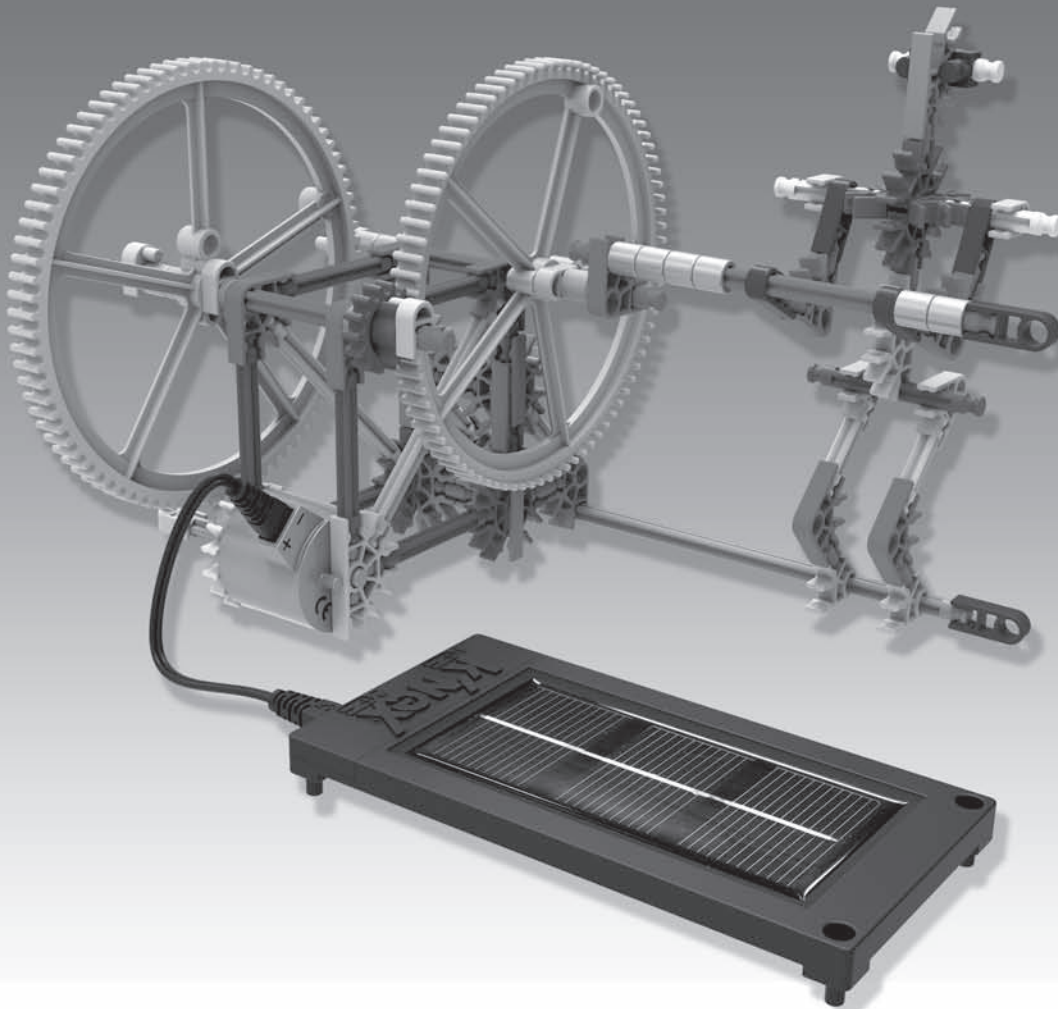
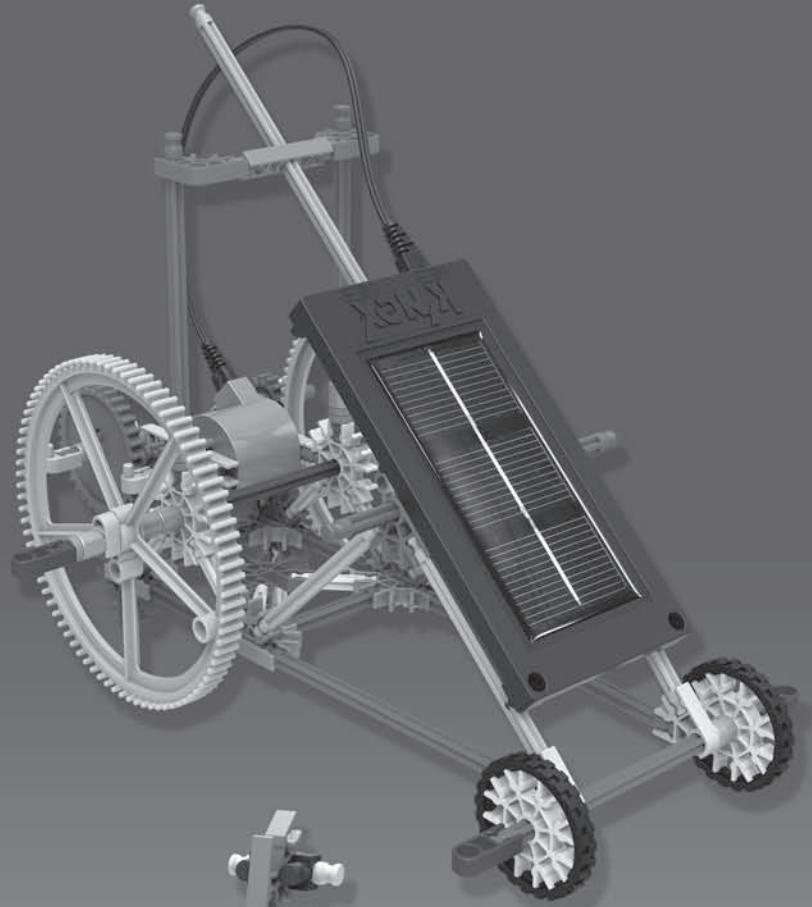
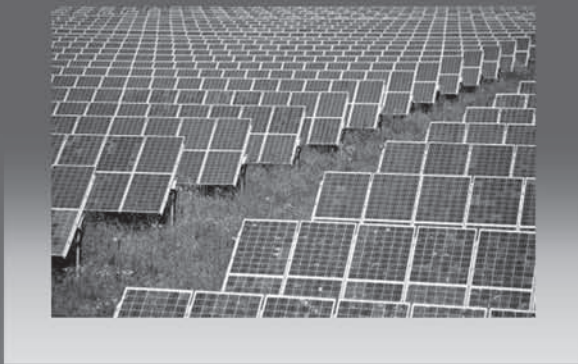


INVESTIGATING SOLAR ENERGY TEACHER'S GUIDE



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V1-10/13

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WARNING:

CHOKING HAZARD - Small parts.
Not for children under 3 years.



AVERTISSEMENT:

DANGER D'ÉTOUFFEMENT - Pièces de petite taille.
Ne pas donner aux enfants de moins de 3 ans.

A NOTE ABOUT SAFETY:

Safety is of primary concern in science and technology classrooms. It is recommended that you develop a set of rules that governs the safe, proper use of K'NEX in your classroom.

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INTRODUCTION

Overview:

The models that can be built using the K'NEX Education Investigating Solar Energy Set are solar powered that are all operational. The models work in the same manner as the machines they were designed to replicate with the ingenious use of K'NEX pieces. However, the designs have compromises that students will easily point out as they explore both the models and the machines they represent. This teaching unit strongly emphasizes the engineering principles of design and systems thinking. Throughout the lessons students are challenged to design flow charts and to trace the flow of energy through a model. Quantitative information can be obtained and experiments can be improved to yield more precise information, just the way science works in a research setting. Coupling the science to the search for design improvements and the careful study of variables provides a series of lessons rich in:

- Scientific process;
- Quantitative measures;
- Limiting and measuring variables;
- Optimizing a system; and
- Understanding the shared responsibilities of science and engineering.

Students will construct the models the building instructions included. Construction is not just matching colors with the blue print designs but an opportunity to watch a three-dimensional model come into being through the use of a two-dimensional design. In addition, this construction has students asking: WHY is this part here? WHAT is its purpose? HOW does this model work? Many students will actively generate hypotheses about the relationships between the various parts during the construction phase of the lessons. Many lessons follow up on this inquiry by asking students for engineering and design suggestions to improve the model. So, it is important that students have the practice of building the models. During this construction phase, students may observe areas where the design can be changed.

The lessons have students design experiments to examine several variables that affect the models' movements. Sometimes these lessons are described in detail, other times students have the responsibility of designing an appropriate experiment that fairly tests a variable. The models were designed to provide a springboard for further improvements and alternate designs. Students can then be challenged to explore, investigate and experiment to find design ideas that will improve the performance of the models. Students will, in fact, be optimizing the performance of the various machines. One important core concept in engineering is determining the most efficient design for any given task. Students will have the opportunity to tackle this core concept.

These models focus on physical science concepts such as force, motion, simple machines, leverage, mechanical advantage, work, energy, and efficiency. The listing of these vocabulary terms and others found in the Glossary come alive in the context of the models.

Finally, these models serve as an excellent way for students to examine some of the challenges of using renewable energy sources in our world. For example, a number of states require that a specific percentage of electrical power come from alternative and renewable sources. By scaling up the results of the models' data, students can come to realize how inefficient the models are. By comparing their models to real life examples, students come to appreciate and

understand the excellent engineering and design shown in some of the working machines operating today. The K'NEX models can provide a starting point for students as they study energy production and use in their community. Some of the constraints and challenges that the students will face with these models are similar to those faced in the real world.

Teacher Notes:

The K'NEX Education Investigating Solar Energy Set provides exciting, dynamic materials and a curriculum that will help you guide your students as they explore a major source of renewable energy: solar. This set is designed to address critical science, technology and engineering concepts and provide instructional models that will enhance students' understanding of these important concepts. Using K'NEX and the lessons provided in this guide, offers a program of study that uses hands-on exploration in conjunction with an engaging inquiry-based approach to learning. Students are encouraged to work together as they build, investigate, discuss and evaluate concepts, ideas and designs.

Teacher's Guide:

This guide is intended as a resource for teachers and students as they tackle meaningful science, technology and engineering content in the classroom. This series of comprehensive lessons each include:

- **Lesson Length:** The suggested class time recommended to complete the lesson.
- **Student Objectives:** Objectives that you can expect your students to achieve through the successful completion of the activity.
- **Materials and Equipment:** A list of the materials that will be needed to complete the lesson.
- **Engagement:** Introductory questions or investigations to pique student interest.
- **Exploration, Experimentation and Elaboration:** Opportunities for students to investigate and carry out fair tests that they can describe with graphs and data that they can analyze.
- **Evaluation:** Suggestions for hands-on assessments of the mathematics concepts discussed in the lesson. These assessments may be done either individually or as a group.
- **Extensions:** Listings of possible extension activities to use when appropriate.
- **Student Response Sheets:** Pages that guide students as they complete activities. These pages also include questions that students will answer to demonstrate their understanding of content and concepts.
- **Answer Sheets:** Expected answers for each of the questions asked on the Student Response Sheets to assist the teacher as they assess their students.

Student Journals:

We suggest that students maintain a journal for the activities they complete from the Investigating Solar Energy Set. A loose-leaf format serves this purpose well. Students should include notes, drawings, conjectures and reflections in addition to copies of the **Student Response Sheets** they complete with each lesson. The journal will provide a comprehensive record of the growth of individual students. This information is an excellent source for assessment data.

ITEA & NSES STANDARDS ALIGNMENTS

ITEA Standards grades 5-8 Students will develop an understanding of:	Solar: Lessons 1, 2, 3
<p>The characteristics and scope of technology:</p> <ul style="list-style-type: none"> • New products and systems can be developed to solve problems or to help do things that could not be done without the help of technology. • Technology is closely linked to creativity which has resulted in innovation. • Inventions and innovations are the results of specific, goal directed research. 	
<p>The core concepts of technology:</p> <ul style="list-style-type: none"> • Systems Thinking • Involves considering how every part relates to others. • Applies logic and creativity with appropriate compromises in complex real-life problems. • Technological systems can be connected to one another. • Different technologies involve different sets of processes. • New Technologies create new processes. 	1
<p>Relationships among technologies and the connections between technology and other fields:</p> <ul style="list-style-type: none"> • Knowledge gained from other fields of study has a direct effect on the development of technological products and systems. 	1
<p>The cultural, social, economic, and political effects of technology:</p> <ul style="list-style-type: none"> • Technology, by itself, is neither good nor bad, but decisions about the use of products and systems can result in desirable or undesirable consequences. • Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects. 	1
<p>The effects of technology on the environment:</p> <ul style="list-style-type: none"> • The management of waste produced by technological systems is an important societal issue. • Decisions to develop and use technologies often put environmental and economic concerns in direct competition with one another. • Humans can devise technologies to conserve water, soil, and energy through such techniques as reusing, reducing, and recycling. • When new technologies are developed to reduce the use of resources, considerations of trade-offs are important. 	

ITEA Standards grades 5-8 (continued)	Solar: Lessons 1, 2, 3
<p>The attributes of design:</p> <ul style="list-style-type: none"> • Design is a creative planning process that leads to useful products and systems. 	
<p>Engineering Design:</p> <ul style="list-style-type: none"> • Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions. 	1, 2, 3
<p>Apply Design Process:</p> <ul style="list-style-type: none"> • Apply a design process to solve problems in and beyond the laboratory-classroom. • Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product. 	1, 2, 3
<p>Assess the impact of technological products and systems:</p> <ul style="list-style-type: none"> • Synthesize data, analyze trends, and draw conclusions regarding the effect of technology on the individual, society, and the environment. 	
<p>Select and use energy and power technologies:</p> <ul style="list-style-type: none"> • Energy is the capacity to do work. • Energy can be used to do work, using many processes. • Power systems are used to drive and provide propulsion to other technological products and systems. • Much of the energy used in our environment is not used efficiently. • Energy resources can be renewable or non renewable. 	

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NSES Standards grades 5-8 Students will develop an understanding of:	Solar: Lessons 1, 2, 3
Unifying Concepts and processes: <ul style="list-style-type: none"> • Systems, order, and organization • Evidence, models, and explanation • Measurement • Form and function 	1, 2
Science as Inquiry: <ul style="list-style-type: none"> • Abilities necessary to do scientific inquiry • Understandings about scientific inquiry 	1, 2, 3
Physical Science: <ul style="list-style-type: none"> • Motions and forces • Transfer of energy 	1, 2, 3
Science and Technology: <ul style="list-style-type: none"> • Abilities of technological design • Understandings about science and technology 	1, 2
Science in Personal and Social Perspectives: <ul style="list-style-type: none"> • Resources • Science and technology in society 	
History and Nature of Science: <ul style="list-style-type: none"> • Nature of Science 	1, 2, 3

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SOLAR POWER

Introduction:

Harnessing energy from the sun is one goal of the Green Revolution. While the sun's energy is essentially a constant, its effect on earth is variable due to cloud cover and time of year. Solar energy is usually broken down into two categories, active solar and passive solar. The lessons included use a photoelectric cell (also called a photovoltaic cell or a solar cell), which converts energy from the sun into electricity. You may also be familiar with solar thermal collectors many people use to heat their swimming pools. These two forms of solar energy are active solar. Passive solar heating would be a building that is oriented to the sun to provide the most heat inside during the winter months.

Students investigating solar energy will optimize the photoelectric cell's efficiency by adjusting its angle to the sun or the light source. They will also investigate the relationship between energy and distance from the photocell in the classroom. Students will have the opportunity to complete both structured and open-ended investigations as a part of their solar experimentation.

Examining the energy that is available to the photocell (potential energy) and then how that energy is transformed into movement (kinetic energy) represent the focus of the lessons. These two concepts provide real world contexts for students to consider as they explore the cost, benefits and limitations of proposed solar use.

Select web resources for solar energy: (NOTE: At the time of publication, these websites were operational and useful resources for information relative to solar energy. Please visit these websites before sharing them with students to ensure that the content is still appropriate.)

- **Earth's Energy Budget:**

See a graph that illustrates some of the variables involved in using solar energy.
<http://marine.rutgers.edu/mrs/education/class/yuri/erb.html>

- **Solar Constant:**

Find discussions about the nature of the sun's energy coming to earth. This Wikipedia article includes the basic vocabulary needed for students as they study solar effects.
http://en.wikipedia.org/wiki/Solar_constant#Solar_constant

- **Light and Latitude:**

See a graph that students can use to determine the number of hours of sunlight per day at a given latitude. This is very important in understanding climate. <http://astro.unl.edu/classaction/animations/coordsmotion/daylighthoursexplorer.html>

- **Hours of daylight vs. Latitude:**

Find data that students can use to look at the number of hours of light at different latitudes.
<http://www.orchidculture.com/COD/daylength.html>

- **How do photocells work?**

Find an explanation on the reaction involved in converting sun light energy into electrical energy.
<http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/>

See the Dow Corning website that advertises and describes the use of photovoltaic cells.
http://www.dowcorning.com/content/discover/discovershowcase/solar.aspx?WT.mc_id=25069301&WT.srch=1&bhcp=1

- **Efficiency of photovoltaic cells:**

A view of photovoltaic cells provided by the electric utility industry. This article and those like it

can be used to investigate the advantages and disadvantages of photovoltaic use. <http://www.renewablegreenenergypower.com/advantages-and-disadvantages-of-solar-photovoltaic-quick-pros-and-cons-of-solar-pv/>

Most commercially available photovoltaic cells used in 2010 have an efficiency of about 15%, this site provides a research article on more efficient cutting edge photovoltaic cells technology. <http://www.futurepundit.com/archives/004418.html>

- **Cost/benefit of photovoltaic cells:**

Find formulas and details about the cost/benefit of using photovoltaic cells. Read this article for bias. <http://zebu.uoregon.edu/1996/ph162/l6a.html>

Through the investigation of solar powered models, students will make concrete observations and gather practical information about this form of energy.

This unit is written using a 5E instructional model. The elements of the 5E model are Engage, Explore, Explain, Elaborate and Evaluate (see BSCS for more explanation at: <http://www.bsos.org/pdf/bsos5eexecsummary.pdf>)

The investigations place an emphasis on STEM (science, technology, engineering and mathematics). The emphasis on engineering includes opportunities for students to work on optimization, improvements to a design, and systems. Students will use flow charts to show the path of energy and its conversion from one form to another in various systems that are explored.

Students can calculate efficiency as energy is converted from light to electricity to motion. Additionally, students will use experimental data with physical science formulas to demonstrate their understanding of energy and its transformations from one form (kinetic) to another (potential or electrical)

There are numerous practical applications for this unit of study. The world is in an energy dilemma brought about by population increases and decreasing availability of crude oil and other nonrenewable energy sources. Alternate energy forms using renewable energy sources like wind, water, solar, and geothermal are increasingly popular alternatives and supplements to the nonrenewable forms of energy the world depends on today. The story of solar use goes back to the Romans who engineered buildings to use sunlight efficiently and protect inhabitants from excess heat and light. Cliff dwelling Indians designed their homes with the sun's energy in mind. While these early passive examples did not use electricity, the problem solving demonstrated is similar to the solar models in this series.

The models used in the lessons challenge the students to undertake a series of problem solving activities. In many ways these activities are similar to the challenges others have faced through history as they attempted to gain the greatest benefit from the sun's heat energy. Energy from the sun or incandescent light sources produces electricity that will power the models used in these investigations. The use of models is consistent with many science investigations and engineering simulations and is not to be taken lightly. Most industries use models to perform many initial tests that examine the feasibility of large scale machines and mechanical systems. The shape of the space shuttle, the hull designs of ocean tankers and many components of airplanes were first explored using scale models. Those systems that produced the best results with models were eventually manufactured in full-scale experimental designs. The use of models has been an efficient and cost saving technique that industry has used to make many of the conveniences and machines we use today.

Solar Power - Lesson 1: SOLAR CAR



Time Frame:

5 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Limit variables in an experiment.
- Collect and report quantitative data accurately.
- Make meaningful conclusions based on data.

Materials:

- The K'NEX Education Investigating Solar Energy Set
- Photoelectric cell, capacitor, solar motor and cord
- Tape measure
- Masking tape
- Calculator
- Light sources for inside use (a utility light or desk lamp and a collection of various watt light bulbs (100, 75, 60, 40) will work very well for the solar car activities. Ensure that the light source is rated for the various wattages used during experimentation.)
- Sunlight for outdoor use
- Graph paper
- Calculator/adding machine tape (optional)
- Stopwatch
- Protractor

Investigation 1: How does the photocell work?

Engagement:

Attach a solar panel to a solar motor using the cord provided. Snap an orange connector to the rod on the solar motor and place the panel under a light source. Allow this simple model to operate for a few minutes and ensure that all of the students can see the spinning motion that results. Add a few extra K'NEX pieces to make the spinning motion more pronounced for larger groups of students.

Ask students the following questions and keep a record of some of their responses:

1. What affects the amount of electricity generated by the photovoltaic cell?
2. Will the model spin faster or slower if you move the light source further from the solar panel? Why?
3. What is the maximum power that this unit can develop? (Check the back of the solar panel.)

Teacher Note: This investigation explores the operation of the photocell. It is required as a first step before experimenting with the various models in the solar section of the Teacher's Guide. This activity is written with the photovoltaic cell hooked to the Solar Car but could also be done with the Crank Man or Shuttle Ride.

Explore and Explain:

Provide at least three different incandescent light bulbs of different wattages along with a 100 watt bulb, preferably from the same manufacturer. Common wattages are 100, 75, 60 and 40. Students will build the solar car model following the instructions in the Instruction Booklet. Ensure that the rear wheels of their car are supported above the table top with white rods as shown in the instructions.

1. Using a 100 watt bulb in an appropriate and safe light fixture, the students will experiment to determine how far they can move the light source from the solar panel and still keep the model moving.
2. Measuring this distance in centimeters (cm), the students will repeat the activity several times and average their results. They will record their findings in the following chart.

Trial #	Distance from the light source (cm) to the solar cell
1	
2	
3	
Average =	

3. Students will then repeat this activity with less powerful bulbs and record their findings in the following chart. Before collecting data with the other light bulbs, students will predict the outcome and explain why. You may wish to have the students share their predictions with you before they proceed. A data chart is provided for students to enter their results.
4. Students will graph these results. The horizontal line (x-axis) will be the wattage of the bulb

Light Wattage	Furthest average distance (cm) from the light source to the photocell where the model would still run
100	
75	
60	
40	

(independent variable) with the vertical line (y-axis) representing the furthest distance from the photocell the model would still run (dependent variable).

Have students analyze their results and determine a conclusion to this investigation.

- A. What do you think the results would be for a 200 watt light bulb?
- B. Would a 15 watt light bulb power the solar car?
- C. Since watts are a measure of electric energy, rewrite your conclusion in terms of energy.

Safety Caution: Students should never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

Extend:

Another variable that students can explore is the speed of the solar car's rear wheels. As a 100W light source gets closer to the panel, the car's wheels start to spin faster and faster. As an extension activity, students can design an experiment to verify these results. Exactly how fast are the rear wheels spinning at given distances from the light source? Students should determine the speed of the rear wheels with the light source held at four different distances from the light source. The data can be placed in a data table of the students' design and the data can be graphed for analysis.

Students may repeat the experiment above with 75, 60, and/or 40 watt light bulbs and compare that data with the results from the 100 watt bulb.

Evaluation:

The following extensions can serve as a performance assessments. Review your state and national standards to create a suitable rubric for each of the challenges. The rubric should contain elements of experimental design, limiting variables, error, and problem solving.

Possible Extensions: To help students better understand the photocell and how it works, these extension questions will guide students as they develop a procedure, collect data, and interpret that data to form a conclusion.

1. Do clear bulbs work better than frosted bulbs in providing energy to the car?
2. Do incandescent bulbs and fluorescent bulbs have the same affect on a photocell?
3. Does the angle the photocell makes with the light effect the energy available?
4. Does the light coming through a red (green, yellow or blue) piece of cellophane affect the speed of the car? What would be a satisfactory control for this activity?

Investigation 2: How does the solar car work?**Engagement:**

1. How does this car work?
2. Trace the flow of energy from the sun (or light) to the motion of the car?

Produce a flow chart to demonstrate this technique and to provide an example for students. Students should provide all of the information for the flow chart.

Explore:

Ask students to examine the gears that connect the motor to the rear wheels. Have students answer the following questions as they examine the Solar Car model.

1. Which spins faster, the gear attached to the motor or the gear that turns the wheel?
2. How many times faster does the motor spin than the big yellow wheel?
3. Why is the model designed like this?
4. Why not connect the motor directly to the axle of the wheels?
5. What are advantages and/or disadvantages of the arrangement of gears on the solar car?

Explore and Explain:

Students will follow the directions on the Student Response Sheet to set up a 2 meter section of track for the solar car (the track may be longer than 2 meters if space is available). Ideally, this activity should be completed outside. (If the activity is completed inside and the car's rear wheels are off the floor, students will use ten spins of the rear wheels to represent the distance the car traveled.)

Using their stopwatches, students will run the car three times to determine an average time to start from a stop and travel 2 meters. This is the base or starting time. Students will fill in the data table below as they complete the activity.

Initial Trials	The time (sec) it takes to travel 2 meters
1	
2	
3	
Average time in seconds =	

Once students have established a base time they will change one thing (independent variable) about the experiment to determine its affect on the time to travel 2 meters. For this experiment, students have already established a control (the base time) that can be used for comparison. Students will keep all other factors constant as they run a new trial after the car or the conditions have been changed. The students can then answer the following questions.

1. Did that change improve the time?
2. Why or why not?

Teacher Note: The solar car activities and investigations allow students to explore and practice designing experiments on their own. Designing experiments and investigations is an important skill for students to master and practice. Your direction and your attempts to facilitate this process will help make your students experienced investigators and problem solvers. This is also an excellent opportunity to use and emphasize appropriate vocabulary with your students (i.e., variable, independent variable, dependent variable, constants, control, etc.).

Extend:

Have students design additional investigations to explore the impact of changing other variables. The data for this section of the investigation of the solar car can be placed in a chart like the one below.

Variable (write a simple description)	The average time (sec) it takes to travel 2 meters

Teacher Note: The students will want to make the car travel the two meter distance in the shortest amount of time possible. As they take on this challenge, they will need to manipulate the photoelectric cell, its angle and possible various features of the car itself to optimize the model's operation. As you review the group's work help them to realize that their efforts are an example of optimization at work. The two meter distance is easy to do in a classroom although longer distances are more dramatic and reduce error in measurement.

Evaluation:

Have students prepare a list of recommended steps they could take to make their solar car run at its optimum speed.

1. Brainstorm a list of steps.
2. Prioritize the list from the most important step to the least important.
3. Write and hand in their list.

Investigation 3: Can the solar car work in the dark?

Engagement:

- How can the solar car operate if there is no light source to power the solar panel?
- Can solar energy be stored for later use?
- How can we store solar power indoors?

Students may suggest that the solar panel could charge a battery when there is light available and use the battery power to operate the car when the lights are off. Have the students describe instances where they might have seen a system where solar energy is being stored. Some may mention decorative solar lights in their yards that light the sidewalk to their homes at night. Others may mention electric road signs along the highway that have solar panels or solar powered calculators that they have used. They may surmise that energy is being stored so the sign or calculator will operate in the absence of light.

As the students conclude discussions of the third question above, provide instruction relative to the capacitor that is included in the K'NEX Education Investigating Solar Energy Set.

The Capacitor:

An electric capacitor has the **capacity** to store charge. It is made from two metal plates that are separated by a thin layer of insulating material. The insulating material does not allow charges to move from one metal plate to the other. A positive charge (+) can be stored on one plate and a negative charge (-) on the other. Charging the capacitor occurs when electrons are transferred from the positive plate to the negative plate. The charging causes the first plate to take on a positive charge and the second plate to take on a negative charge. The K'NEX solar panel can be used to make such a transfer of electrons, as the negative plate fills with electrons and a voltage results between the plates. If a device that uses electrons is wired between the positive and negative plates, the electrons will flow from the negative plate through the device (i.e., a K'NEX motor) where their energy will be converted to mechanical energy. The electrons will eventually make their way to the positive plate until an equilibrium is reached. At that point, the capacitor is said to be discharged. It will remain discharged until something like the solar panel is used to recharge the system.

Unlike a rechargeable battery, the capacitor requires no chemical reaction to produce a voltage, it merely stores electric charge. Additionally, a battery will release its energy much more slowly than a capacitor. Capacitors are used in devices that need small amounts of electricity to even out their electrical supply while large items like street signs and warning signs along the highway need a longer term supply of energy that can be supplied by rechargeable batteries.

Capacitor Polarity:

The capacitor does have polarity, much like a battery. The polarity is marked on the housing of the capacitor with a (+) and (-). **It is important to match the polarity of the solar panel and the capacitor during charging. Reversing polarity when recharging can damage the capacitor.**

Do not short the terminals of the capacitor together. The terminals are recessed in the capacitor housing to reduce the chances of an accidental short.

To Charge the Capacitor:

- Plug one end of the power cord (lead) into the silver capacitor, making sure that you line up the polarity marks (+ to + and – to -). The other end of the power cord plugs into the solar panel. It will take a short time for the solar panel to charge the capacitor.
- When charged, unplug the power cord from the solar panel and plug it into the motor that is installed on your model. The capacitor should hold its charge for up to 10 or 15 minutes when it is not in use. It will provide power for over a minute as it discharges depending on which model it is operating.

Explore:

Ask students to charge the capacitor and to operate their model with the capacitor. Let the students investigate on their own and then ask them to describe what they have discovered about the capacitor.

You may wish to ask the follow questions of the students.

- Does the capacitor provide enough power to operate the model?
- How long did the model run using the capacitor?
- Is there any advantage to using the capacitor to run the car?
- Finally, can the solar car work in the dark?

Experiment:

Students will follow the instructions on the Student Response Sheets for Lesson #1 to complete an experiment with a capacitor powered car. They will answer the question: **What is the relationship between the amount of time the capacitor is charged and the distance the car travels?**

(This activity can be completed with the sun or an incandescent light source used to charge the capacitor.)

For this activity, students will design their own experiment and collect the data that they feel will best support their answer to the question. The following materials should be available to use during their experimentation.

- Meter stick or metric tape measure
- Masking tape
- Light source
- K'NEX solar car
- K'NEX capacitor
- K'NEX solar panel and power cord

Explain:

Students will explain what they have discovered and report their results in written form. They will use their data to justify their conclusions. The students should discover that the capacitor charges very quickly and that there is a limit to the amount of charge that it can hold.

Evaluate:

Have students determine, based on their data, how many times the capacitor would need to be recharged in order for their car to travel from one side of the classroom to the other. Students can test their answer after they have completed their computations.

Extend:

As students complete activities with each of the solar powered models they can explore the operation of the capacitor with these models. The experiments they run may be similar to those above or of the student's own design. Again, students must maintain the proper polarity when charging the capacitor with a motor.



Lesson 1: SOLAR CAR



Investigation 1: How does the photocell work?

1. Construct the K'NEX Solar Car using the instructions provided. Ensure that the rear wheels are supported above the table top with white rods as shown in the instructions.

Safety Caution: Never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

2. Select at least three incandescent light bulbs of different wattages and a 100 watt bulb.
3. Using a 100 watt bulb, determine how far you can move the bulb from the solar panel and still keep the model moving. Measure that distance and enter it in the chart below. Using this chart, complete two other trials and average the results.

Trial #	Distance from the light source (cm) to the solar cell
1	
2	
3	
Average =	

Repeat this activity with less powerful bulbs and complete the next chart. Before completing this task. Explain what you expect will happen.

Light Wattage	Furthest average distance (cm) from the light source to the photocell where the model would still run
100	
75	
60	
40	

4. Graph these results on a separate sheet of graph paper with the wattage of the bulb on the x-axis and the average distance on the y-axis. Complete the questions and directions below.
- What is the most obvious conclusion that you can draw from your results and graph?
 - What do you think the results would be for a 200 watt light bulb?
 - Would a 15 watt bulb provide enough energy to spin the wheels of the solar car?
 - Since watts are a measure of electrical energy, rewrite your conclusion in terms of energy.

e. What are advantages and/or disadvantages of the arrangement of gears on the solar car?

3. Move outdoors and prepare an area to operate your solar car. Use masking tape to set up a 2 meter section of the pavement where you will operate your car.

Use a stopwatch to determine how long it takes the car to travel two meters. Complete three trials and average your results. This time will be used for comparison during later activities.

Fill in the table below as you collect your data.

Initial Trials	The time (sec) it takes to travel 2 meters
1	
2	
3	
Average time in seconds =	

4. Next, carefully watch how the car works, and change one thing (this is a variable) about the car to make it run faster. Run three trials to test the car after you have made your change. Use the chart below to investigate four changes (variables), one at a time, in an effort to make the car run as fast as you can.

Variable (write a simple description)	The average time (sec) it takes to travel 2 meters

a. Did the change(s) you made to the car improve the time(s)?

b. Why or why not?

5. Based on your data and experimentation, recommend one or more other changes that would increase the speed of the solar car.

Investigation 3: What is the relationship between the amount of time the capacitor is charged and the distance the car travels?

Design an experiment to answer the question above. Read and follow the directions below specific to the correct use of the capacitor with the solar panel as you experiment.

Capacitor Polarity:

The capacitor does have polarity, much like a battery. The polarity is marked on the housing of the capacitor and the solar panel with a large (+) and (-). **It is important to match the polarity of the solar panel and the capacitor during charging.** Reversing polarity when recharging can damage the capacitor.

Do not short the terminals of the capacitor together. The terminals are recessed in the capacitor housing to reduce the chances of an accidental short.

To Charge the Capacitor:

- Plug one end of the power cord (lead) into the silver capacitor, and the other end of the power cord plug into the solar panel, making sure that you line up the polarity marks (+ to + and - to -). It will take a short time for the solar panel to charge the capacitor.
- When charged, unplug the power cord from the solar panel and plug it into the motor that is installed on your model. The capacitor should hold its charge for up to 10 or 15 minutes when it is not in use. It will provide power to operate your model.

Your Experiment:

Describe an experimental procedure that will enable you to answer the question above. You must discharge the capacitor between each trial (run the model until it no longer moves). Your first trial will provide a 10 second charging time. Each successive trial will extend the charging time by 10 additional seconds.



Lesson 1: SOLAR CAR



Investigation 1: How does the photocell work?

1. Construct the K'NEX Solar Car following the instructions provided. Ensure that the rear wheels are supported above the table top with white rods as shown in the instructions.

Safety Caution: Never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

2. Select at least three incandescent light bulbs of different wattages and a 100 watt bulb.
3. Using a 100 watt bulb, determine how far you can move the bulb from the solar panel and still keep the model moving. Measure that distance and enter it in the chart below. Using this chart, complete two other trials and average the results.

(This is sample data. Student data will vary from these numbers.)

Trial #	Distance from the light source (cm) to the photocell
1	55 cm
2	48 cm
3	46 cm
Average =	49.7 cm

Repeat this activity with less powerful bulbs and complete the next chart. Before completing this task. Explain what you expect will happen.

State your hypothesis: The lower the wattage of the bulb, the closer the bulb must be to the model. A bulb with low wattage gives off less light.

(This is sample data. Student data will vary from these numbers.)

Light Wattage	Furthest average distance (cm) from the light source to the photocell where the model would still run.
100	<i>48 cm</i>
75	<i>40 cm</i>
60	<i>36 cm</i>
40	<i>20 cm</i>

4. Graph these results on a separate sheet of graph paper with the wattage of the bulb on the x-axis and the average distance on the y-axis. Complete the questions and directions below.

a. What is the most obvious conclusion that you can draw from your results and graph?

(The students should have produced a bar graph that shows taller bars for bulbs with higher wattage. The higher the wattage of the bulb, the further the bulb could be placed from the solar panel and still operate the model.)

b. What do you think the results would be for a 200 watt light bulb?

(If the students extrapolate the graph they may arrive at a value near 80 cm. They should at least indicate that the distance would be more than the value for a 100 watt bulb.)

c. Would a 15 watt bulb provide enough energy to spin the wheels of the solar car?

(Students data should indicate the answer is No.)

d. Since watts are a measure of electrical energy, rewrite your conclusion in terms of energy.

(The more energy a bulb produces, the further the bulb can be placed from the solar panel and still operate the model.)

Investigation 2: How does the solar car work?

1. Observe the car, its gears and wheels as it operates.

a. How does this car work?

(The students should indicate something to the effect that the solar panel provides power that spins the motor which turns the gears that eventually turns the large yellow gear.)

b. Trace the flow of energy from the sun (or light) to the motion of the car?

(Light energy > solar cell > electrical energy [through wire] > motor > mechanical energy spins [rotational motion] the blue gear > blue gear drives [mechanical energy] the rest of the gear train > yellow gear moves [mechanical energy] the car forward [linear motion].)

2. Examine the gears that connect the motor to the wheels.

a. Which spins faster, the gear on the motor or the gear that turns the wheel?

(The gear on the motor spins faster because the gear train is gearing down the system.)

b. How many times faster does the motor spin than the big yellow wheel?

(Based on the gear ratios, the motor spins about 14.4 times faster.)

c. Why is the model designed like this?

(The model is geared down to provide more power to the wheels.)

d. Why not connect the motor directly to the axle of the wheels?

(The motor does not produce enough energy to turn the yellow gears on the solar car. The motor must use a gear train to multiply the force that the motor is able to deliver.)

- e. What are advantages and/or disadvantages of the arrangement of gears on the solar car?

(The arrangement of the gears on the solar car multiplies the force that is available to move the wheels. By itself, the motor is unable to produce enough force to move the car. In exchange for force, the system gives up distance or in this case speed. The wheels spin at a much slower speed than the motor.)

3. Move outdoors and prepare an area to operate your solar car. Use masking tape to set up a 2 meter section of the pavement where you will operate your car.

Use a stopwatch to determine how long it takes the car to travel two meters. Complete three trials and average your results. This time will be used for comparison during later activities.

Use the table below as you collect your data.

Initial Trials	The time (sec) it takes to travel 2 meters
1	<i>Answers will vary.</i>
2	<i>Answers will vary.</i>
3	<i>Answers will vary.</i>
Average time in seconds =	<i>Answers will vary.</i>

4. Next, carefully watch how the car works, and change one thing (this is a variable) about the car to make it run faster. Run three trials to test the car after you have made your change. Use the chart below to investigate four changes (variables), one at a time, in an effort to make the car run as fast as you can.

Variable (write a simple description)	The average time (sec) it takes to travel 2 meters
<i>Variables will differ.</i>	<i>Answers will vary.</i>
<i>Variables will differ.</i>	<i>Answers will vary.</i>
<i>Variables will differ.</i>	<i>Answers will vary.</i>
<i>Variables will differ.</i>	<i>Answers will vary.</i>

a. Did the change(s) you made to the car improve the time(s)?

(Student answers will vary based on their success.)

b. Why or why not?

(Student answers will vary. Ensure that the reasons that they offer are credible based on the evidence that they provided.)

5. Based on your data and experimentation, recommend one or more other changes that would increase the speed of the solar car.

(Students may suggest that reducing the mass of the car, changing the size of the front wheels, adjusting the angle of the solar panel, etc. will increase the speed of the solar car.)

Investigation 3: What is the relationship between the amount of time the capacitor is charged and the distance the car travels?

Design an experiment to answer the question above. Read and follow the directions below specific to the correct use of the capacitor with the solar panel as you experiment.

Capacitor Polarity:

The capacitor does have polarity, much like a battery. The polarity is marked on the housing of the capacitor and the solar panel with a large (+) and (-). **It is important to match the polarity of the solar panel and the capacitor during charging.** Reversing polarity when recharging can damage the capacitor.

Do not short the terminals of the capacitor together. The terminals are recessed in the capacitor housing to reduce the chances of an accidental short.

To Charge the Capacitor:

- Plug one end of the power cord (lead) into the silver capacitor, and the other end of the power cord plug into the solar panel, making sure that you line up the polarity marks (+ to + and - to -). It will take a short time for the solar panel to charge the capacitor.
- When charged, unplug the power cord from the solar panel and plug it into the motor that is installed on your model. The capacitor should hold its charge for up to 10 or 15 minutes when it is not in use. It will provide power to operate your model.

Your Experiment:

Describe an experimental procedure that will enable you to answer the question above. You must discharge the capacitor between each trial (run the model until it no longer moves). Your first trial will provide a 10 second charging time. Each successive trial will extend the charging time by 10 additional seconds.

(The student designed experiments should include the following:

- A 'Fair Test'
- The same surface for each test
- A data collection strategy, etc.)

Place a table below that shows the data that you collected during your experiment.

Trial Number	Length of Charge Time in Seconds	Distance Traveled in Meters
1	10	0.7
2	20	1.6
3	30	2
4	40	2.5
5	50	3.1
6	60	3.6
7	70	3.6
8	80	3.7
9	90	3.6

(This sample data may not match student results.)

1. What did you discover? Provide evidence to support your findings.

(The longer the capacitor is charged, the further the car will travel to a point. Eventually, the capacitor seems to have reached the maximum amount of charge that it can hold.)

2. Calculate how many times the capacitor would need to be recharged in order for the car to travel from one side of the room to the other. Show your calculations below.

(Based on my data, the car can travel across the room on a total of three recharges.)

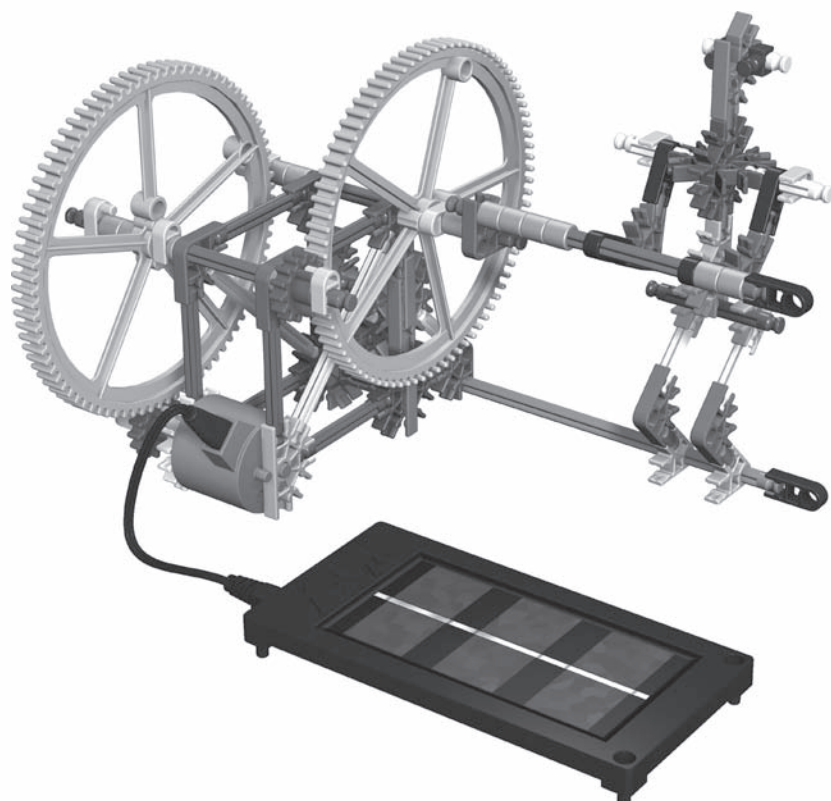
Distance across the room = 8.5 meters

Distance car can travel on one recharge = 3.6 meters

8.5 meters divided by 3.6 meters gives an answer over 2 which would mean three recharges would be required.)



Solar Power - Lesson 2: CRANK MAN



Time Frame:

2 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Observe and explore the moving parts of a simple machine.
- Make numerical comparisons of machines and systems in written and in ratio form.
- Evaluate a machine and describe it as a geared down machine (for power) or a geared up machine (for speed).

Materials:

- The K'NEX Education Investigating Solar Energy Set.
- Masking or blue painting tape
- Metric ruler
- Graph paper
- Light sources for inside use (a utility light or desk lamp and a collection of various watt light bulbs (100, 75, 60, 40, 25, or 15) will work very well for the solar car activities. Ensure that the light source is rated for the various wattages used during experimentation.)
- Sunlight for outdoor use
- Calculator
- Timer or stopwatch

Engagement:

Provide several simple machines for students to observe. Demonstrate the operation of each. Ask the following questions of students to gather their ideas and to determine the extent of their simple machine vocabulary knowledge.

1. How do simple machines make work easier?
2. Do simple machines really save us work?

Explore and Explain:

Students will connect a solar cell to the motor on the Crank Man and shine a light on the solar cell. As they observe the model in operation they will trace the flow of energy in this model starting with the light source. This will be in the form of a flow chart of the students' own design.

As the students move the light closer and further away from the solar cell, they will gather useful information that will allow them to complete the following.

Safety Caution: Students should never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

1. Describe how the speed of the Crank Man changes?
2. What is the relationship between the light's distance from the solar panel and the speed of the model?
3. How far from the solar cell can a 100 watt bulb be placed and still provide enough energy to turn the crank?

Trial #	The distance (cm) from light source to the photocell.
1	
2	
3	
Average distance (cm) =	

Elaborate:

Have students count the number of rotations made by the Crank Man when the light source is held at different distances from the solar cell. The students will take on the responsibility to determine the various distances at which to gather data. Students will then make a chart that shows the relationship between light distance and cranking speed. As students analyze their results and report their findings they should use the term light energy in their conclusion.

The distance (cm) from light source to the photocell.	Number of cranks in 15 sec.

1. Students will graph this relationship.

Students will examine the Crank Man model and draw a conclusion based on their knowledge of the model and simple machine technology.

2. If the Crank Man were really turning the crank, how could we make his job easier? (There are several possible answers to this question.) Draw a picture or write your response.
3. If the Crank Man were really turning the machine, what would be the output of the machine?

Math Extensions:

1. Students can compare the yellow and blue gears on this model and find the ratio of the number of teeth on each. This value is an acceptable way to determine the gear ratio of the gears. The blue gear has _____ teeth and the yellow gear has _____. The ratio of the gear teeth on the large gear/gear teeth on the small gear is _____.

Teacher Note: Suggest that students place a small mark on each gear with a marker or small brightly colored piece of tape for reference.

2. If students examine this machine from the motor to the Crank Man, they should be able to determine if it is geared up for speed or geared down for power? They can then outline their evidence and reasoning.

Evaluate:

3. Ask students to meet this challenge: If the Crank Man turns the lever arm one complete rotation, how many times does the motor turn?

Extension Activities:

1. Earlier students found the number of teeth on the Crank Man's gears and expressed this as a ratio.
 - a. Is the ratio of the diameters of the yellow gear and the blue gear the same as the value computed for the gear ratio? Have students complete the following to find out for themselves.
 - Using a metric ruler measure the diameter of each gear in millimeters. Should you measure to the outer edge or just to the middle of the gears? Why?
 - What is the ratio of the diameters?

- How does the ratio of diameters compare to the ratio of the number of gear teeth?
 - What do you think the ratio of circumferences between the blue and yellow gear would be?
2. These ratios represent the Ideal Mechanical Advantage (IMA) of a simple machine. The Crank Man has three simple machines: two sets of yellow and blue gears and a lever arm attached to the yellow gear that holds the Crank Man. For the purposes of this extension activity, the students should consider only the sets of blue and yellow gears.

Have students complete the following:

- Moving from the motor toward the Crank Man, what is the ratio of the number of teeth on the first set of one blue and one yellow gear?
 - What is the ratio of the number of teeth on the second set of one blue and one yellow gear?
 - Now you have two numbers that each describes the IMA of one of the blue/yellow gear trains. How do you determine the IMA of the two gear trains working together? Did you multiply, divide, add, or subtract the two IMAs to determine the total IMA of the gear systems? (Multiply.)
 - Explain your reasoning.
3. The model can be investigated with a delicate Newton spring scale. A rubber band scale with a paper backing can be easily calibrated and used to investigate the force needed to move different components of the Crank Man. A #16 rubber band is satisfactory to collect several measurements on this model.
4. Compare this model to the simple machines on a bicycle – gears, wheels, pedals, hand brakes, brake levers, quick release posts, etc.

4. How far from the solar cell can a 100 watt bulb be placed and still provide enough energy to turn the crank?

Trial #	Distance from the light source (cm) to the solar cell
1	
2	
3	
Average =	

5. Begin with the solar panel 20 cm from the light source and move the light further from the solar panel in five centimeter intervals. Count the number of rotations the Crank Man makes in 15 seconds at each interval. Fill in the chart below to show the relationship of light distance and cranking speed

The distance (cm) from light source to the photocell.	Number of cranks in 15 sec.

- Graph this relationship on a separate sheet of graph paper.
 - Describe the relationship and use the term light energy in your response.
6. Examine the Crank Man model. If the Crank Man were really turning the crank, how could we make his job easier? (There are several possible answers to this question.) Draw a picture and/or write your response. If the Crank Man were really turning the machine, what would be the output of the machine?
7. Can you think of a practical use of this type of cranking machine other than turning the K'NEX figure?

Math Extensions:

1. Compare the yellow and blue gears on this model and find the ratio of the number of teeth on each. This value is an acceptable way to determine the gear ratio of the gears. The blue gear has _____ teeth and the yellow gear has _____.

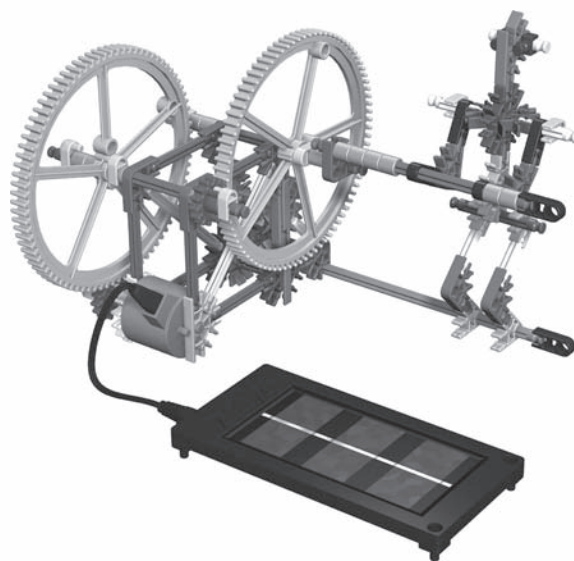
Ratio of Teeth = Gear Ratio: _____

2. If you examine this machine from the motor to the Crank Man, is it geared up for speed or geared down for power?

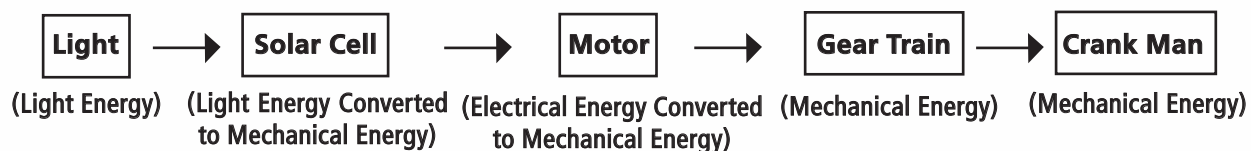
3. What is your evidence and reasoning?



Lesson 2: CRANK MAN



1. Construct the K'NEX Crank Man using the building instructions provided.
2. Attach a solar cell to the motor and shine a light on the panel. (If the model turns backwards, reverse the plug in the motor.) Trace the flow of energy in this model by making a flow chart starting with the light source.



(The light source produces light energy— the solar cell [converts light to electricity] – the motor converts electrical energy to mechanical energy – the Crank Man moves in response to the mechanical energy provided by the gear train.)

Safety Caution: Never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

3. Move the light closer and further away from the solar panel. Describe how the speed of the Crank Man changes? What is the relationship between the distance between the light and solar cell and the speed of the Crank Man?

(The speed increases as the light nears the solar panel and decreases as the light is moved away from the solar panel. As the light gets closer to the solar cell, the crank man rotates faster.)

4. How far from the solar cell can a 100 watt bulb be placed and still provide enough energy to turn the crank?

Trial #	Distance from the light source (cm) to the solar cell
1	<i>Answers will vary.</i>
2	<i>Answers will vary.</i>
3	<i>Answers will vary.</i>
Average =	<i>Answers will vary.</i>

5. Begin with the solar panel 20 cm from the light source and move the light further from the solar panel in five centimeter intervals. Count the number of rotations the Crank Man makes in 15 seconds at each interval. Fill in the chart below to show the relationship of light distance and cranking speed

The distance (cm) from light source to the photocell.	Number of cranks in 15 sec.
20	16
25	13
30	10
35	7

Graph this relationship on a separate sheet of graph paper.

Describe the relationship and use the term light energy in your response.

(As the light source is moved further from the solar panel there is less light energy available to turn into electricity.)

6. Examine the Crank Man model. If the Crank Man were really turning the crank, how could we make his job easier? (There are several possible answers to this question.) Draw a picture and/or write your response. If the Crank Man were really turning the machine, what would be the output of the machine?

(Reduce the gear ratio between the blue and yellow gears by using other gears. Lengthen the lever arm that connects to the rod that the crank man is turning.)

(If the Crank Man were really turning the machine, the motor would be turned backwards. Students will learn later that this will make the motor act as a generator.)

7. Can you think of a practical use of this type of cranking machine other than turning the K'NEX figure?

(Answers will vary! Reward originality and answers that have a strong basis in good science.)

Math Extensions:

1. Compare the yellow and blue gears on this model and find the ratio of the number of teeth on each. This value is an acceptable way to determine the gear ratio of the gears. The blue gear has 14 teeth and the yellow gear has 84.

Ratio of Teeth = Gear Ratio: 6:1 or 6 to 1

2. If you examine this machine from the motor to the Crank Man, is it geared up for speed or geared down for power?

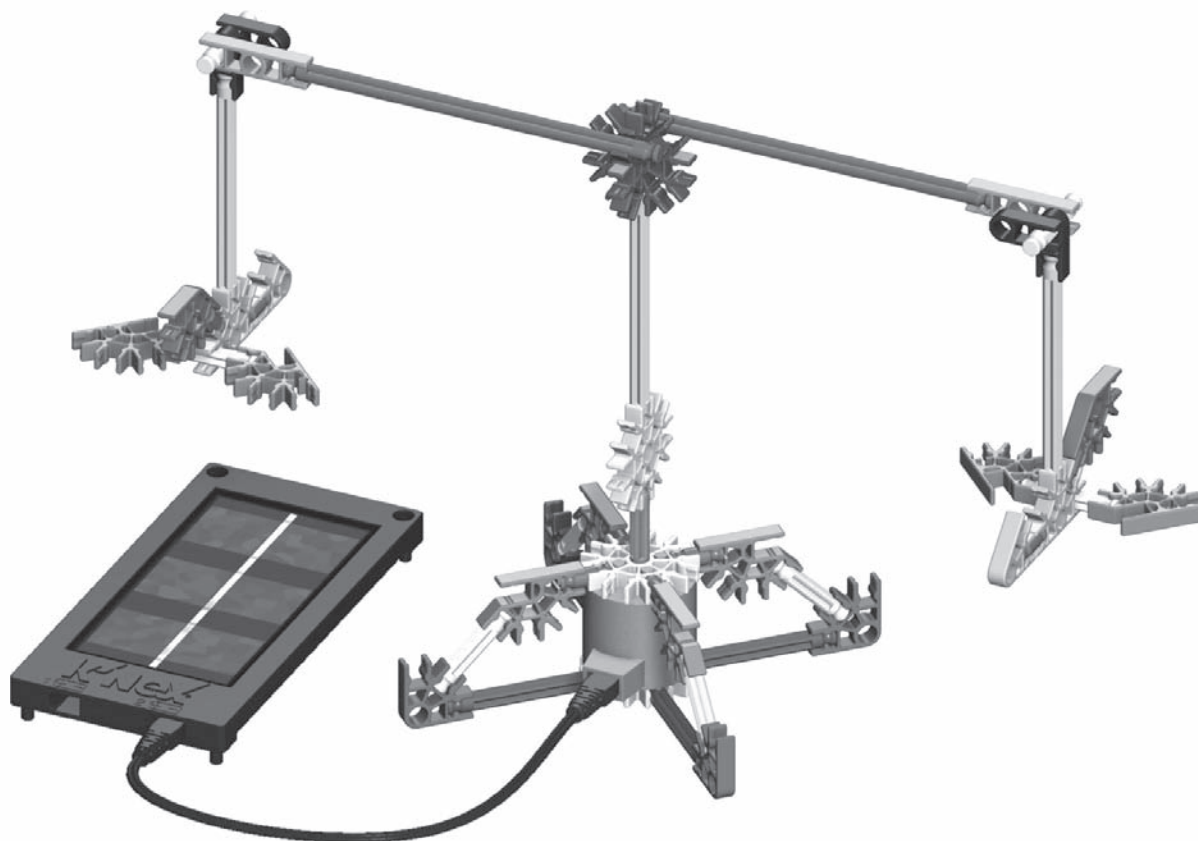
(It is geared down for power.)

3. What is your evidence and reasoning?

(When a small gear drives a large gear the system is geared down. In the Crank Man, there are two pairs of gears and in each case the small gear is driving the large gear. Therefore, the system is geared down.)



Solar Power - Lesson 3: SHUTTLE RIDE



Time Frame:

2 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Describe variables that affect the spinning of the Shuttle Ride.
- Compare light intensity with the speed of the Shuttle Ride

Materials:

- The K'NEX Education Investigating Solar Energy Set
- Photovoltaic cell
- Light source
- Metric ruler
- Stopwatch

Investigation 1:

Engagement:

Ask students to respond to the following questions. Keep a record of responses.

1. What makes Carousels, Swing Rides, or Merry-Go-Rounds fun to ride?
2. How is riding on the inside of the ride a different feeling than on the outside of the ride?

Explore and Explain:

Students will:

1. Use the Instructions Booklet and construct the Shuttle Ride model.
2. Examine how this model is constructed before attaching it to the solar panel.
 - Where does the energy come from to make it turn?
 - How many turns of the motor will be needed to turn the model once?
3. Connect the model to a solar cell.
 - How fast can you make it spin when the light source is 20 cm from the solar panel? (Count the number of turns in 20 seconds.)
 - Test the speed of the model with the light at different distances from the solar panel. Where was the light when the Shuttle Ride was going fast? Going slowly?
4. What is the furthest distance the light can be held from the solar panel and still operate the Shuttle Ride?
5. Move the light at five centimeter intervals from the solar panel and see how the number of rotations changes. Complete the chart below to show the relationship between the distance from the light source to the solar panel and the speed of the ride.

(A sample data chart is provided as an example)

Distance in cm	Rotations in 20 Seconds
20	11
25	9
30	7
35	5

6. Describe the relationship between the distance the light is held from the solar cell and the number of spins the Shuttle Ride makes by completing the following sentence:

As the light is moved closer to the solar cell _____
_____.

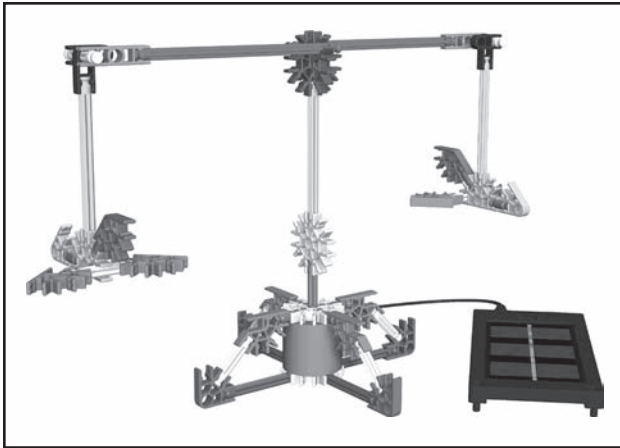
7. Place the light 20 cm from the solar cell and measure the speed of the ride. Figure out a way of blocking some of the light that hits the solar cell. How much of the solar cell (express this as a fraction) needs light at this 20 cm distance to operate the Shuttle Ride?

Investigation 2:

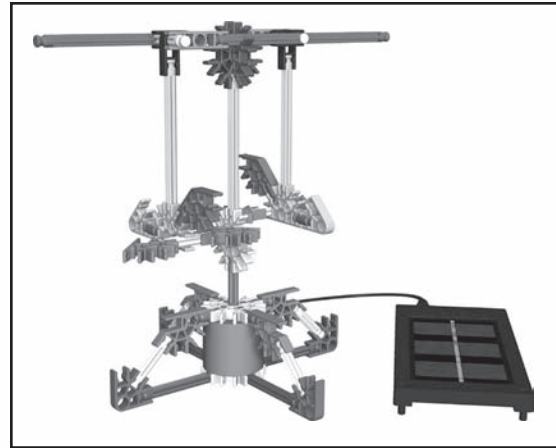
Students will complete an experiment to determine the effect of the diameter of the Shuttle Ride on the speed that it turns. This circular rate of motion [angular velocity] is expressed in RPMs or revolutions per minute. If your students are not familiar with revolutions per minute, this would be an excellent time to introduce this unit of measure.

Explore:

1. Challenge students to design an experiment to determine if the shuttle cars on the Shuttle Ride spin faster when they are close to the center post or when they are further from the center post. Show them how the shuttle cars can be moved to different distances from the center post of the ride. Students should collect data at four distances from the center post as part of their experiment.



About 14 cm from the center post



About 4 cm from the center post

Teacher Note: The photos above demonstrate how the red rods can be slid along the blue connector to lengthen or shorten the diameter that separates the shuttle cars. Given the picture and the question above, many students can generate their own procedure to find an answer to the challenge. It is important that students be given this opportunity to design and problem solve on their own.

This text represents a possible procedure if the students require a more structured approach to this exercise.

1. It is important that the same amount of energy be available to the motor for this experiment. Therefore, the light source and distance from the photocell needs to remain constant.

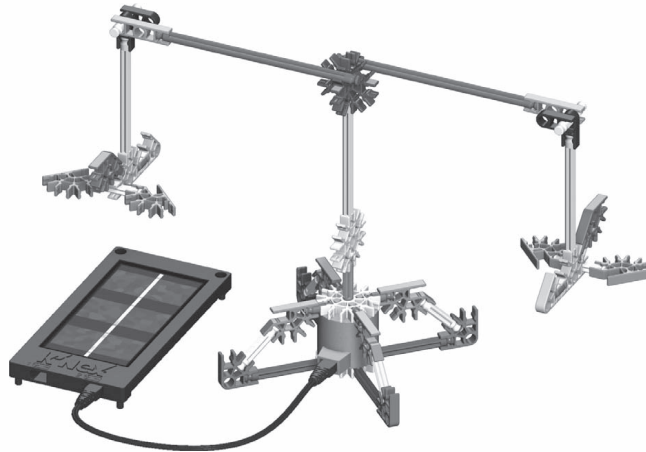
2. The following data table allows the students to collect readings for the different car distances from the center post of the Shuttle Ride. These results create quantitative data for this activity that describes the angular velocity (rpm) of the shuttle cars (Procedure note: The ride needs to spin at a rate that students can count easily and accurately. The students can find this speed by moving the photocell closer or further from the light. Attach brightly colored tape or a ribbon to one of the shuttle cars to help the students as they count turns of the ride.

Distance front center post (cm)	Velocity (turns in 20 seconds)	x 3 for RPM
4		
6		
8		
10		
12		
14		

3. Students can graph this data with the diameter of the ride (the independent variable) on the x-axis and the speed (the dependent variable) on the y-axis.
4. Explain what the graph and data show. What does the data and graph tell us about the relationship between the diameter of the Shuttle Ride and the speed at which it turns?
5. What does this relationship mean in terms of light energy from the light source or sun?
6. Relate this activity to levers and use words like force, motion, momentum to describe why you got these results. (Some research may be required to define these terms.)
7. Ask students what else can be changed on the Shuttle Ride in order to make it spin faster. (Examples: lighter cars, heavier cars, increase wind resistance of cars, less or more electricity from the solar collector.) Challenge the students to identify something they would like to change on the model (variable) and to develop a procedure to test their idea. After students have your approval, instruct them to collect the data and observations. They can then finish their experiment by organizing and analyzing the data. They should state a conclusion that is consistent with the data. This evaluation requires students be able to model scientific methods as they investigate a variable. This challenge should be done as independent of the teacher as possible.



Lesson 3: SHUTTLE RIDE



Investigation 1:

1. Construct the K'NEX Shuttle Ride using the building instructions provided.
 2. Examine how this model is constructed before attaching it to the solar panel.
 - Where will the energy come from to make it turn? Trace the flow of energy through this model by making a flow chart starting with the light source.
-
- How many turns of the motor will be needed to turn the Shuttle Ride once?

Safety Caution: Never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

3. Connect the model to a solar cell and select a light source to use with this activity.
- How fast can you make it spin when the light source is 20 cm from the solar panel? (Count the turns in 20 seconds as your measurement.)

Trial #	Turns in 20 seconds
1	
2	
3	
Average =	

- Test the speed of the model with the light at different distances from the solar panel. Where was the light when the Shuttle Ride was going fast? Going slowly? Describe the set up that gave the fastest speed of rotation.
4. What is the furthest distance the light can be held from the solar panel and still have the ride rotate?
5. Move the light at five centimeter intervals from the solar panel and see how the speed of the Shuttle Ride changes. Complete the chart below to show the relationship between the distance from the light source to the solar panel and the speed of the ride.

Distance from light to solar cell in cm	Spins in 20 seconds
20	
25	
30	
35	
40	

6. Describe the relationship between the distance the light is held from the solar cell and the number of spins the Shuttle Ride makes by completing the following sentence:

As the light is moved closer to the solar cell, _____
_____.

7. Place the light 20 cm from the solar cell and count how many times the model spins in 20 seconds.

Figure out a way of blocking some of the light that hits the solar cell. Describe a procedure that you will use to block some of the light.

8. How much of the solar cell (express this as a fraction) needs light at this 20 cm distance to turn the Shuttle Ride? Does the ride spin as fast as it did before you blocked some of the light?

Investigation 2:

In this investigation you will be challenged to design an experiment to determine if the shuttle cars on the Shuttle Ride spin faster when they are close to the center post of the ride or when they are further from the center post. (The rate that the model spins is measured in a unit of measure called RPM or revolutions per minute.) NOTE: You may have noticed during construction of the shuttle ride that the red rods can slide through the blue connector. By moving the red rods you can change the diameter of the model and move the shuttle cars further from the center post of the ride.

Challenge:

Design an experiment to determine if the shuttle cars on the Shuttle Ride spin faster when they are close to the center post or when they are further from the center post.

Write your procedure below:

What is the variable that you are studying in this experiment?

A data table is presented below.

Distance front center post (cm)	Velocity (turns in 20 seconds)	x 3 for RPM
4		
6		
8		
10		
12		
14		

Remember to collect enough data so that you have confidence in your values!

On a separate sheet of graph paper, make a graph that shows the relationship between these two variables.

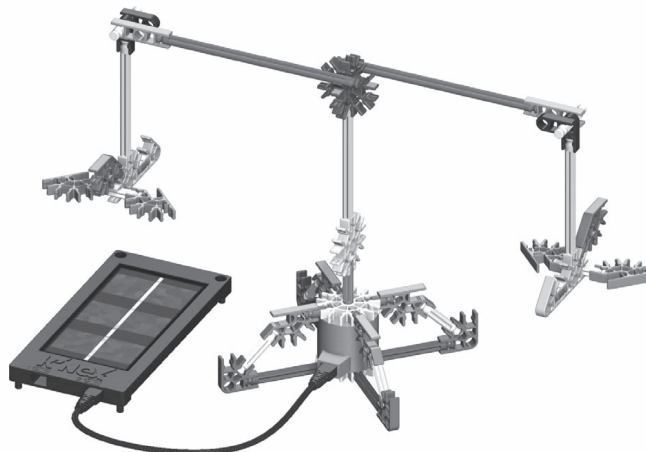
Explain what your data shows:

Enrichment Question:

What else can be changed on the Shuttle Ride to make it spin faster? Test your ideas before writing them below.



Lesson 3: SHUTTLE RIDE



Investigation 1:

1. Construct the K'NEX Shuttle Ride using the building instructions provided.
2. Examine how this model is constructed before attaching it to the solar panel.
 - Where will the energy come from to make it turn? Trace the flow of energy through this model by making a flow chart starting with the light source.



(The light produces light energy – solar cell (converts light energy to electrical energy) – electricity travels through the wire to the motor – the motor converts electrical energy to a form of mechanical kinetic energy.)

- How many turns of the motor will be needed to turn the Shuttle Ride once?

(One time. This is a direct drive system.)

Safety Caution: Never place the photoelectric cell closer than the length of one K'NEX gray rod (7.5 inches) from the light source at any time.

3. Connect the model to a solar cell and select a light source to use with this activity.
- How fast can you make it spin when the light source is 20 cm from the solar panel? (Count the turns in 20 seconds as your measurement.)

Trial #	Turns in 20 seconds
1	<i>Answers will vary.</i>
2	<i>Answers will vary.</i>
3	<i>Answers will vary.</i>
Average =	<i>Answers will vary.</i>

- Test the speed of the model with the light at different distances from the solar panel. Where was the light when the Shuttle Ride was going fast? Going slowly? Describe the set up that gave the fastest speed of rotation.

(The light was close to the solar panel. The light was further from the solar panel. The closer the light is to the solar panel the faster the Shuttle Ride spins.)

4. What is the furthest distance the light can be held from the solar panel and still have the ride rotate?

(Answers will vary.)

5. Move the light at five centimeter intervals from the solar panel and see how the speed of the Shuttle Ride changes. Complete the chart below to show the relationship between the distance from the light source to the solar panel and the speed of the ride.

(A sample data chart is provided)

Distance from light to solar cell in cm	Spins in 20 seconds
20	29
25	26
30	23
35	18
40	14

6. Describe the relationship between the distance the light is held from the solar cell and the number of spins the Shuttle Ride makes by completing the following sentence:

As the light is moved closer to the solar cell, _____ **(the shuttle ride spins faster)** _____

7. Place the light 20 cm from the solar cell and count how many times the model spins in 20 seconds.

(Answers will vary based on the wattage of the light bulb.)

Figure out a way of blocking some of the light that hits the solar cell. Describe a procedure that you will use to block some of the light.

(Some students will use their hand; however, by using heavy paper or cardboard is a better choice since they can measure the amount of light blocked more accurately.)

8. How much of the solar cell (express this as a fraction) needs light at this 20 cm distance to turn the Shuttle Ride? Does the ride spin as fast as it did before you blocked some of the light?

(Answers will vary. The solar cell is rectangular and students may block one of the three sections they see on the panel. In testing this, the shuttle stopped. HOWEVER, when a third of each solar cell was blocked the shuttle ran. There is more power available when light hits a third of each of the three panels rather two complete sections of the panel.)

Investigation 2:

In this investigation you will be challenged to design an experiment to determine if the shuttle cars on the Shuttle Ride spin faster when they are close to the center post of the ride or when they are further from the center post. (The rate that the model spins is measured in a unit of measure called RPM or revolutions per minute.) NOTE: You may have noticed during construction of the shuttle ride that the red rods can slide through the blue connector. By moving the red rods you can change the diameter of the model and move the shuttle cars further from the center post of the ride.

Challenge:

Design an experiment to determine if the shuttle cars on the Shuttle Ride spin faster when they are close to the center post or when they are further from the center post.

Write your procedure below:

(Students should include: a way of measuring the distance to the center post, a way to counting the spins, experimental factors they will keep constant [wattage of the bulb, distance from the bulb to the solar panel, etc.], and the number of trials they will complete)

What is the variable that you are studying in this experiment?

(The variable is the distance of shuttle cars from the center post of the shuttle ride at rest.)

A data table is presented below.

(Student data may vary from this data.)

Distance front center post (cm)	Velocity (turns in 20 seconds)	x 3 for RPM
4	26	78
6	23	69
8	20	60
10	18	54
12	14	42
14	11	33

Remember to collect enough data so that you have confidence in your values!

On a separate sheet of graph paper, make a graph that shows the relationship between these two variables.

(The Independent variable should have been placed on the horizontal axis of this line graph.)

Explain what your data shows:

(The greater the distance from the center post, the slower the Shuttle Ride spins. The graph showed that the change in the above data is linear.)

Enrichment Question:

What else can be changed on the Shuttle Ride to make it spin faster? Test your ideas before writing them below.

(Answers will vary. The mass of the shuttle cars is one place to start. The length of the rod suspending the cars is another possible variable.)

(This is an excellent opportunity for students to design another investigation on their own.)



Glossary of Terms

Abscissa: The horizontal lines of a graph. Sometimes referred to as the X values.

Active Energy Collector: To be an active energy collector, there need to be machines and equipment which increase the amount of energy that can be collected. For example, liquid heated by solar energy can be pumped to rooms where the heat is needed.

Cell: Used in conjunction with electricity, a cell is a single electrical producing device. Household flashlights commonly have two cells in them. When many cells are hooked together to generate more electrical power they are called a battery. For example, our cars use a 12 volt battery that contains many cells.

Centrifugal Force: This force pulls rotating bodies away from the middle of the spin. e.g. The moon's inertia in moving around the earth creates a centrifugal force.

Centripetal Force: This force pulls rotating bodies toward the middle of the spin. e.g. Gravity is a centripetal force that holds the moon to the earth.

Constant: In an experiment, factors which do not change or are kept the same by the researcher are constants.

Dependent Variable: The dependent variable changes in response to the variable that is being changed by the researcher. The dependent variable depends on the manipulated variable.

Efficiency: A measure of the amount of energy that a machine can produce (Output) compared to the amount of energy that goes in (Input). Usually expressed as a per cent and it can never be more that 100%.

Energy: Energy is the capacity to do work. Energy is usually divided into two types, potential and kinetic. In the metric system, energy is measured in watts which represents 1 joule of work done each second.

Force: Any kind of push or pull applied to an object. $F = m \times a$. In the metric system mass (m) is in kilograms, acceleration (a) is 9.8 meters/sec² and force (F) is in Newtons. Weight is one example of a force.

Gearred Down: Gear driven machines designed for power are geared down. Their mechanical advantage is larger than one. Force is increased by the gear train, but distance is decreased.

Gearred Up: Gear driven machines designed for speed are geared up. Their mechanical advantage is less than one. Distance is increased by the gear train, but force is decreased.

Ideal Mechanical Advantage (IMA): IMA is usually performed mathematically by comparing the force coming out of a machine (output) with the force going into a machine (input). (Refer to geared up and geared down.) This is a theoretical number that does not consider the mass of the machine or frictional losses.

Independent Variable: This variable is manipulated or changed on purpose by the researcher during an experiment.

Inertia: A property of matter that resists being moved. A rock has more inertia than a pebble. It requires a greater force to move the rock than it does to move the pebble.

Kinetic Energy: Energy of an object because of its motion. An object that is moving faster than a similar sized object has more kinetic energy.

Machine: A device we use to extend our reach, multiply force, or change the distance that the force moves. Simple machines include levers, pulleys, wheel and axles, screws, wedges, and inclined planes.

Momentum: Think of this as mass in motion. The faster an object moves, the more momentum it has. The heavier an object is, the more momentum it has.

Optimize: When used in engineering, this term means to regulate the various variables in a machine, industrial process, or a system such that it operates in the best manner for which it was designed. Most optimized systems are also the most efficient.

Ordinate: The vertical lines of a graph. Sometimes referred to as the Y values.

Passive Energy Collector: Passive energy collectors do not use external machines and equipment to collect the energy. For example, dark-colored tiles in a porch with floor to ceiling windows. The tiles absorb energy from the sun and become warm. The warmth is passed to the air on the porch helping to heat the room.

Photoelectric Cell: An electric generating device that uses light (photo) energy to generate the electricity. Also called a solar cell or a photovoltaic cell.

Potential Energy: Energy as a result of position. Objects that are above other objects have more potential energy.

Power: Is the rate at which work is being done. In the English system, power is measured in horsepower which is 746 watts or 550 foot lb/sec.

Protractor: A drafting tool that measures degrees.

Glossary of Terms

Right Angle: An angle of 90° .

Solar Energy: Energy that is produced from the sun's light or the sun's heat.

Variable: In an experiment, the parts that can be changed that might affect the experiment's results are called variables.

Watt: The unit of power equivalent to the amount of work in Joules done in a second.

Work: Applying a force through a distance is work. The formula for calculating work is $W = F \times d$. In the metric system Force is measured in Newtons and distance (d) is in meters. Work (W) is in Joules.