Solar Education for NY

SchoolPower

...Naturally

Junior Solar Sprint Series: Gears and Drive Belts

SPN LESSON #7

TEACHER INFORMATION

LEARNING OUTCOME

After investigating the mechanical advantages of gear-to-gear, gear-and-chain, and belt-and-pulley systems, students recognize the trade-off between speed and power inherent in these devices.

LESSON OVERVIEW

Students evaluate system-and-size ratio combinations and determine which will work best with the solar cell and electrical motor devices used to power their model solar cars.

GRADE-LEVEL APPROPRIATENESS

This Level II, general energy, technology education lesson is designed for students in grades 5–8.

MATERIALS (per student group)

Two-gear set
Ruler
10-speed bike
Bike stand
Hammer
2 Eight-penny nails
12-inch 2x4 board
Rubber band
Larger-diameter wooden spool
Smaller-diameter wooden spool

SAFETY

There are no safety concerns for this lesson.

TEACHING THE LESSON

As part of the sequence of developing the design for the students' solar cars, discuss the need to mechanically connect the solar-powered motor to the axle and wheels of the car. Solicit ideas concerning possible drive mechanisms, and ask about the strengths and weaknesses of each system mentioned. Invite students to investigate one or more of the drive mechanisms to see if their ideas are valid and to provide experiences that will help them decide what type of mechanism they want to use for their cars. After they read the student handout, have them gather the needed materials and carry out their investigations.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Activity 1: Part A: Gears

Chart entries will vary according to the gear pairings used. The ratios for the first three columns should be the same for any particular gear pair. The last column should be an inverse ratio and in the opposite direction.

1. Variable according to gear pairings
2. Same as 1
3. The smaller gear turns faster.
4. It would make the wheels turn slower than the motor rpm's.
5. It would make it more powerful [but slower]
6. It would make it more powerful [but slower]

Part B: Bicycle Gears

Develop Your Understanding

1. No
2. Same
3. Yes

Activity 2

Develop Your Understanding

1. Answers will vary according to relative diameter of spools. Results should be similar to gear results.
2. Similar in speed change according to diameter size, but it does not change the direction of spin. Also, transfer of energy depends on friction between the rubber band and the spool surface.
3. It is similar to gear-and-chain mechanism.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED LESSON

This lesson was adapted from materials developed for Junior Solar Sprint by the Northeast Sustainable Energy Association and NREL.

BACKGROUND INFORMATION

This lesson is one of several preliminary classroom investigations leading to an understanding of the scientific phenomena underlying the operation of, and the eventual building of, a competitive model solar car. This competition is sponsored by the Junior Solar Sprint (JSS) Program, developed originally under the auspices of the U.S. Department of Energy and currently sponsored by the Northeast Sustainable Energy Association (NESEA) and the U.S. Army. Visit NESEA at www.nesea.org for complete information and more learning activities.

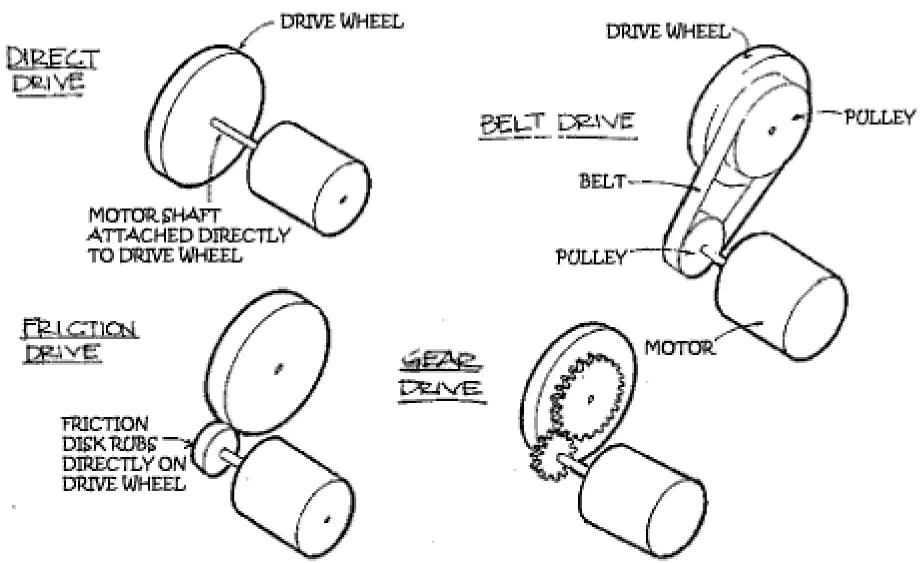
Transmission

Purpose

A car's transmission transfers the power from the motor to the wheels. While doing so, it may make the wheels spin at a different speed than the motor.

Ideas

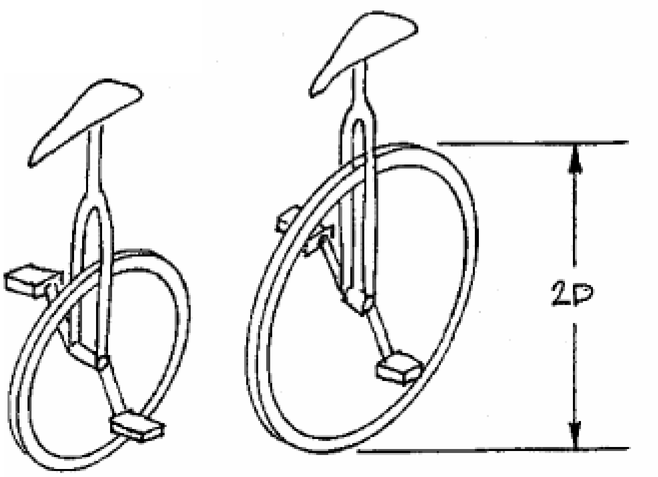
There are different ways to transfer power from the motor to the wheels. Some popular techniques are direct drive, friction drive, belt drive, chain drive, and gears.



Some transmissions are easier to build than others, and not all are appropriate for a solar car.

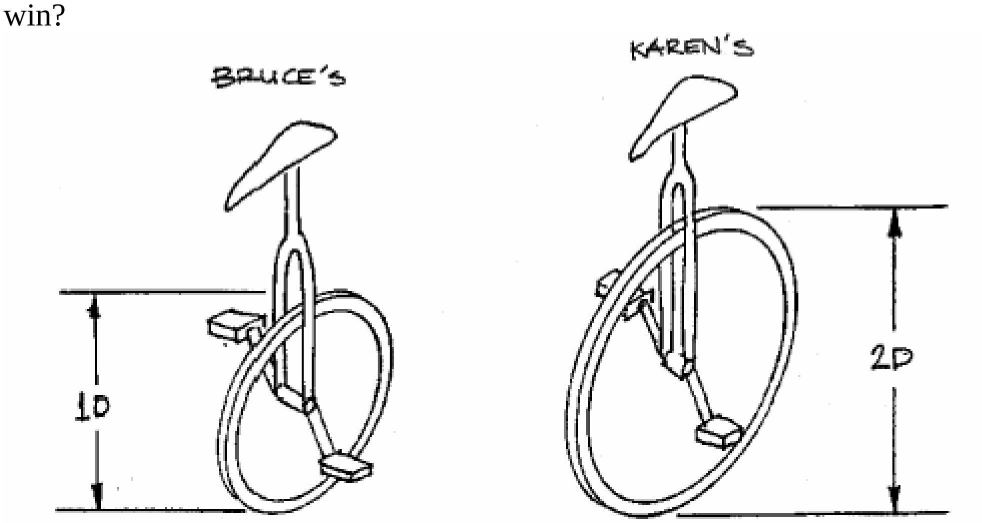
Concept: Speed versus Force

The simplest 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 use direct drive is a unicycle. Every time your feet make one revolution, the front wheel makes one revolution.



Speed

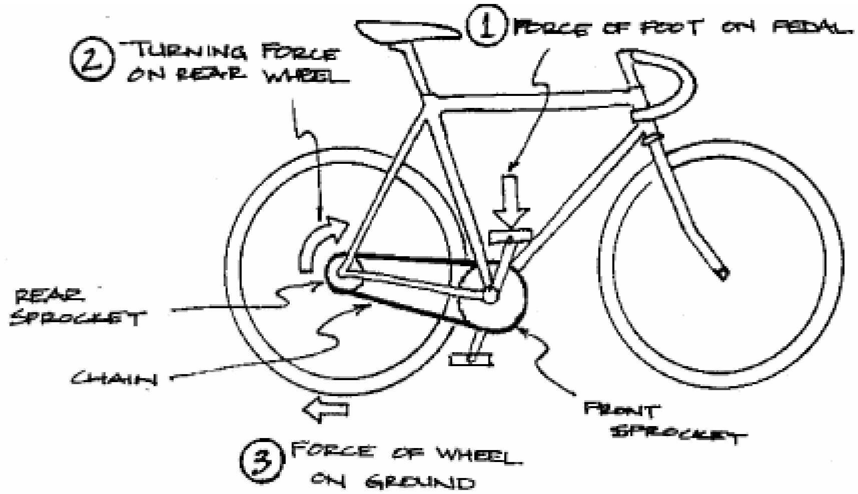
Imagine that two of your neighbors have a unicycle race. Bruce's unicycle has a regular wheel, and Karen's has a very large wheel. If they both pedal at the same rate, which one of them will win?



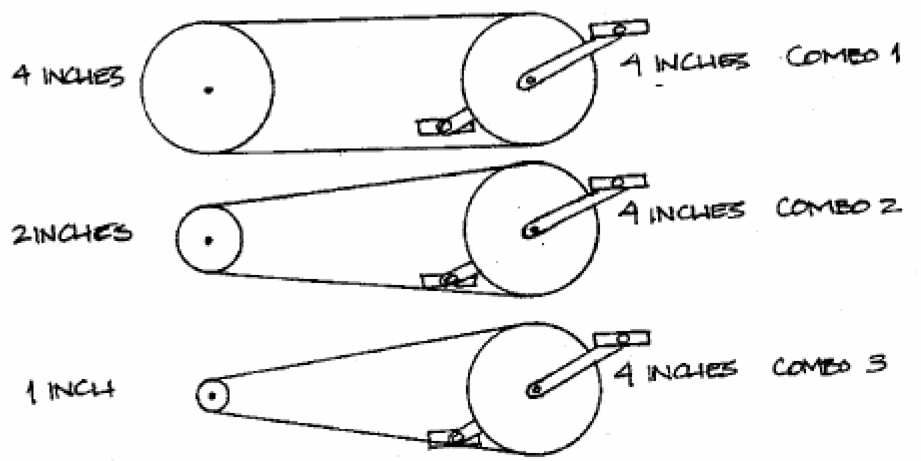
In both cases, each revolution of the pedal results in one revolution of the wheel. But one revolution of Karen's wheel will roll twice as far as Bruce's wheel. So, Karen would win if they both pedaled at the same rate. If Bruce wanted to win, he would have to pedal more than twice as fast as Karen.

Have you ever seen pictures of very old bicycles that have huge front wheels? These bicycles allow the rider to go faster without pedaling like a maniac!

As mentioned before, most vehicles are not direct drive, so let's look at another type of vehicle: a 3-speed bicycle. A bicycle uses a chain drive. It allows you to move the pedals, and the chain transfers the energy from the pedals to the rear wheel accordingly.



The chain glides over different-sized sprockets, depending on the speed setting chosen by the rider.
Which sprocket combination will make the rider go the fastest, given the same pedaling rate, or cadence? (Hint: consider how many times the back sprocket [and therefore the back wheel] will turn with each rotation of the front sprocket.)



Each rotation of the front sprocket will make the back wheel rotate once in combo 1, twice in combo 2, and four times in combo 3. So, combination 3 will go the fastest. (These sprocket combinations may also be called *gear ratios*, because the new speed is calculated as the ratio of the driven [front] sprocket over the back sprocket.)

So how do these sprocket choices affect the way a biker would use the bicycle? Well, when she starts out, she starts in first gear (combo 1). As she pedals faster, the bike starts going faster. After a while, her legs are moving very fast, so she switches to second gear (combo 2). Now her legs go only half as fast, but the bike is still going fast. She can increase her cadence again and make the bike go even faster. Once her cadence is very high again, she can shift up to third gear (combo 3).

If she was going 5 miles per hour in first gear, how fast will she be going in third gear with the same pedaling rate?
Well, the jump from first to second gear doubles the speed, and the step from second to third gear doubles it again. So, she is going four times as fast as in first gear. She is now going 20 miles per hour, but her legs are going at the same rate as at the very beginning.
The term *3-speed bike* is not entirely correct, because a biker can go more than just three different speeds with this bike. As we saw in the previous example, our biker was able to continuously speed up from 5 mph to 20 mph. The name comes from the fact that given one cadence, the three gear ratios will give the rider three different speeds.

Force

You may ask, then, why isn't it best to go for the highest speed possible? Well, you can't get something for nothing! What are you giving up when you gain speed? Let's investigate.…
Imagine two bikers approaching a very steep hill. Jeff and Dave are both in third gear, because they are going very fast. Dave downshifts into second. But Jeff decides to stay in third gear, because he knows that third gear is for going fast, and he wants to go up this hill very fast.
Dave is going half the speed now, because he just downshifted. Jeff smirks as he blows by Dave. But Jeff goes up the hill, and suddenly realizes that his legs can't go very fast anymore—it has become very hard to pedal! He goes slower and slower, and finally stops pedaling because it's too hard to do so. Dave passes, slowly but surely, and makes it to the top of the hill.
What happened? If only Jeff could have kept pedaling at the same rate, he would have beaten Dave soundly! Let's look at each pedal stroke. Each time Dave and Jeff pedal once,
Dave's back wheel goes around once (let's say it travels 10 feet), but Jeff's back wheel goes around twice (20 feet).
Dave realizes that he only has to expend half as much energy per pedal revolution as Jeff does, because Jeff goes twice as far each time. That is why Jeff started getting very tired: his pedals were difficult to push. In other words, his pedals required more force than Dave's did.
So, does Dave expend less energy going up the same hill?

Selecting the Proper Gear Ratio

So, how might you choose the best gear ratio for a Solar Sprint vehicle? Investigating is probably the easiest way to find out.
The idea is that the motor, like your legs when you ride a bike, works best at a certain speed. Motors also have a limit as to how much force they can exert. First you must find the speed at which the motor gives the most power (this is usually half the speed the motor will rotate at if there is no load, or force, exerted on the motor shaft). Try to keep the motor turning at approximately that speed as you try different gear ratios.
It helps if a car is built in such a way that a person can change the gear ratios easily. Remember, the ideal gear ratio may change somewhat if different characteristics of a car are changed such as size or weight. Just remember, if a car is not going very fast, it could be either that the wheel speed is too slow or (as in the case of Jeff riding uphill) that the force required to turn the wheel is too high. Then try a different gear ratio!

Materials

The materials that might be chosen will vary greatly depending on the type of transmission that is to be built.

To build a belt drive, try stiff, rubbery materials for the belt, such as a slice of inner tube or an o-ring. Then make sure the pulleys are pulled away from each other, so that the belt is tight. A way to change the gear ratio on a pulley drive is to add or remove masking tape around the pulley; this changes its diameter.

If a friction drive is used, make sure that there is enough traction on the *friction disk*, or it will slip (see the Materials section for wheels and bearings). Also, make sure the friction gears are pressed against each other snugly to ensure traction.

In all cases, wheel-like parts will be needed to put on the motor shaft and the wheel. Participants can get ideas from reading the suggestions for wheel materials.

REFERENCES FOR BACKGROUND INFORMATION

Northeast Sustainable Energy Association, 50 Miles Street, Greenfield, MA 01301, phone 413-774-6051 nesea@nesea.org

Minnesota Renewable Energy Society, R. Brown: brownrw@tcfreenet.org

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

NYS Intermediate Level Science Core Curriculum Grades 5–8

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematics Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

M1.1: Extend mathematical notation and symbolism to include variables and algebraic expressions in order to describe and compare quantities and express mathematical relationships.

M1.1a: Identify independent and dependent variables.

M1.1b: Identify relationships among variables including: direct, indirect, cyclic, constant; identify non-related material.

M1.1c: Apply mathematical equations to describe relationships among variables in the natural world.

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

M2.1: Use inductive reasoning to construct, evaluate, and validate conjectures and arguments, recognizing that patterns and relationships can assist in explaining and extending mathematical phenomena.

M2.1a: Interpolate and extrapolate from data.

M2.1b: Quantify patterns and trends.

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.

M3.1: Apply mathematical knowledge to solve real-world problems and problems that arise from the investigation of mathematical ideas, using representations such as pictures, charts, and tables.

M3.1a: Use appropriate scientific tools to solve problems about the natural world.

Science Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

S2.1: Use conventional techniques and those of their own design to make further observations and refine their explanations, guided by a need for more information.

S2.1b: Conduct an experiment designed by others.

S2.1d: Use appropriate tools and conventional techniques to solve problems about the natural world, including:

4. measuring
5. observing
6. describing
7. classifying
8. sequencing

S2.2: Develop, present, and defend formal research proposals for testing their own explanations of common phenomena, including ways of obtaining needed observations and ways of conducting simple controlled experiments.

S2.2b: Design scientific investigations (e.g., observing, describing, and comparing; collecting samples; seeking more information, conducting a controlled experiment; discovering new objects or phenomena; making models).

S2.3: Carry out their research proposals, recording observations and measurements (e.g., lab notes, audiotape, computer disk, videotape) to help assess the explanation.

S2.3b: Conduct a scientific investigation.

S2.3c: Collect quantitative and qualitative data.

Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

S3.1a: Organize results, using appropriate graphs, diagrams, data tables, and other models to show relationships.

S3.2: Interpret the organized data to answer the research question or hypothesis and to gain insight into the problem.

S3.2a: Accurately describe the procedures used and the data gathered.

S3.2d: Formulate and defend explanations and conclusions as they relate to scientific phenomena.

S3.2e: Form and defend a logical argument about cause-and-effect relationships in an investigation.

S3.2g: Suggest improvements and recommendations for further studying.

S3.3: Modify their personal understanding of phenomena based on evaluation of their hypothesis.

Engineering Design Key Idea 1: Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints); this process is used to develop technological solutions to problems within given constraints.

T1.2a: Use all available information systems for a preliminary search that addresses the need.

T1.3: Consider constraints and generate several ideas for alternative solutions, using group and individual ideation techniques (group discussion, brainstorming, forced connections, role play); defer judgment until a number of ideas have been generated; evaluate (critique) ideas; and explain why the chosen solution is optimal.

T1.3a: Generate ideas for alternative solutions.

T1.3b: Evaluate alternatives based on the constraints of design.

T1.4: Develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship.

T1.4a: Design and construct a model of the product or process.

T1.4b: Construct a model of the product or process.

T1.5: In a group setting, test their solution against design specifications, present and evaluate results, describe how the solution might have been modified for different or better results, and discuss trade-offs that might have to be made.

T1.5a: Test a design.

T1.5b: Evaluate a design.

Standard 6—Interconnectedness: Common Themes. Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 6: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.

6.1: Determine the criteria and constraints and make trade-offs to determine the best decision.

6.2: Use graphs of information for a decision-making problem to determine the optimum solution.

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision-making, design, and inquiry into phenomena.

1.4: Describe and explain phenomena by designing and conducting investigations involving systematic observations, accurate measurements, and the identification and control of variables; by inquiring into relevant mathematical ideas; and by using mathematical and technological tools and procedures to assist in the investigation.

Key Idea 2: Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

2.1: Students participate in an extended, culminating mathematics, science, and technology project. The project would require students to:

- Working Effectively: Contributing to the work of a brainstorming group, laboratory partnership, cooperative learning group, or project team; planning procedures; identify and managing responsibilities of team members; and staying on task, whether working alone or as part of a group.
- Gathering and Processing Information: Accessing information from printed media, electronic data bases, and community resources and using the information to develop a definition of the problem and to research possible solutions.
- Generating and Analyzing Ideas: Developing ideas for proposed solutions, investigating ideas, collecting data, and showing relationships and patterns in the data.
- Common Themes: Observing examples of common unifying themes, applying them to the problem, and using them to better understand the dimensions of the problem.
- Realizing Ideas: Constructing components or models, arriving at a solution, and evaluating the result.
- Presenting Results: Using a variety of media to present the solution and to communicate the results.

Standard 4: The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

5.1: Describe different patterns of motion of objects.

5.1a: The motion of an object is always judged with respect to some other object or point. The idea of absolute motion or rest is misleading.

5.1b: The motion of an object can be described by its position, direction of motion, and speed.

5.1c: An object's motion is the result of the combined effect of all forces acting on the object. A moving object that is not subjected to a force will continue to move at a constant speed in a straight line. An object at rest will remain at rest.

5.1d: Force is directly related to an object's mass and acceleration. The greater the force, the greater the change in motion.

5.1e: For every action there is an equal and opposite reaction.

5.2: Observe, describe, and compare effects of forces (gravity, electric current, and magnetism) on the motion of objects.

5.2c: Machines transfer mechanical energy from one object to another.

5.2d: Friction is a force that opposes motion.

5.2e: A machine can be made more efficient by reducing friction. Some common ways of reducing friction include lubricating or waxing surfaces.

5.2f: Machines can change the direction or amount of force, or the distance or speed of force required to do work.

5.2g: Simple machines include a lever, a pulley, a wheel and axle, and an inclined plane. A complex machine uses a combination of interacting simple machines, e.g., a bicycle.

PROCESS SKILLS BASED ON STANDARD 4

General Skills

2. safely and accurately use the following measurement tools:
   - metric ruler
3. use appropriate units for measured or calculated values
4. recognize and analyze patterns and trends
8. identify cause-and-effect relationships

Physical Setting Skills

16. determine the speed and acceleration of a moving object

Produced by the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ____________________________________

Date ______________________________________

Junior Solar Sprint Series: Gears and Drive Belts

Activity 1: How do gear size and tooth number affect the transfer of energy from my car's motor to its wheels?

Materials Needed:
Two-gear set
Ruler
10-speed bike
Bike stand

Part A: Gears

Procedure:
1. Mark one tooth on each gear.
2. Count the number of teeth on each gear and record this data in the chart below.
3. Measure the diameter between the base of the teeth on opposite sides of each gear and calculate circumference.
4. Turn the larger gear one turn clockwise. On the chart below, record how many turns and in which direction the smaller gear turns.

DEVELOP YOUR UNDERSTANDING

Gear Size	Number of Teeth	Diameter (centimeters)	Circumference (centimeters)	Number of Turns
Larger Gear				
Smaller Gear				
Ratio Larger:Smaller				

1. What is the ratio between the number of teeth on the large gear and the number of teeth on the small gear?

2. What is the ratio between the diameter of the large gear and the diameter of the small gear?

3. Which gear size turns faster?

4. How would using the smaller gear to transfer mechanical energy from the motor of the solar car to the larger gear attached to the axle of the car affect the speed of the car wheels?

5. How would this gear arrangement affect the power of the car?

Part B: Bicycle Gears

Procedure:

1 Check your responses to the questions above by using different gear combinations to pedal the 10-speed bike on the bike stand.

DEVELOP YOUR UNDERSTANDING

1. Are the gears of the bike connected directly to one another?

2. Does this drive mechanism affect the gear ratios of the various gear combinations, or are they the same as if the chain wasn't there?

3. Could this drive mechanism be used for your solar car?

Activity 2: Do drive belts and spools work the same way gears do?

Materials:

Procedure:

1. Hammer the two nails into the board far enough apart to lightly stretch the rubber band between them.
2. Using the micrometer, determine the diameter of each of the spools:

Diameter of Larger Spool: Diameter of Smaller Spool:

3. Place the wooden spools over the nails.
4. Stretch the rubber band around both spools.
5. Place a mark on the top edge of each spool.
6. Turn the large spool through one complete turn.

DEVELOP YOUR UNDERSTANDING

1. How many times did the small spool turn?

2. How does this drive mechanism compare with the gear-to-gear mechanism?

3. How does this drive mechanism compare with the gear-and-chain mechanism?

Additional Sources of Information

Bright Ideas published by the Arizona Energy Office, 3800 North Central Ave., Suite 1200, Phoenix, AZ 85012.
Lowery, Thomas. *The Everyday Science Book*, Palo Alto, CA: Seymour Publications, 1985.
American Tour de Sol pamphlet published by the Northeast Sustainable Energy Association, 23 Ames Street, Greenfield, MA 01301.
Pollard, Michael. *How Things Work*, New York: Larousse & Co., 1978.

Helpful Hints for Transmission Design

1. How should I design the transmission?
Be creative. There is no one solution to the problem.
2. How should I get power from the motor to the wheels?
Try several different ways such as gears, pulleys, or some other drive method to get power to the wheels. Don't be discouraged—your first try may not work.
3. What should I know about gears?
The pitch of a gear describes the number of teeth that can be put on a 1-inch diameter gear. Gears with different pitches will not fit together well, so the same pitch must be used throughout the transmission. Gears in 48 and 64 pitch are the ones typically used in slot cars. You can buy gears for the 1/24-scale slot cars through local hobby shops.
4. Where can I find parts?
Cheap motorized toys, old cassette or 8-track tape players, old motorized can openers, recycled materials, and small gear reduction boxes might have gears and pulleys that will work in your

transmission. Look for them in secondhand stores, in discount stores such as Target and Wal-Mart, or in your sibling's toy box.

5. What else should I think about as I design the car?

Think about the friction of the following components:

_ Gears moving against each other
_ The stretching or slipping of a belt
_ The tires on the track
_ All the other moving parts of the car