Junior Solar Sprint –Drive Train & Transmission

Student Objectives

The student:

- given a design using a transmission will be able to predict how the power, speed and torque will change as variables in the drive system and wheel size are manipulated
- will explain the difference between direct drive, belt drive, and gear drive transmissions
- will explain ways in which a transmission can change the speed and torque while transmitting the mechanical power
- will calculate gear ratios and from that be able to determine torque ratios
- will know the purpose of idler gears

Key Words:

direct drive
drive train
driven gear
driver gear
friction drive
gear
gear ratio
gear train
idler gear
pitch
power
pulley
pulley drive
ratio
tension
torque
transmission
transmission ratio

Materials:

- Junior Solar Sprint panels
- Junior Solar Sprint motors
- board with two nails hammered in it (one per group). See pre-class procedure
- large spool and small spool (one set per group) to put on nails
- wide rubber bands
- gear table and gears with several different sizes of gears (such as Lego, K'nex or other educational sets) or:
  - non-corrugated cardboard (such as 'shirt' cardboard)
  - glue stick
  - scissors
  - ruler
  - T-pins or other large pins (3 per group)
  - 6 x 8" piece of foamboard (per group)
- Design Notebook

Time:

1 ½ – 2 hours for investigation

Procedure (prior to class time)

1. For each team hammer two nails in a board far enough apart to stretch the rubber bands between them.

Procedure (in class)

1. Students should work in their JSS teams (2 – 4 students).
2. Lead a classroom discussion/review of key words and terms, asking them what they already know about transmissions, drive trains, and gears. Some key points that you might want to make sure that they cover are:
   - Most vehicles use transmissions to accelerate and get the maximum speed available from the motor, as well as to travel in reverse.
   - Many simple machines such as can openers, bicycles, and clocks use gears.
3. Students should complete the exercises in their Science Journal in groups.
4. Give teams time to discuss how they plan to incorporate these findings in their vehicle design.
5. Teams should sketch their ideas in their Design Notebooks.
6. Teams should then continue constructing their vehicles.

Tips for Success

- Many students choose to use gears, but that is not the only way a JSS car can be powered. Successful cars have been made using belt drives; however, it is best to steer your students away from direct drive transmissions.
- The gears used on the car must have the same pitch to work properly. (Pitch refers to the size and angle of the teeth, not how many teeth the gear has).
- If the gears make a chattering noise when running, the gears are either not lined up correctly or are too loose and slipping. The connection between the gears must be made more solid. However, if the gears are too tight, they won't spin freely.
- If the car 'runs' great when held in the air but won't run when set on the ground, the car does not have enough torque to overcome the friction of the ground.
- A 4-to-1 gear ratio is a good place for students to start. Wheel size, car weight, wheel traction and number of gears will influence where the students will go from there.
- If the car runs backwards when the motor is connected, reverse the wires coming from the panel, then mark the connections.
- Since the JSS motor is a small hobby motor, it may need to be replaced after several years (or particularly hard) usage. The regulation motor and panel 'kits' for JSS are specifically paired and sold as a unit by the manufacturer (Pitsco or Solar Made). If the motor is changed out, it must be the same brand and size of motor that came with the panel you are using. Additionally, if you are using one panel for several different cars and moving it as you need it, make sure the additional motors that you purchase match the panel that will be powering them.

Key Words & Definitions

- **direct drive** – a transmission that has the motor connected directly to the axle of the driven wheel, as in a unicycle
- **drive train** – the components that cause the wheels to turn. This would include the transmission and the axle.
- **driven gear** – the output motion and force are transmitted by this gear. It receives its power from the prior gear in the sequence.
- **driver gear** – the input motion and force is applied to this gear. It then transfers the power to the next gear in the sequence.
- **friction drive** – a transmission that uses the friction between the motor shaft and the drive wheel. The motor shaft may have a driver wheel on it.
- **gear** – a wheel with teeth on the outer edge. It can be paired with other gears in order to provide torque or to change the direction or speed of rotation.
- **gear ratio** – the ratio of the rotation speed (number of turns) of the output shaft (driver gear) divided by the rotation speed of the input shaft (driven gear. This ratio is usually written as: ***gear ratio = rotations of a driver gear*** **:** ***rotations of a driven gear.***
- **gear train** – a series of two or more meshing gears
- **idler gear** – a gear in a gear train that is used to keep the driver and driven gears rotating in the same direction
- **pitch** – the number of teeth that can be put on 1 inch around a gear. Gears of the same pitch must be used together.
- **power –** the product of force times speed (or the product of torque and rotational speed)
- **pulley** – a wheel used with a belt, rope, chain (or other device formed in a circle). Pulleys can change the direction of force and motion, and the speed of motion. Pulleys can also be used in various combinations to increase the applied force.
- **pulley drive** – a transmission that uses a belt or chain between pulleys or wheels
- **ratio** – a set of numbers that describes a constant relationship between two values
- **tension** – the force that an object that is being stretched exerts on its supports
- **torque –** the measurement of how much of a force is needed to produce rotary motion.
- **transmission** – any device which transmits mechanical power from one place to another. Transmissions can also be used to change the speed, rotation direction and force proportions while transmitting power.
- **transmission ratio** – the ratio between speed and torque produced by a transmission. Different applications and jobs will require differing transmission ratios to obtain the desired power. Transmission ratios are often called 'gear ratios' but they do not have to involve gears.

Related Research

1. What do the mass production electric vehicles currently use for a "transmission"? How does it work?

Internet Sites

http://www.nrel.gov/docs/gen/fy01/30827.pdf

National Renewable Energy Lab's Junior Solar Sprint page "Inside Tips on Parts and Construction". Pages 4 - 7 focus on drive trains and includes the formulas needed to determine gear ratios, wheel speed in revolutions per second, optimal wheel circumference, and optimal drive pulley length.

http://www.nrel.gov/docs/gen/fy01/30830.pdf

National Renewable Energy Lab's Junior Solar Sprint page "Classroom Investigations". Page 4 includes an easy to fabricate transmission test box that is very useful for testing transmissions, axles and bearings before they are mounted on the car. Page 7 includes investigations that students can do with a multi-speed bicycle at home, including a racing investigation.

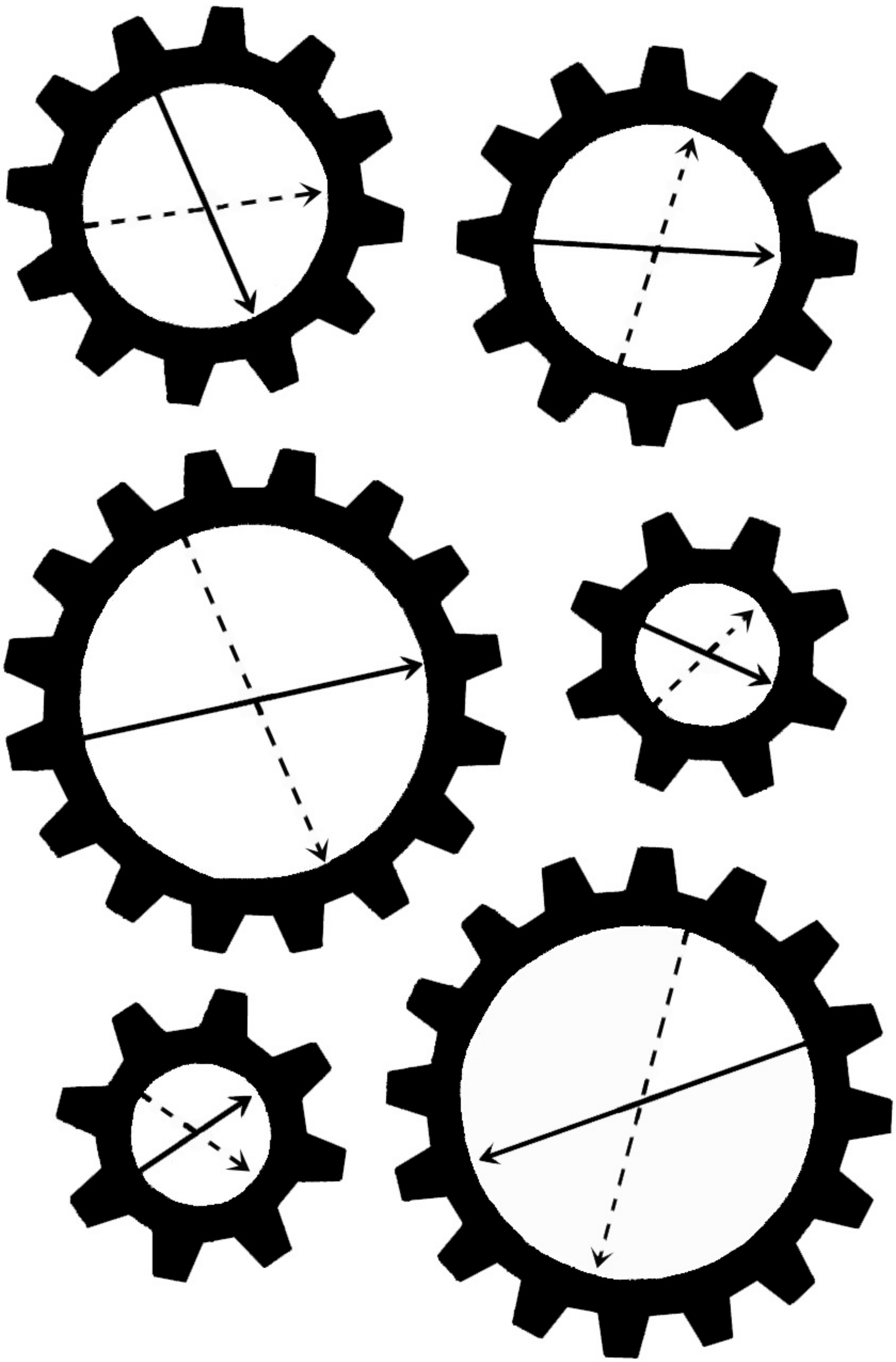
http://www.societyofrobots.com/mechanics_dynamics.shtml

Humorous site discussing dynamics (acceleration, torque, wheel diameter, etc) in building motorized robots. The same basic principles apply to JSS cars.

https://makezine.com/2015/04/20/understand-1700-mechanical-linkages-helpful-animations

Make magazine article includes 1700 gears, couplings, clutches, and differentials, with links to video examples.

Junior Solar Sprint – Drive Train & Transmission



Junior Solar Sprint – Drive Train & Transmission

Florida NGSS Standards & Related Subject Common Core

			.1	.2	.3	.4	.5	.6	.7	.8	.9	.10	.11	.12
Grade 6														
Practice of Science	**# 1**	**SC.6.N.1**	**X**			**X**	**X**							
Theories, Laws, Hypothesis, Models	**# 3**	**SC.6.N.3**				**X**								
Motion of Objects	**#12**	**SC.6.P.13**	**X**											
Forces & Changes in Motion	**# 13**	**SC.6.P.13**	**X**											
Grade 7														
Practice of Science	**# 1**	**SC.7.N.1**	**X**											
Energy Transfer & Transformations	**# 11**	**SC.7.P.11**		**X**										
Grade 8														
Practice of Science	**# 1**	**SC.8.N.1**	**X**	**X**				**X**						
Role of Theories, Laws, Hypotheses, and Models	**# 3**	**SC.8.N.3**	**X**											
Mathematics Standards	**Sixth Grade:** MAFS.6.RP.1.1, MAFS.6.RP.1.2, MAFS.6.RP.1.3 **Seventh Grade:** MAFS.7RP.1.2													

Sixth Grade Benchmarks
Science--Big Idea 1: The Practice of Science

- SC.6.N.1.1 - Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.
- SC.6.N.1.4 - Discuss, compare, and negotiate methods used, results obtained, and explanations among groups of students conduction the same investigation.
- SC.6.N.1.5 - Recognize that science involves creativity, not just in designing experiments, but also in creating explanations that fit evidence.

Science–Big Idea 3: The Role of Theories, Laws, Hypothesis and Models

- SC.6.N.3.4 - Identify the role of models in the context of the sixth grade science benchmarks.

Science–Big Idea 12: Motion of Objects

- SC.6.P.12.1 - Measure and graph distance versus time for an object moving at a constant speed. Interpret this relationship.

Science–Big Idea 13: Forces and Changes in Motion

- SC.6.P.13.1 - Investigate and describe types of forces including contact forces and forces acting at a distance, such as electrical, magnetic and gravitational.

Mathematics–Ratios and Proportional Relationships

- MAFS.6.RP.1.1 - Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.
- MAFS.6.RP.1.2 - Understand the concept of a unit rate a/b associated with a ratio a:b with $b \neq 0$, and use rate language in the context of a ratio relationship.
- MAFS.6.RP.1.3 - Use ratio and rate reasoning to solve real-world and mathematical problems.

Seventh Grade Benchmarks

Science--Big Idea 1: The Practice of Science

- SC.7.N.1.1 - Define a problem from the seventh grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Science–Big Idea 11: Energy Transfer and Transformations

- SC.7.P.11.2 - Investigate and describe the transformation of energy from one form to another.

Mathematics–Ratios and Proportional Relationships

- MAFS.7.RP.1.2 - Recognize and represent proportional relationships between quantities.

Eighth Grade Benchmarks

Science--Big Idea 1: The Practice of Science

- SC.8.N.1.1 - Define a problem from the eighth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.
- SC.8.N.1.2 - Design and conduct a study using repeated trails and replication.
- SC.8.N.1.6 - Understand that scientific investigations involve the collection of relevant empirical evidence, the use of logical reasoning, and the application of imagination in devising hypotheses, predictions, explanations and models to make sense of the collected evidence.

Science–Big Idea 3: The Role of Theories, Laws, Hypotheses, and Models

- SC.8.N.3.1 - Select models useful in relating the results of their own investigations.

National Next Generation Science Standards - Sixth to Eighth Grade Standards
Science–Engineering Design

- 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.

Note: Related Common Core Mathematics Standards are listed in the Florida section above.

Junior Solar Sprint – Drive Train & Transmission

The transmission in a solar car is the part that connects and transmits power from the motor shaft to the wheels or axle. In general, a transmission is any device which transmits mechanical power from one place to another. In doing so, transmissions are also used to change the speed and torque (rotational force) while transmitting the mechanical power.

Part 1 - Direct Drive
The most simple type of transmission is direct drive, which means the motor is connected directly to the axle of the driven wheel. Direct drives are not common in vehicles; one of the few vehicles that uses direct drive is a unicycle. In the unicycle, every time your feet make one revolution, the wheel makes one revolution.

1. Attach your motor to your solar panel (or to a battery if the day is cloudy), and observe. The shaft of your motor should be spinning very fast. Grasp the motor shaft with your fingers to simulate gravity and friction. What happens? Are you able to slow down or stop the motor?

2. If you were to attach your car's drive wheel directly onto the motor shaft, it would spin very fast. However, what do you think would happen when the car was placed on the ground and had to overcome the weight of the car and the friction of the surface? Would the motor be spinning as fast?

3. Would your car tend to move forward fast or slow?

Part 2 – Belt Drive
A transmission can help us overcome the problem that we observed in making a direct drive vehicle. A transmission can be a belt, friction, chain, pulley or gear drive that makes the wheels turn with higher torque (making them harder to stop), but at a slower speed than the motor shaft. Obviously, this can be a tradeoff. High speed but not enough torque and the car won't start or accelerate quickly. Low speed and high torque and the car will accelerate quickly until it reaches its final, lower speed.

4. Make sure you have the following materials for the investigation: board with two nails in it, rubber band, large spool, and small spool. Place the small spool over one nail and the larger spool over the other nail. The spools should turn freely. Slip the rubber band around both spools so when one spool is turned, the other moves. Place a mark on the top edge of each spool. Watching the mark, turn the small spool (the driver wheel) 10 complete rotations. Count how many rotations the larger spool (the driven wheel) turns. How many turns did the driven wheel make?

5. When you turn the driver wheel clockwise, in which direction does the driven wheel turn?

6. Loop the rubber band over the spools in a "figure 8" (the rubber band will cross in the area between the spools). Turn the smaller spool ten complete rotations. How many times did the large spool turn?

7. When you turn the driver wheel clockwise, in which direction does the driven wheel turn?

Part 3 – Gear Drive

For this next investigation you will be using a gear set. If you have a gear set, continue to question #8. If you do not have a set of pre-made gears, you can make your own. You will need:

- gear template
- piece of cardboard
- glue stick or other paper glue
- (3) T-pins
- scissors
- ruler
- piece of foamboard (for base).

Glue the template to the cardboard. Carefully cut out the gears. (Note: the more accurate your cuts the better your test gears will work!). Bend the teeth of your gears halfway up (approximately 45°). Count the teeth on your gears and write the number of teeth on each gear.

8. With the ruler, draw a straight line across the length of your base (or foamboard). You will use this as a guide line to help you line up your gears. Attach two gears of the same size on your board so that the teeth mesh, and an arrow on each gear is matched up with the line on your base (if using foamboard, attach the gears with large pins). Make sure that when you turn one gear the other also turns freely. Adjust the gears position as needed. Notice that when turning the driver gear one full turn, the driven gear also turns one full turn. This is because the gears are the same size. However, when you turn the driver gear clockwise, what direction does the driven gear turn?

9. Attach the middle-sized gear for the driver and the large gear for the driven gear. Mark both gears where they are meshed (touching). Turn the driver gear and count the rotations of each gear until the marks line up again. How many rotations did each gear make? Enter your data in the chart below.

	Number of Teeth	**Number of Turns**
Driver Gear		
Driven Gear		

Repeat the investigation above two more times using different combinations of gears for each trial and record your findings below.

	Number of Teeth	**Number of Turns**
Driver Gear		
Driven Gear		

	Number of Teeth	**Number of Turns**
Driver Gear		
Driven Gear		

10. What is the relationship between the two ratios for each of the trials? (Hint: reduce each ratio as far as possible) Remember: ***ratio = driver gear : driven gear***

Trial 1: Teeth to teeth ratio __________ Turn to turn (gear) ratio _________

Trial 2: Teeth to teeth ratio __________ Turn to turn (gear) ratio _________

Trial 3: Teeth to teeth ratio __________ Turn to turn (gear) ratio _________

11. From this data, what can you say about the relationship between the ratio of number of teeth on a gear and the gear (turning) ratio?

12. If you had two gears with a 5:1 gear ratio and the driver gear rotates 50 times, how many times does the driven gear rotate?

From the trial above, you should also notice that the more teeth a gear has the fewer rotations it makes, and conversely, the less teeth a gear has the more rotations it makes. We lose speed in the larger gear, but we gain "torque". What is torque? We use the word force to describe a pushing of something in a straight line. But, when we are trying to twist something, as in rotating gears, **the measure of turning force is called torque**.

13. Construct a gear train composed of the large and small gear. Use one finger on the smaller gear to turn the gear train and have a team member lightly touch the driven gear on the top close to the outside (near the teeth), and then increase downward pressure on the gear while it is turning. Notice how much pressure is needed to slow the gear train, and how much turning force (torque) the gear has. Repeat with the other gear being the driver. Which driven gear has more torque and is more difficult to stop?

14. For your vehicles you will want to increase the torque (force) that is at the end of your gear train (the wheels) to help your car overcome the forces of friction and gravity. Will you want the larger or the smaller gear to be your driver gear?

How does torque relate to gear ratios? The larger the diameter of a gear, the more torque it has; the smaller the diameter of a gear, the less torque it has. In fact if we could measure the torque on our gears we would find that the torque ratios are exactly the same as the gear tooth ratios.

In summary, a driver gear transmits a force at its teeth to the driven gear. This force depends on the torque supplied by the motor and the size (radius) of the gear. A driven gear transmits a torque to its axle, which depends on the force applied to its teeth and the radius of the driven gear.

But what about a vehicle's speed? Remember that there is a tradeoff. High torque which will help the vehicle overcome the forces of gravity and friction is accomplished with larger (slower turning) gears. But, low speed and high torque and the car will accelerate quickly until it reaches its top speed, which could be very slow! And conversely, high speed but not enough torque and the car won't start or accelerate quickly.

Idler Gear

15. Set up your gears in a train of three with a small gear in the middle and the two large gears on the ends. The gear in the middle is called an idler gear. Rotate the driver gear once. How many rotations does the driven gear make? Why?

16. If you turn the driver gear clockwise, what direction does the driven gear turn in?

17. What do you think the purpose of the idler gear is?

18. Try using the medium sized gear for the idler gear. Are your results the same or different?

19. Does the size of the idler gear change the output of the gear train?

Part 4 – Wheel Size

Wheel size is as important a factor in a car's design as the transmission ratio; in fact, they are closely related. In a solid axle/wheel assembly, for every revolution of the axle, the wheel makes one turn also. To measure how far your vehicle travels on each revolution of the wheels, measure the circumference of one of the drive wheels (length around the outside of the circle).

20. If you built your car with drive wheels that had a 3" circumference how far would you expect your vehicle to travel in 10 revolutions of the axle?

21. If you switched to a wheel with a 6" circumference, how far would you expect your vehicle to travel in 10 revolutions of the axle?

22. The larger wheel acts much the same way as a larger gear in a gear train does. Why wouldn't you want to put the largest wheel you could find on your vehicle? (Hint: remember torque)

Discussion and Design

With your group, discuss how you might use the findings from your investigations to help you design your Sprint vehicle. As before, remember there are a lot of variables to consider. The challenge from this investigation is to decide what type of transmission will give your vehicle the acceleration and speed needed to win the race! Here are some points to consider:

- Experiment with several different transmissions. Don't be discouraged. Your first try may not work well. It helps if you build your car in such a way that you can change the gear ratios or transmission as you experiment.
- If you prefer, during this stage you can use two 1.5v batteries (equals 3V) to test your transmission.
- The speed at which the motor gives the most power is usually full speed if there is no load. As you experiment with different gear ratios, try to keep the motor turning at approximately that speed.
- The ideal gear ratio may change some if you change other characteristics of your car such as size, weight or wheel size.

- You can experiment with larger sized drive wheels by wrapping tape, foam insulation, or other materials around your wheels to run your tests.
- Mount your motor securely on a stiff part of the chassis. If the motor sags or moves, the transmission will be affected.
- Parts for your transmission may be found in old motorized toys, cassette players, and old can openers. Pulleys could be drawer pulls, videocassette reels or thread spools. Belts could be a slice of an inner tube or an o-ring. You may also purchase transmission parts from a hobby shop. Just make sure that the pitch of all your gears are the same.
- Different sun conditions may require different gear ratios. Test your vehicle in several different sun intensities. It may be that different gear ratios are best for different amounts of sunlight. You may want to be able to quickly change ratios the day of the race if the day turns out to be cloudy.

Belt/Pulley drives:

- Belts may stretch or slip off in the middle of the race. Most rubber bands are too elastic to make a good belt. Use stiff rubbery materials. You may also want to design your pulleys so that it is less likely for the belt to slip off. A "crowned" pulley (one with a convex or humped center) will usually solve this problem even though it seems as if the opposite would be true.
- One easy way to change the gear ratio on a pulley drive is to add or remove masking tape around a pulley, which changes its diameter.

Friction drives:

- If you use a friction drive, make sure you have enough traction on the friction disk or it will slip. However, too much tension between the motor and the drive wheel will slow the motor and your car down. The motor on a friction drive can be mounted with springs (spring loaded) so that it keeps a constant tension on the drive wheel.

Gear drives

- Make sure the gears are pressed against each other snugly to ensure traction
- Listen for the sound of gear slippage when you test your vehicle.

Just remember, if your car is not going very fast it can either be that the wheel speed is too slow, or the force required to turn the wheel is too high. Try a different gear ratio!