we have supplied values for these - use your own values to do the calculations on your own transmission.

The variables for a Pulley System

D_m = **1.25** cm D_d = **0.25** cm

The variables for a Gear System

N_m = **40** teeth N_d = **8** teeth

The variables for a YOUR System

[___]$_m$ = [______] [___]$_d$ = [______]

Step 1: Determine the gear ratio.

For a Pulley System the gear ratio is

R = D_m / D_d or **R** =**1.25** cm / **0.25** cm or **R** =**5**

For a Gear System the gear ratio is

R = N_m / N_d or **R** =**40** / **8** or **R** =**5**

For YOUR System the gear ratio is

R = [__]$_m$ / [__]$_d$ or **R** =[___] / [___] or **R** =[___]

Step 2: Find out the speed of the wheel in rpm.

For a Pulley or Gear System wheel speed is

w_d = w_m / **R** or w_d = **8300** rpm (revolutions per second) / **5** or w_d = **1660** rpm

For YOUR System wheel speed is

w_d = w_m / **R** or w_d = [____] rpm / [____] or w_d = [_____] rpm

Step 3: Find out wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **1660** rpm / **60** spm (seconds per minute) or w_d = **27.6** rps

For YOUR System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **[____]** rpm / **60** spm or w_d = **[____]** rpm

Step 4: Calculate the wheel circumference.

To determine the wheel diameter, we first need to know the circumference of the wheel (the distance the car will travel each time the wheel turns one full revolution).

For a Pulley or Gear System the circumference is

C = **V** / w_d or **C** = **300** cmps / **27.6** rps or **C** = **11** cm

For YOUR System the circumference is

C = **V** / w_d or **C** = **[____]** cmps / **[____]** rps or **C** = **[___]** cm

Step 5: Determine the wheel diameter.

Now we can find out what diameter wheel, D_w we need. The wheel diameter is determined from the circumference.

For a Pulley or Gear System the diameter is

D_w = **C** / **pi** or D_w = **11** cm / **3.14** or D_w = **3.5** cm (1.4 in)

For YOUR System the diameter is

D_w = **C** / **pi** or D_w = **[___]** cm / **3.14** or D_w = **[____]** cm

Step 6: Check your calculations.

Now check to make sure the diameter of your wheel is bigger than the diameter of the drive gear. If it is, you're up and running. If it is not, you need to choose smaller pulleys or gears.

WHEEL SIZE

If we already have a wheel size we want to use, we must find a suitable gear ratio to drive it. For sample purposes we have supplied values for these--use your own values to do the calculations on your own transmission.

The variables for a Wheel

$\mathbf{D_w}$ = **8** cm (3.1 in)

The variables for a YOUR Wheel

$\mathbf{D_w}$ = **[_____]**

Step 1: Calculate the wheel circumference.

For a Pulley or Gear System wheel circumference is

$\mathbf{C} = \mathbf{D_w} * \mathbf{pi}$ or $\mathbf{C}$ = **8** cm * **3.14** or $\mathbf{C}$ = **25** cm

For YOUR System wheel circumference is

$\mathbf{C} = \mathbf{D_w} * \mathbf{pi}$ or $\mathbf{C}$ = **[___]** cm * **3.14** or $\mathbf{C}$ = **[____]** cm

Step 2: Find the wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

$\mathbf{w_d} = \mathbf{V} / \mathbf{C}$ or $\mathbf{w_d}$ = **300** cmps / **25** cm or $\mathbf{w_d}$ = **12** rps

For YOUR System wheel speed in rps is

$\mathbf{w_d} = \mathbf{V} / \mathbf{C}$ or $\mathbf{w_d}$ = **[____]** cmps / **[___]** cm or $\mathbf{w_d}$ = **[___]** rps

Step 3: Find the wheel speed in revolutions per minute.

For a Pulley or Gear System wheel speed in rpm is

$\mathbf{w_d}$ = **60** spm * $\mathbf{w_d}$ or $\mathbf{w_d}$ = **60** spm * **12** rps or $\mathbf{w_d}$ = **720** rpm

For YOUR System wheel speed in rpm is

$\mathbf{w_d}$ = **60** spm * $\mathbf{w_d}$ or $\mathbf{w_d}$ = **60** spm * **[___]** rps or $\mathbf{w_d}$ = **[_ __]** rpm

Step 4: Determine the gear ratio.

For a Pulley or Gear System the ratio is

$\mathbf{R} = \mathbf{w_m} / \mathbf{w_d}$ or $\mathbf{R}$ = **8300** rpm / **720** rpm or $\mathbf{R}$ = **11.5**

For YOUR System the ratio is

$\mathbf{R} = \mathbf{w_m} / \mathbf{w_d}$ or $\mathbf{R}$ = [____] rpm / [____] rpm or $\mathbf{R}$ = [____]

DESIGN A TRANSMISSION

Since the drive pulley or gear can be no larger than the drive wheel, we need to select a pulley or gear accordingly.

For a Pulley System we might select a drive pulley of 6 cm in diameter.

$\mathbf{D_m} = \mathbf{D_d} / \mathbf{R}$ or $\mathbf{D_m}$ = **6** cm / **11.5** or $\mathbf{D_m}$ = **.52** cm

For a Gear System we might select a drive gear of 69 teeth.

$\mathbf{D_m} = \mathbf{D_d} / \mathbf{R}$ or $\mathbf{D_m}$ = **69** teeth / **11.5** or $\mathbf{D_m}$ = **6** teeth

For YOUR System select a drive pulley or gear that is appropriate

$\mathbf{D_m} = \mathbf{D_d} / \mathbf{R}$ or $\mathbf{D_m}$ = [_______] / [____] or $\mathbf{D_m}$ = [_______]

WHAT ELSE IS IMPORTANT?

- Chassis: Brains and brawn apply here—your chassis needs to support the motor and your PV panel.
- Wheels & Bearings: Wheel size is as important a factor in the car's design as the transmission ratio; in fact, they are closely related. Try to calculate what distance your car travels per one revolution of the motor. The transmission ratio will tell you how many revolutions the wheel axles will turn per motor revolution, and the size of the wheels will tell what linear distance the car will travel per wheel revolution. (You have done this hard work in the Gear Ration Calculations part.)
- Body Shell & PV Panel: How are you going to direct your solar panel? Will you use reflectors? How light do you want your car to be?

Here are some additional resources you could look at for ideas:

- National Renewable Energy Lab (NREL) website: **http://www.nrel.gov/education/natjss.html**
- How a Photovoltaic Cell Works from the Florida Solar Energy Center (FSEC): **http://www.fsec.ucf.edu/pvt/pvbasics/index.htm**

PART 3: ALLOW YOUR CLASS DEVELOPMENT TEAM TO REVIEW YOUR DESIGN

1) An important part of the design process is comparing your design to others and select the most promising you decide is best. Your task in Part 3 is to share your final sketch or drawing of the car with your classmates. Some ideas you should consider when planning your 5 minute presentation are:

- ✓ How are you going to present your information? (You may want to ask your teacher if you can make a transparency of your car design to use).

- ✓ What components have you decided on for the following?

  a. Transmission

  b. Chassis

  c. Wheels & Bearings

  d. Body Shell & PV Array

- ✓ What design considerations are important to your team? [Drag, Rolling Resistance, Drive Train, Car Weight, etc].

- ✓ What materials will you use to build the body of the car?