K'NEX® Education™

TEACHER'S GUIDE

RENEWABLE ENERGY™

Hydroelectric Generator
Générateur Hydro-électrique
Generador Hidroeléctrico

Solar Powered Crank Man
Homme Détraqué Actionné Solaire
Hombre Inestable Accionado Solar

Wind Powered Water Lift
Ascenseur Actionné par le Vent de l'eau
Elevación Eólica del Agua

78976

RENEWABLE ENERGY™
Teacher's Guide

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⚠ **WARNING:** CHOKING HAZARD - Small parts. Not for children under 3 years.

⚠ **ADVERTENCIA:** PELIGRO DE ASFIXIA - Piezas pequeñas. No para niños menores de 3 años.

⚠ **AVERTISSEMENT :** DANGER D'ÉTOUFFEMENT - Pièces de petite taille. Ne convient pas aux enfants de moins de 3 ans.

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Introduction

Overview:

The nine models that can be produced using the K'NEX Education Renewable Energy Set include wind, solar and hydro powered models 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 from full-color Building Instruction Booklets. 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 various models in the Instruction Booklets 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 various 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. Your students will have the opportunity to tackle this core concept in your classroom.

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 classroom models are similar to those faced in the real world.

Teacher Notes:

The K'NEX Education Renewable Energy Set provides exciting, dynamic materials and a curriculum that will help you guide your students as they explore three of the major sources of renewable energy: wind, water and solar. This set is designed to address critical science, technology and engineering concepts in the middle school classroom and provide instructional models that will enhance students' understanding of these important concepts. Using K'NEX and the lessons provided in this guide, teachers are able to offer students a program of study that uses hands-on exploration in conjunction with an engaging inquiry-based approach to learning. As students work cooperatively they 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 Renewable 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.

The Renewable Energy Set:

This K'NEX Education Set has the materials needed to serve three groups of 3 – 4 students each working cooperatively. One group will work on the wind lessons, one group will work on the water lessons and the final group will work on the solar lessons that are outlined in this Teacher's Guide.

The materials can also be divided into three smaller units and used to supply a series of renewable energy learning centers around the classroom.

The tub that holds the K'NEX pieces will be used extensively in the water power (hydro) lessons. The tub will serve to collect the water that is used during many of the experiments that the students will complete.

As with any classroom manipulative, it is suggested that you provide time for students to explore building with the K'NEX parts on their own at the beginning of their first session. Students are curious and will want to explore and investigate.

When you first introduce K'NEX, ask for a show of hands to indicate which students have used K'NEX in other classrooms or at home. When you form groups for instruction, include an experienced K'NEX builder in each group. Also, assign groups carefully so that students of varying abilities are in each group. Research findings recommend that the teacher assign students to the work groups and not allow students to self select groups. It is important to change group makeup from time to time.

ITEA & NSES Standards Alignments with the 9 Renewable Energy Lessons

ITEA Standards grades 5-8 **Students will develop an understanding of:**	**Solar:** Lessons 1, 2, 3	**Wind:** Lessons 4, 5, 6	**Hydro:** Lessons 7, 8, 9
The characteristics and scope of technology: • 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.		4	
The core concepts of technology: • 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	4, 5, 6	7, 8, 9
Relationships among technologies and the connections between technology and other fields: • Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.	1	5	
The cultural, social, economic, and political effects of technology: • 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	4	7, 8
The effects of technology on the environment: • 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.		4	7

ITEA Standards grades 5-8 (continued)	**Solar:** Lessons 1, 2, 3	**Wind:** Lessons 4, 5, 6	**Hydro:** Lessons 7, 8, 9
The attributes of design: • Design is a creative planning process that leads to useful products and systems.		4	7
Engineering Design: • Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.	1, 2, 3	4, 5, 6	7, 8, 9
Apply Design Process: • 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	4, 5, 6	7, 8, 9
Assess the impact of technological products and systems: • Synthesize data, analyze trends, and draw conclusions regarding the effect of technology on the individual, society, and the environment.		4	7
Select and use energy and power technologies: • 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.		4	7

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NSES Standards grades 5-8 **Students will develop an understanding of:**	**Solar:** Lessons 1, 2, 3	**Wind:** Lessons 4, 5, 6	**Hydro:** Lessons 7, 8, 9
Unifying Concepts and processes: • Systems, order, and organization • Evidence, models, and explanation • Measurement • Form and function	1, 2	4	7
Science as Inquiry: • Abilities necessary to do scientific inquiry • Understandings about scientific inquiry	1, 2, 3	4, 5, 6	7, 8, 9
Physical Science: • Motions and forces • Transfer of energy	1, 2, 3	4, 5, 6	7, 8, 9
Science and Technology: • Abilities of technological design • Understandings about science and technology	1, 2	4, 5, 6	7, 8, 9
Science in Personal and Social Perspectives: • Resources • Science and technology in society		4	
History and Nature of Science: • Nature of Science	1, 2, 3		7, 8, 9

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 in the K'NEX Education Renewable Energy Set all 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 following three 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 day light 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.articlesnatch.com/Article/Photovoltaic-Cells-Convert-Sunlight-Into-Dc-Current/1157918*

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. These observations and the information students gather will enable them to better compare the three renewable energy resources highlighted in this K'NEX Education Set.

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.bscs.org/pdf/bscs5eexecsummary.pdf*)

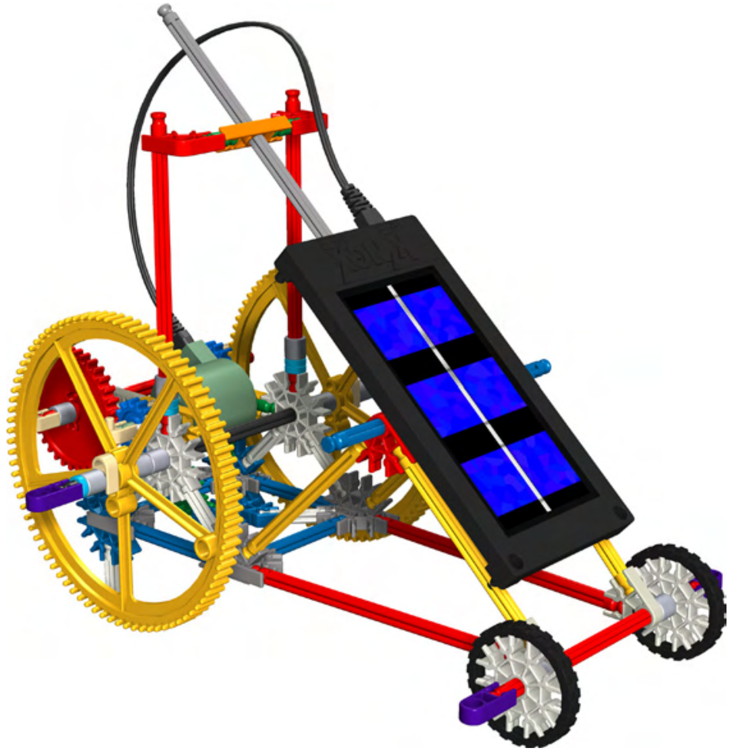
The investigations place an emphasis on STEM (science, technology, engineering and mathematics). The emphasis on engineering includes opportunities for students to work on optimization, improvements to a design, and systems. Students will use flow charts to show the path of energy and its conversion 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 non renewable 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 this series of 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 Renewable Energy Set
- ➤ Photoelectric cell, capacitor, solar motor and cord
- ➤ Tape measure
- ➤ Masking tape
- ➤ Calculator
- ➤ Light sources for inside use (a utility light 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. If the students are using all three models, then consider the photocell investigation just once. 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 a utility light or some other 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, student groups 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.

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

4. Students will graph these results. The horizontal line (x-axis) will be the wattage of the bulb (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 on the board 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 another student could take to make their solar car run at its optimum speed.

The students will:

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 in the classroom?

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. Can 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 Renewable 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 materials 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 their 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. Each group will have the following materials available to used 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.

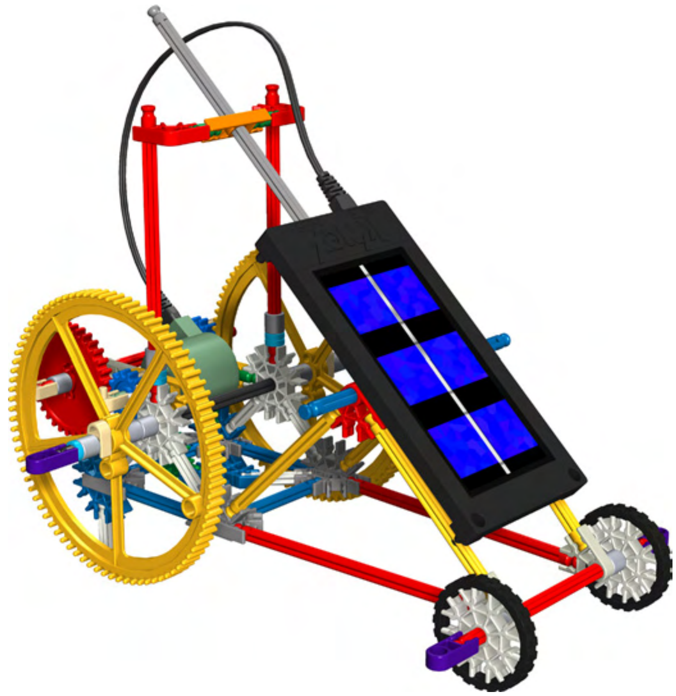
Evaluate:

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 in the Renewable Energy Set 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, discuss what you expect to discover with your group. 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.

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

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

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

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

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?

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

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?

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

c. Why is the model designed like this?

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

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:

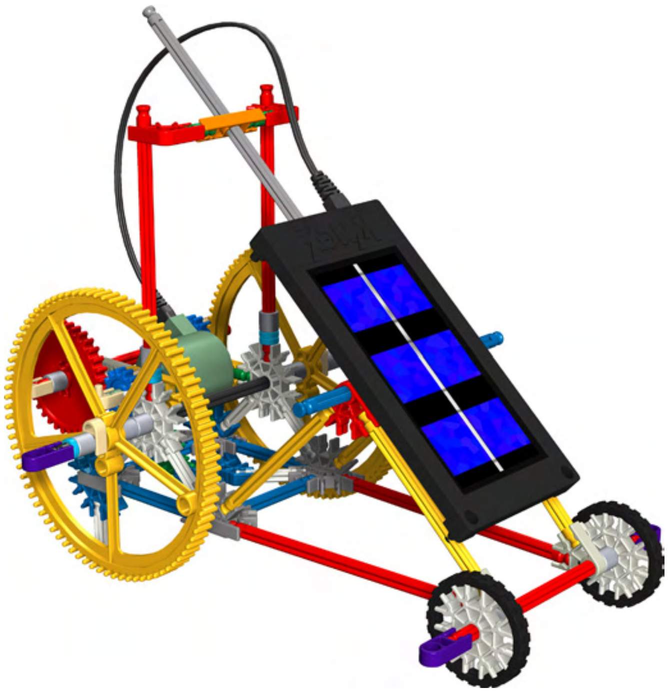
Describe an experimental procedure that will enable you to answer the question above. You must discharge the capacitor between each trial (run the model until it no longer moves). Your first trial will provide a 10 second charging time. Each successive trial will extend the charging time by 10 additional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

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

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

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

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, discuss what you expect to discover with your group. 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.)

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

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

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	*Answers will vary.*
2	*Answers will vary.*
3	*Answers will vary.*
Average time in seconds =	*Answers will vary.*

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
Variables will differ.	*Answers will vary.*
Variables will differ.	*Answers will vary.*
Variables will differ.	*Answers will vary.*
Variables will differ.	*Answers will vary.*

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.

(This sample data may not match student results.)

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

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 classroom to the other. Show your calculations below.

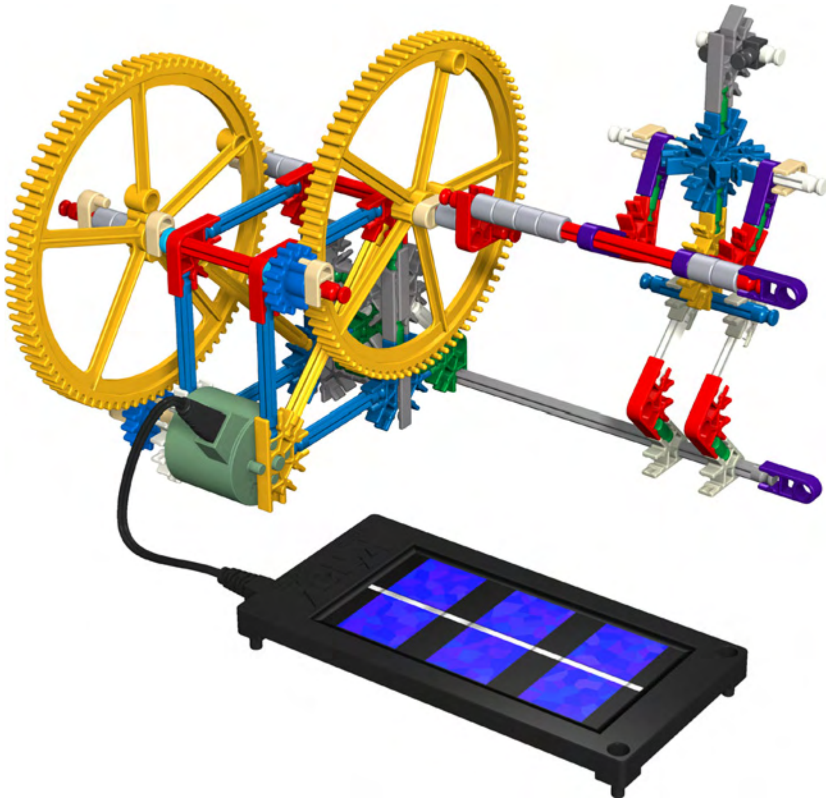
(Based on my data, the car can travel across the room on a total of three recharges.

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 Renewable Energy Set.
- Masking or blue painting tape
- Metric ruler
- Graph paper
- Light sources for inside use (a utility light 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.

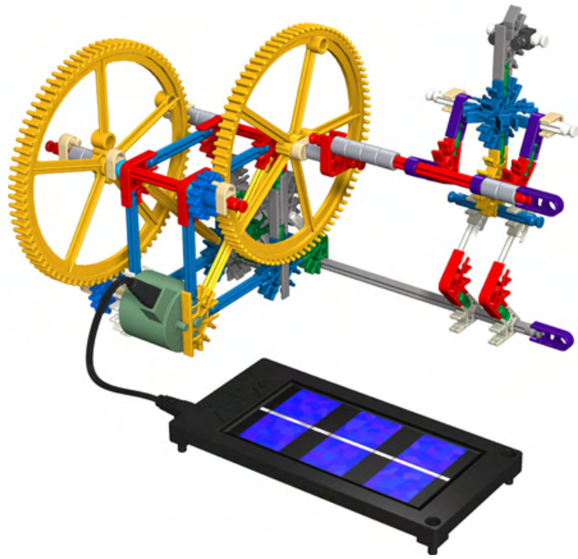
Have students complete the following:

- 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.

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.

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?

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:

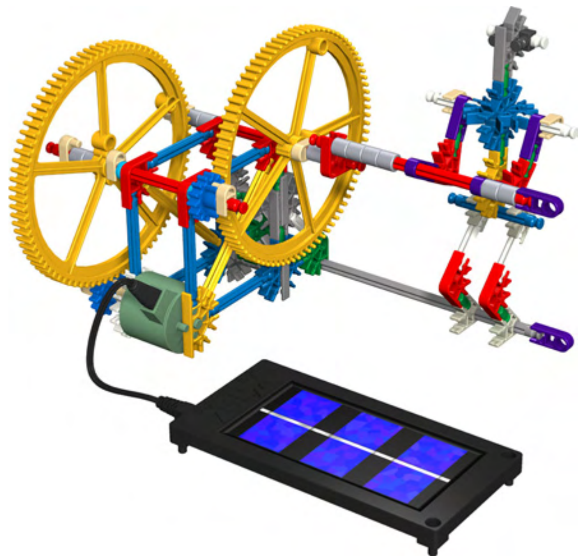
1. Compare the yellow and blue gears on this model and find the ratio of the number of teeth on each. This value is an acceptable way to determine the gear ratio of the gears. The blue gear has _______________ teeth and the yellow gear has ________________.

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.

Light	→	Solar Cell	→	Motor	→	Gear Train	→	Crank Man
(Light Energy)		(Light Energy Converted to Mechanical Energy)		(Electrical Energy Converted to Mechanical Energy)		(Mechanical Energy)		(Mechanical Energy)

(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	Answers will vary.
2	Answers will vary.
3	Answers will vary.
Average =	Answers will vary.

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**____

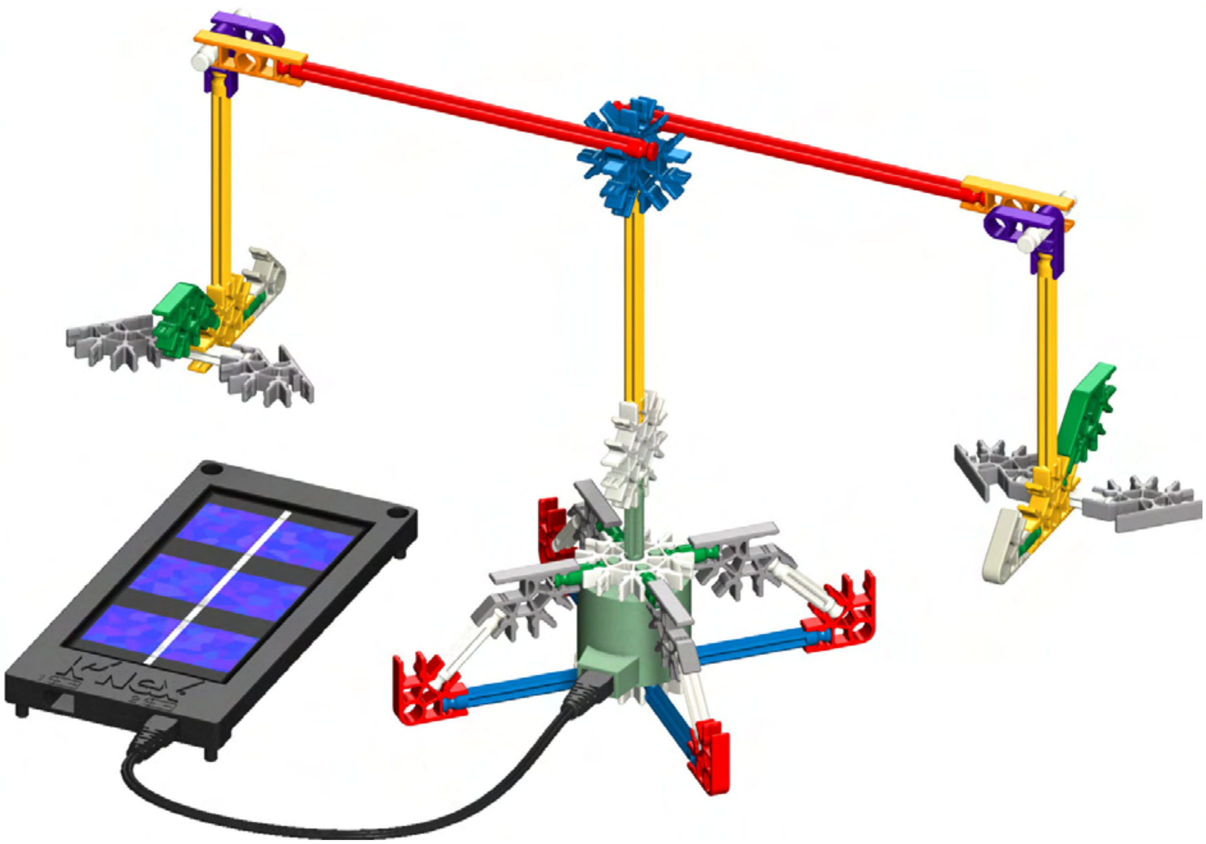
2. If you examine this machine from the motor to the Crank Man, is it geared up for speed or geared down for power?

(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 Renewable 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 on the board or on chart paper.

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. 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.

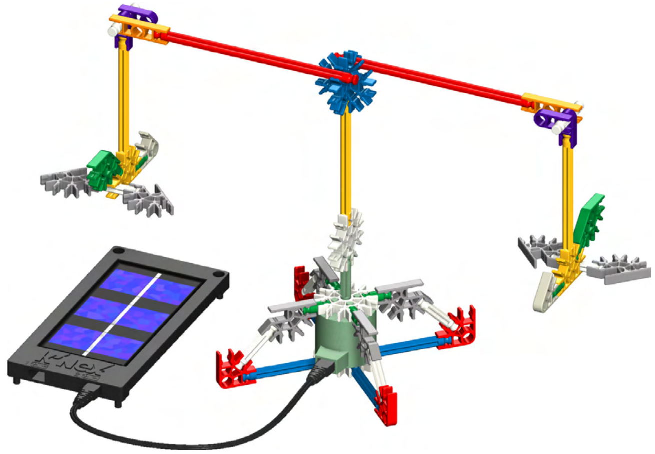
4. Explain what the graph and data show. What does the data and graph tell us about the relationship between the diameter of the Shuttle Ride and the speed at which it turns?

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 (either individually or in groups) 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!

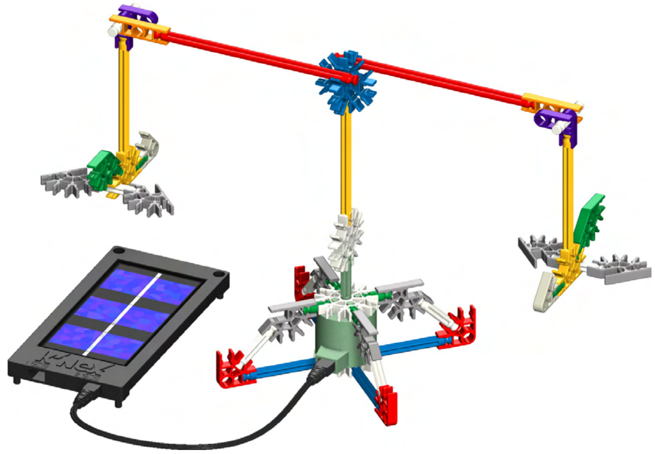
On a separate sheet of graph paper, make a graph that shows the relationship between these two variables.

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.

Light	→	Solar Cell	→	Motor	→	Axle of Ride	→	Shuttle Ride
(Light Energy)		(Light Energy Converted to Mechanical Energy)		(Electrical Energy Converted to Mechanical Energy)		(Mechanical Energy)		(Mechanical Energy)

(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	Answers will vary.
2	Answers will vary.
3	Answers will vary.
Average =	Answers will vary.

- 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.)

Water (Hydro) Power

Introduction:

Harnessing energy from our vast water resources is one goal of the Green Revolution. Water covers over 70% of the earth and is a dense fluid. Therefore, the movement of water is able to create great forces to move materials. Perhaps the most common example of water's force is shown by all of the sediment carried in streams and in rivers as a result of erosion. Just consider the Grand Canyon alone: thousands of feet of rock has been eroded and carried away by the force of the Colorado River. These three hydropower lessons use the power of moving water and can be done inside the classroom with proper attention to water management or outside providing there is an available source of water.

As Students investigate water power they will explore K'NEX models as built from the Instructions Booklet and then they will optimize their models so that the force of the water is used more efficiently. Student observations and adjustments to the procedures and the structure of the models are important learning opportunities as students seek to optimize each model's efficiency. Optimization is an important engineering principle and concept that is highlighted throughout the K'NEX Education Renewable Energy Set.

Examining the energy that is available to the model (potential energy) and then how that energy is transformed into movement (kinetic energy) represent the focus of the three lessons related to water power. These two concepts provide real world contexts that state, regional, and local governments and their utility companies must consider as they evaluate the costs, benefits and limitations of proposed water use to generate energy for the future.

Water power has been used by man for at least that last 2,250 years. Selected websites that support the content that will be explored in these hydropower lessons are listed below.

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

- **Potential and kinetic energy:**
  This site provides a comparison and basic definitions for potential and kinetic energy:
  http://www.schools.utah.gov/curr/science/sciber00/8th/forces/sciber/potkin.htm
  This site provides a comparison and basic definitions for potential and kinetic energy:
  http://www.google.com/images?hl=en&q=potential+vs+kinetic+energy&rlz=1R2ADRA_enUS351&um=1&ie=UTF-8&source=univ&ei=3DVDTIroLsL68AbZ4JgI&sa=X&oi=image_result_group&ct=title&resnum=4&ved=0CCoQsAQwAw
- **Work and energy formulas can be reviewed in most physics texts:**
  Here is one online source for work and energy formulas:
  http://zonalandeducation.com/mstm/physics/mechanics/energy/work/work.html
- **Energy in moving water:**
  Relate to horsepower:
  http://www.energyquest.ca.gov/story/chapter12.html
- **History of use of water power:**
  See:
  http://library.thinkquest.org/17658/hydro/hydhistoryht.html
  A timeline with emphasis on US history of water power use:
  http://www1.eere.energy.gov/windandhydro/hydro_history.html

Provides an interesting history of the use of water powered machines. The water powered train is considered in lesson 2, the water powered car:
http://www.hp-gramatke.net/history/english/page0600.htm

Through the investigation of hydro powered models, students will observe practical information about this form of energy and use water to power the models they have created as they investigate and experiment.

This particular 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.bscs.org/pdf/bscs5eexecsummary.pdf)

In addition, 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 their understanding of systems and their components. Students will use flow charts to show the path of energy and its conversion from one form to another in various hydro powered systems.

Students can calculate efficiency as energy is converted from moving water to motion in the model and then to the creation of electricity or practical, mechanical work. 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).

The world faces an energy dilemma brought about by population increases and decreasing availability of crude oil and other non renewable energy sources. Alternate energy forms using renewable energy sources like wind, water, solar, and geothermal are increasingly popular alternatives and supplements to the non-renewable forms of energy. Students can check with their electricity provider to see what percentage of the electrical energy produced in their area is generated from hydro power and other renewable sources.

The story of water power use dates back to Rome and Greece where water wheels were used to grind flour and perform other tasks. The Middle Ages saw the development of more and more applications for water power and at the beginning of the industrial revolution, much of the garment industry relied on water power to drive the looms that produced cloth. According to ThinkQuest: (http://library.thinkquest.org/26663/en/4_2_4.html) 25 % of the world's power comes from water and 61% of power in Switzerland is water generated. The rich information on the internet and in the library related to the use of water for power can provide a wide range of research opportunities for students.

The models used in this series of lessons challenge students to undertake a series of problem solving activities that are in many ways similar to the challenges others have faced through history as they attempted to gain the greatest force and power from available water resources. Falling water (as opposed to flowing water) is used with each of these models to generate power that causes motion or to produce electricity.

Water (Hydro) Power - Lesson 4:

HYDROELECTRIC GENERATOR

(Black Paddle Water Wheel)

Time Frame:

3 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Observe and describe how a water wheel can generate electricity.
- Gather, organize, present, and analyze data.
- Manipulate a model to improve its efficiency.

Materials:

- The K'NEX Education Renewable Energy Set
- K'NEX solar motor
- Bright colored stickers on labels
- Pitchers of water or water bottles
- Water measuring containers
- Stopwatch
- Electrically powered model from the Renewable Energy Set such as Shuttle Ride or Crank Man
- Funnels of varied sizes and/or heavy duty aluminum foil to build stream channels
- Masking tape
- Sponges and plastic drop cloths (tarps) to provide a water barrier to protect your classroom floor from water if the activity is to be completed indoors.

Engagement:

1. How can a water wheel generate electricity?

2. What does it mean to optimize a system?

3. What steps could be used to optimize the operation of a water wheel system?

- What is a system?
- What does optimize mean?
- Why are these important concepts in engineering and design?

Allow time for students to brainstorm ideas and then write several of their suggestions on the board or chart paper. Once a list of suggested answers has been developed, move on to the next question. Students may suggest: using more water, dropping water from higher levels, etc. Build upon their ideas and make them aware that they are going to build and optimize a water wheel system as a part of this activity.

Investigation 1: Mechanics of a Working Water Wheel

1. Build the Hydro Electric Generator model using the building instructions provided. The black paddles on the water wheel should be suspended over the green tub as shown.

2. **Explore** the model and determine how it operates.

3. Turn the black paddle wheel with your hand and trace the movement of the different parts through the model.

4. **Explain** the flow of motion (energy) through the model.

Teacher Note: The exploration and explanation phase of the activity allows students to build, explore and investigate on their own. The students are essentially self-directed with the assistance of the Student Response Sheets provided for this activity. The quality of the students' answers will depend on the level of their prior knowledge and any direct instruction that has preceded their work.

Elaborate:

5. During this phase of the lesson the students will experiment with one or more independent variables that they will manage during experimentation.

Select one of the variables listed below to test the energy producing performance of the water wheel model.

- The height from which the water is dropped on the black paddles.
- The amount of water that is dropped on the black paddles.

Write down the selection you made and then describe how you will test the variable you have chosen.

Determine how to collect the data fairly as you experiment with this variable. Your group will vary either the height of the water or the amount of water. Use a brightly colored sticker or label to attach to one of the paddles on the water wheel for ease of counting.

Sample Data Provided as an Example

Amount / Height of water (Circle Your Variable)	Complete Turns of the Water Wheel
Trial 1: 10 cm	**6**
Trial 2: 20 cm	**9**
Trial 3: 30 cm	**13**
Trial 4: 40 cm	**15**

Teacher Note: It is difficult to pour water at a consistent rate from a pitcher or water bottle. By using a funnel (or different sized funnels), the rate at which the water hits the water wheel will be more constant.

6. What did you discover? Is there a relationship between the variable you studied and the number of turns of the paddles?

7. Write a single sentence that describes the effect of your variable on the performance of the water wheel.

Teacher Note: Students should find that more water and faster water both produce more turns of the water wheel. Careful experimentation should find that the speed of water is more important than the amount of water. Challenge the students to determine why.

Investigation 2: Generating Electricity with Water Power

1. Notice the small green solar motor that is covered by a small black dome on your model (Make every effort to keep this motor dry.). When the water wheel turns, the gear attached to the motor turns causing the shaft of the motor to spin. When this happens, the motor acts like a generator and produces electricity.

2. Attach a solar panel wire from the generator to the Shuttle Ride or Crank Man model.

Explore:

3. Observe this system of two models attached by an electrical wire and determine how it operates.

4. Turn the black paddle wheel as your partner holds the water wheel system securely in place. What do you observe? What happens to the other model you have wired to your water wheel system?

5. **Explain** the flow of motion (energy) through both of the models.

6. How does the second model respond when you spin the water wheel faster? Slower?

Elaborate:

8. During this phase of the lesson the students will experiment with an independent variable that they will manage during experimentation.

   Your group will select a variable to test the electrical energy producing performance of the water wheel model. In the previous activity you were given choices for your variable. In this activity, you may select one of those variables or your group may select a completely different variable to test.

   Write down the selection you made and then describe how you will test the variable you have chosen in the spaces provided below.

   <u>Be sure to design a fair test that will demonstrate the impact of your variable.</u> You can measure the impact of your variable by counting the rotations of the water wheel or by counting the resulting spins of the second model you have added to the system. If you will count rotations of the water wheel mark, one of the black paddles with a bright sticker to help with your count.

Sample Data Provided as an Example

Your Variable (The amount of water used)	Rotations of Your Second Model
Trial 1: 1 liter	**2**
Trial 2: 2 liters	**3**
Trial 3: 3 liters	**5**
Trial 4: 4 liters	**8**

Teacher Note: It is important that students have as many opportunities as possible to design experiments, complete the experiments, and defend their results.

Redesign Challenge:

9. Alter the design of the water wheel to make it produce more electrical energy?

Describe the changes you made to the model in detail. List all materials that you added or removed from the model.

Sample Data Provided as an Example

What modification did you make to the water wheel? e.g. We made the paddles flat rather than rounded	Rotations of the Second Model
Variable Amount of Water	(Resulting effect)
Trial 1: 2 liters	**4**
Trial 2: 4 liters	**9**
Trial 3: 6 liters	**14**
Trial 4: 8 liters	**21**

Teacher Note: One conclusion that may be reached is that not all ideas or designs result in an improvement. This activity provides students with opportunities to optimize a design to improve the efficiency of their model. As you move about the room observing students at work, ask questions to gain insight into their levels of understanding and encourage students to use the terms *optimize* and *efficiency* as they describe their experiments and their expected outcomes.

Evaluate:

10. Describe and trace the flow of energy and the different forms it takes as it travels through the water wheel system and then through the second model that the water wheel powers. Use a flow chart to present the flow of energy through the two combined systems. Label the input energy and the output energy. Label each type of energy that is demonstrated by the model.

Evaluation Challenge:

- Using your group's best redesign of the water wheel, determine the longest time that you can keep the second model moving using only one gallon of water poured through the water system. You will only have three chances to get your best time. Save your results to compare to other groups when they have completed the activity.

Math Extensions:

1. Ratios are like a fraction and provide a numerical description of the relationship between two objects. The ratio is a numerical pattern.

a. Observe the water wheel as it turns. When it goes around once, the yellow gear, which is essentially the same diameter of the wheel, goes around once. So the ratio is 1:1. In other words, each turn of the wheel produces one turn of the gear. When the yellow gear turns once, how many times does the blue gear turn? The ratio is _________:1 which shows that the system is geared up. The final gear in the system turns more times than the gear that drives it. (This system is geared up.)

b. Observe the Crank Man model, the input or blue gear attached to the motor spins very fast when compared to the yellow gear that it meshes with. In this system, the final gear in the system turns fewer turns that the gear that drives it. (This system is geared down.) Determine the gear ratio of the Crank Man. Remember, there are two additional gears in this system that will need to be considered. The ratio is _______ : _______.

c. Describe the difference between gearing up and gearing down. What are advantages of each? What are disadvantages of each?

The activities that make up this lesson provide an excellent opportunity to begin discussions with students related to the relationship between force, energy, work and power. Excellent resources to extend these discussions can be found in your science textbook and in some of the on-line resources presented at the beginning of the lesson.

Lesson 4:

HYDROELECTRIC GENERATOR

(Black Paddle Water Wheel)

Investigation 1: Mechanics of a Working Water Wheel

1. Build the Hydroelectric Generator model using the building instructions. The black paddles on the water wheel portion of the model should be suspended over the green tub as shown.
2. Explore the model and determine how it operates. Describe it's operation below.
3. Turn the black paddle wheel gently with your hand and trace the movement of the parts as the energy you have added passes through the model.
4. Explain the flow of motion (energy) through the model.

5. Select one of the variables listed below to test the energy producing performance of the water wheel model.

- The height from which the water is dropped on the black paddles.
- The amount of water that is dropped on the black paddles.

Write down the selection you made and then describe how you will test the variable you have chosen.

Determine how to collect data fairly as you experiment with this variable. Your group will vary either the height of the water or the amount of water. Use a brightly colored sticker or label to attach to one of the paddles on the water wheel for ease of counting. Place your data in the following table.

Amount/Height of water (Circle Your Variable)	Complete Turns of the Water Wheel
Trial 1	
Trial 2	
Trial 3	
Trial 4	

6. What did you discover?

7. Write a single sentence that describes the effect of your variable on the performance of the water wheel system.

Investigation 2: Generating Electricity with Water Power

1. Notice the small green solar motor that is covered by a small black dome on your model (Make every effort to keep this motor dry.) When the water wheel turns, the gear attached to the motor turns causing the shaft of the motor to spin. When this happens, the motor acts like a generator and produces electricity.

2. Attach the generator wire to a Shuttle Ride or Crank Man model. Explore the new model and determine how it operates. Describe how it operates below:

3. Turn the black paddle wheel as your partner holds the water wheel system securely in place. What do you observe? What happens to the other model you have wired to your water wheel system?

4. Explain the flow of motion (energy) through both of the models.

5. How does the second model respond when you spin the water wheel faster? Slower?

6. Select a variable that will allow you to test the electrical energy producing performance of the water wheel model. In the previous activity you were given choices for your variable. In this activity, you may select one of those variables or your group may select a different variable to test.

Write down the selection you made and then describe how you will test the variable you have chosen below.

Determine how to collect data fairly to study the variable your group has chosen. Use the data table below to organize your data.

Your Variable	Rotations of Your Second Model
Trial 1:	
Trial 2:	
Trial 3:	
Trial 4:	

Redesign Challenge:

9. Alter the design of the water wheel to allow it to produce more electrical energy. How will you know if there is more electricity being produced?

Describe the changes you made to the model in detail. List all materials that you added or removed from the model.

What modification did you make to the water wheel?	
Variable	(Resulting effect)
Trial 1:	
Trial 2:	
Trial 3:	
Trial 4:	

10. Did your alterations result in the production of more electrical energy? How do you know?

Lesson 4:

HYDROELECTRIC GENERATOR

(Black Paddle Water Wheel)

Investigation 1: Mechanics of a Working Water Wheel

1. Build the Hydroelectric Generator model using the building instructions. The black paddles on the water wheel portion of the model should be suspended over the green tub as shown.

2. Explore the model and determine how it operates. Describe its operation below.

   (This is a model of a water wheel. The water pours down onto the black cups and causes the wheel to rotate. In this configuration, this water wheel has the water coming over the top. The other type of water wheel is in the current of the stream and the current pushes against the paddles. Students might wish to research the history of each type, its advantages and disadvantages.)

3. Turn the black paddle wheel gently with your hand and trace the movement of the parts as the energy you have added passes through the model.

   (Our hand turns the paddles causing the yellow gear to spin. The yellow gear turns the blue gear which in turns spins the shaft of the motor.)

4. Explain the flow of motion (energy) through the model.

   (See above)

5. Select one of the variables listed below to test the energy producing performance of the water wheel model.

- The height from which the water is dropped on the black paddles.
- The amount of water that is dropped on the black paddles.

Write down the selection you made and then describe how you will test the variable you have chosen.

(There are two variables. For each, students should recognize the need to try several different amounts of water or several different heights from which the water is dropped. Students should attempt to control the other variables as they experiment.)

Determine how to collect data fairly as you experiment with this variable. Your group will vary either the height of the water or the amount of water. Use a brightly colored sticker or label to attach to one of the paddles on the water wheel for ease of counting. Place your data in the following table.

Amount/Height of water (Circle Your Variable)	Complete Turns of the Water Wheel
Trial 1	*Answers will vary.*
Trial 2	*Answers will vary.*
Trial 3	*Answers will vary.*
Trial 4	*Answers will vary.*

6. What did you discover?

(Data should support the ideas that the higher the water falls, the faster the wheel spins [it is difficult to control where the water falls and that will affect the results.] Students experimenting with the amount of water should find that, up to a point, the more water the faster the paddles spin. The small paddles can only handle a certain amount of water.)

7. Write a single sentence that describes the effect of your variable on the performance of the water wheel system.

A. (The further the water falls, the faster the paddles spin.)

B. (The more water poured onto the paddles, the faster the paddles spin.)

Investigation 2: Generating Electricity with Water Power

1. Notice the small green solar motor that is covered by a small black dome on your model (Make every effort to keep this motor dry.). When the water wheel turns, the gear attached to the motor turns causing the shaft of the motor to spin. When this happens, the motor acts like a generator and produces electricity.

2. Attach the generator wire to a Shuttle Ride or Crank Man model. Explore the new model and describe how it operates below.

(As the water wheel turns, it turns the generator which makes electricity. There is enough electricity to turn the other ride slowly. Students will find that it is easier to cause the Shuttle Ride to move than the Crank Man.)

3. Turn the black paddle wheel as your partner holds the water wheel system securely in place. What do you observe? What happens to the other model you have wired to your water wheel system?

(The Crank Man moves but slowly and intermittently. The Shuttle Ride turns easily as the water wheel spins. The Shuttle Ride works easier than the Crank Man and is a better indicator of the electricity being produced by the water wheel.)

4. Explain the flow of motion (energy) through both of the models to your teacher.

(Answers will vary. Students should recognize the different gearing.)

5. How does the second model respond when you spin the water wheel faster? Slower?

(The Crank Man works consistently when the water wheel spins faster. The Shuttle Ride spins faster with increased water wheel speed.)

6. Select a variable that will allow you to test the electrical energy producing performance of the water wheel model. In the previous activity you were given choices for your variable. In this activity, you may select one of those variables or your group may select a different variable to test.

Write down the selection you made and then describe how you will test the variable you have chosen below.

(Students may wish to study other variables that are different from those in Investigation 1. Students may decide to change the size, number or shape of the scoops.)

(Procedures will vary. Ensure that student investigations address the importance of keeping other variables constant.)

Determine how to collect data fairly to study the variable your group has chosen. Use the data table below to organize your data.

Your Variable Answers will vary.	Rotations of Your Second Model
Trial 1: Answers will vary.	Answers will vary.
Trial 2: Answers will vary.	Answers will vary.
Trial 3: Answers will vary.	Answers will vary.
Trial 4: Answers will vary.	Answers will vary.

Redesign Challenge:

9. Alter the design of the water wheel to allow it to produce more electrical energy. How will you know if there is more electricity being produced?

(If the Shuttle Ride or the Crank Man goes faster, we will know that there is more electricity being produced.)

Describe the changes you made to the model in detail. List all materials that you added or removed from the model.

(Answers will vary.)

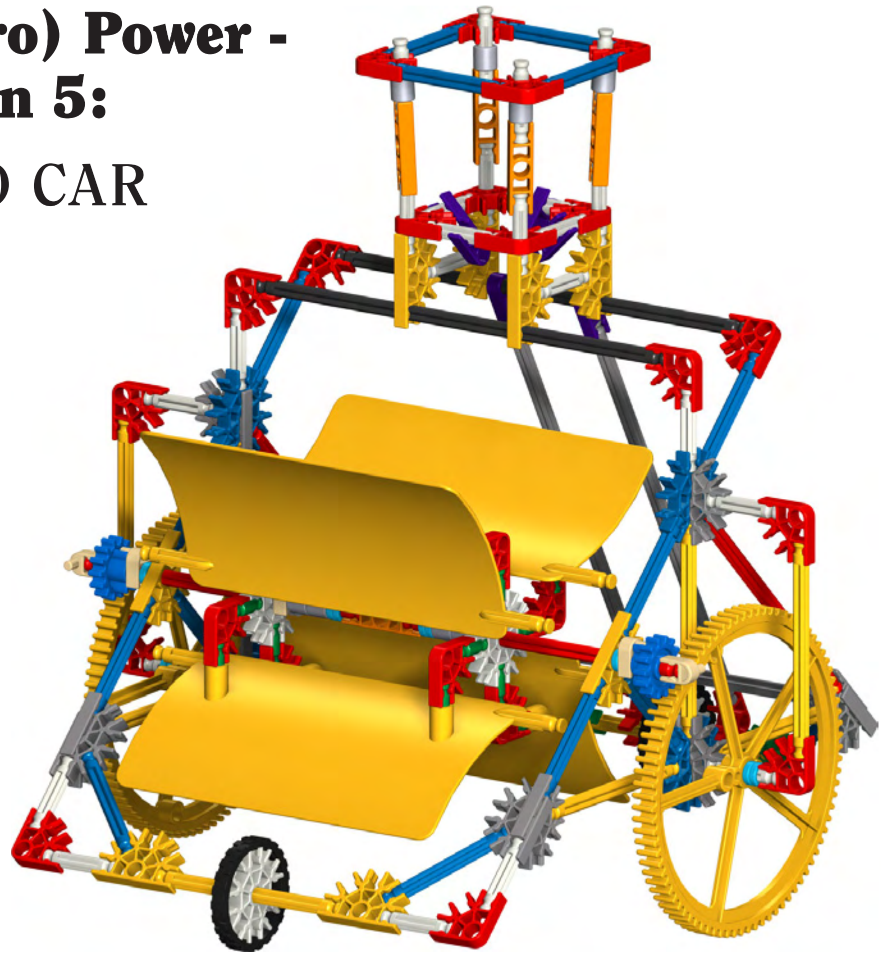
What modification did you make to the water wheel?	
Variable Answers will vary.	(Resulting effect)
Trial 1: Answers will vary.	Answers will vary.
Trial 2: Answers will vary.	Answers will vary.
Trial 3: Answers will vary.	Answers will vary.
Trial 4: Answers will vary.	Answers will vary.

10. Did your alterations result in the production of more electrical energy? How do you know?

(Answers will vary. Students should base their determinations on the data that they gathered.)

Water (Hydro) Power - Lesson 5:

HYDRO CAR



Time Frame:

3 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Observe a functioning machine and identify it's parts and their purpose.
- Optimize a system based on observation and measurement
- Make inferences about the efficiency of a design and suggest improvements.
- Evaluate the feasibility of hydropower cars.

Materials:

- The K'NEX Education Renewable Energy Set
- Funnels of various sizes (from kitchen shops/auto supply/lab supplies)
- Heavy duty aluminum foil
- Measuring containers of different sizes (e.g. water bottle, 1 liter soda bottle, calibrated beakers)
- Buckets of water
- Sponges, plastic tarp or drop cloth
- Duct tape, masking tape
- Meter stick or tape
- Stopwatch

Teacher Note: If this investigation is done in a classroom, it is best done on a plastic tarp surrounded by sponges. After each trial, the water needs to be collected—it can be reused. Your best course of action would be to provide an opportunity for students to complete this activity outdoors where clean up can be left to the sun.

Engagement:

1. Can a car be powered by water?

2. What are some advantages and disadvantages to this type of power for a vehicle?

Allow time for students to brainstorm ideas and then write several of their suggestions on the board or chart paper. Once a list of suggested answers has been developed move on to the next question. Build upon their ideas and make them aware that they are going to build and optimize a water powered car as a part of this activity. The first question is also an excellent research topic. Consider challenging students to use the internet to gather information on vehicles that use water for power.

Investigation 1: How can the design of a hydro car be improved?

Explore:

1. Students will build the Hydro Car model using the building instructions provided.

   After the car has been constructed students will explore its operation. In order for the model to move, water must drop on the paddles thus causing them to turn and move the car. Students will observe the model closely and gently push the paddles with their fingers. Is it easy or hard to push the paddles? Will several drops of water be powerful enough to turn the paddles and cause the car to move? How much water might be needed to turn the paddles ten times? How far will the car move with ten turns of the paddles?

2. Students will collect a water supply (one or two liters) and experiment by dropping (or pouring) water on the paddles. The square frame on top of the model will support a commercial funnel or a funnel of the students' own design made from heavy duty foil. Their challenge is to determine which funnel enables the car to move the furthest with one bottle of water (the water must always be dropped into the funnel from the same height). Students will need several funnels of different sizes. What funnel appears to work best?

Teacher Note: In the absence of varied sized funnels, aluminum foil can be crafted into a funnel shape. The opening size can be varied by using pencils as an opening template: 1, 3 and 5 pencils might be used for a first trial and then modified based on the students' findings. It is suggested that the water be limited to a specific amount for each trial such as 500 or 1,000 ml. Some students may not get any movement with their funnels. While this is frustrating to young scientists, this is valid discovery. Urge them to examine their first experiment closely and to see if they can improve the performance of their hydro car.

(Sample data has been added below as an example of what students may discover as a part of their investigations.)

Funnel hole size	Distance car traveled (cm)
1	7
3	22
5	50

Explain:

- Students will make a bar graph of the data showing the funnel size (independent variable) on the x-axis and distance traveled (dependent variable) on the y-axis. What is an appropriate title for this graph? Which funnel worked the best? How did you judge which funnel worked the best? Students will be asked to describe what this graph shows to their teacher. When you feel the students have a sound understanding of what the graph means, ask them to write their analysis on the back of their Student Response Page.
- Students will revisit this activity when all of the groups in the class have completed this lesson. The students will compare their data with at least one other group (or with the entire class). If students find their data varies significantly from other groups, have them propose reasons for the differences.

Teacher Note: This first investigation keeps the distance that the water falls constant but varies the funnels the water passes through. While the sample chart uses the size of the funnel opening as the variable, an investigation based on the volume of water going through a single funnel could be used as an alternate variable for experimentation. Some volumes of water trickle and hardly move the paddles. Other volumes spin the paddles very fast and there is wasted water, so the optimum may be an intermediate volume that is powerful enough to move the paddles without much waste. This is an operational definition of optimizing the system that students should be able to recognize and express in their own words.

Investigation 2:

Elaboration:

1. In the first investigation, students found that water can turn the paddles and move the hydro car. In this experiment, the challenge is to move the car as far as possible with 500 ml of water. (Larger water bottles are appropriate for this investigation if 500 ml of water are measured into them. It is enough water to gather data and is easily sponged up when the trial is over. Larger volumes can be used outdoors.)

Experimental Design: Use your observations and results from the first experiment to suggest a change to the model or the technique you use to pour water that will result in the car moving as far as possible. Individual groups will craft their own procedures. It is important that students design this experiment on their own. Since we are looking for the furthest distance, this activity can be a competition between groups of students. As other groups will be completing the activity later, each group will have to save their results for later comparison.

Teacher Note: Students will have to use their supply of water effectively and efficiently to move their car the greatest distance. Students might suggest using different sized funnels that they used in the introductory activity or no funnels at all. There are numerous other variables, such as, but not limited to: modifying the paddles to hold water better or pouring the water from a higher distance so it hits the paddle with more force. Suggest to each student group that they explore a variety of options before they modify their experiment. Require that the procedure be written first and that there be a clearly developed data table. After students do their trials, they are asked to make a graph and explain what they discovered **(EVALUATION)**. As a result of their student designed experiments, they should be able to state a claim and then to provide the evidence that they gathered which supports that claim.

2. Does twice the water result in twice the distance traveled? Students can use the same experimental design as before but they will vary the amount of water they use. Students should be able to collect appropriate data and make a suitable graph as in the first activity before making a thoughtful analysis of their results. Care must be taken to use the same model and same pouring rate to ensure that the only variable is the volume of water.

Teacher Note: Teachers might use the experiment outlined in # 3 as a performance assessment of student work. The rubric should include criteria such a limiting the variables of study, attention to collecting a sufficient amount of quantitative data, using appropriate vocabulary, and drawing appropriate conclusions based on the data.

Extensions:

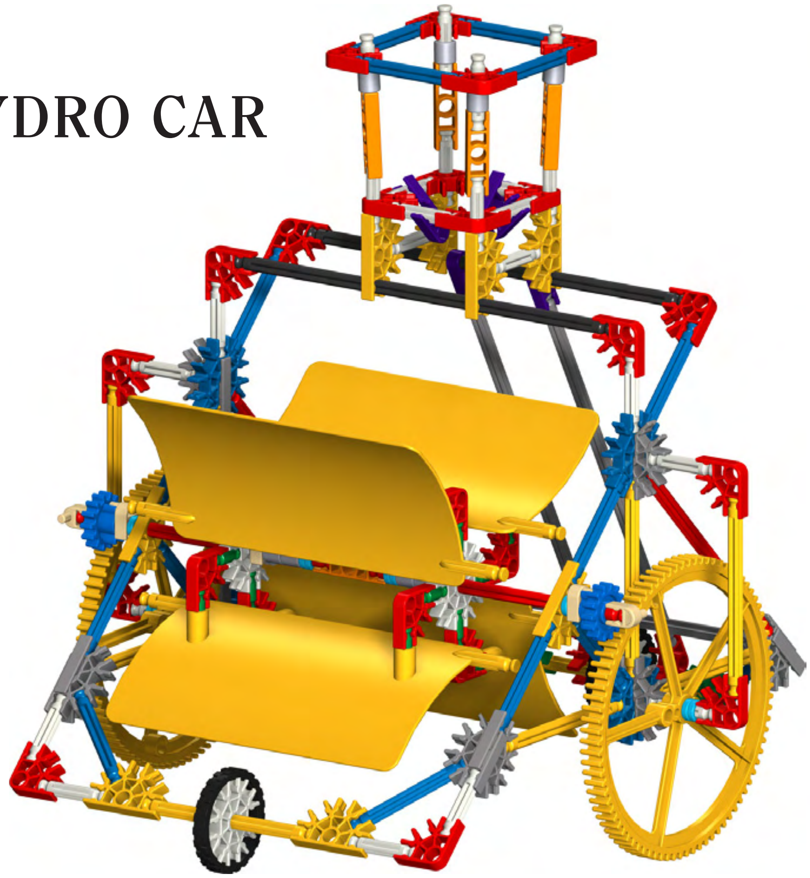
1. Use your experimental data and calculate the rate of water use by the hydro car. The best label for this number would be the distance traveled (centimeters) per 1000 ml of water.

2. In engineering, we always look for ways to improve a design. Examine this model and explain several improvements you could recommend for this model. Try to improve upon this design. (When all of the students' experiments are completed, students may rank the variables in order of their importance in improving efficiency.)

3. How many turns must the paddle make for the hydro car to travel 100 cm. Use this number and calculate the number of turns it would take to travel 1 kilometer. Show all your work and explain how to solve this problem in your own words

4. Discuss the practicality of this type of vehicle. (Research is available on water powered vehicles on the Internet.)

Lesson 5: HYDRO CAR



Investigation 1:

1. Build the Hydro Car model using the building instructions provided.

2. Water dropping on the paddles causes them to turn and move the car. Observe the model closely and gently push the paddles with your fingers. The following questions will guide you as you explore the hydro car.

- Is it easy or hard to push the paddles?

- Will several drops of water be powerful enough to turn the paddles and cause the car to move?

- How much water might be needed to turn the paddles ten times?

- How far will the car travel if the paddles turn ten times?

3. Collect a bottle of water and experiment by dropping (or pouring) the water on the paddles. The square frame on top of the model will support a commercial funnel or a funnel of your own design made from heavy duty foil. Your challenge is to determine which of the funnels enables the car to move the furthest with one bottle of water. You will need to have several funnels of different sizes. Collect your data in the chart below. What funnel appears to work best? How did you judge which funnel worked the best?

Make sure you use the same amount of water and that you pour the water from the same height for each trial. You should run several trials with each funnel.

Funnel size Diameter (cm)	Distance traveled (cm)

- On a separate sheet of graph paper make a graph of the data. Provide an appropriate title for your graph. After you have analyzed your graph describe what you have discovered. Write your findings.

- When all of the groups in the class have completed this activity you will compare your data findings with theirs. If your group finds your data varies significantly from other groups, discuss the experiment with the other groups and propose reasons for any differences.

Conclusions:

What funnel appears to work best?

How did you judge which funnel worked the best?

Investigation 2:

1. In the first investigation you found that water can turn the paddles and move the hydro car. In this experiment, the challenge is to move the car as far as possible with 500 ml of water.

2. Use your observations and results from the first experiment to suggest a procedure that will result **in your model traveling as far as possible.** Run several tests before you decide on a procedure. Write the procedure you will follow in the space below.

3. Design a data table to display the number of trials you attempted and the results of each of these trials. Place the data table in the space below

4. How far did your car travel during your best trial?

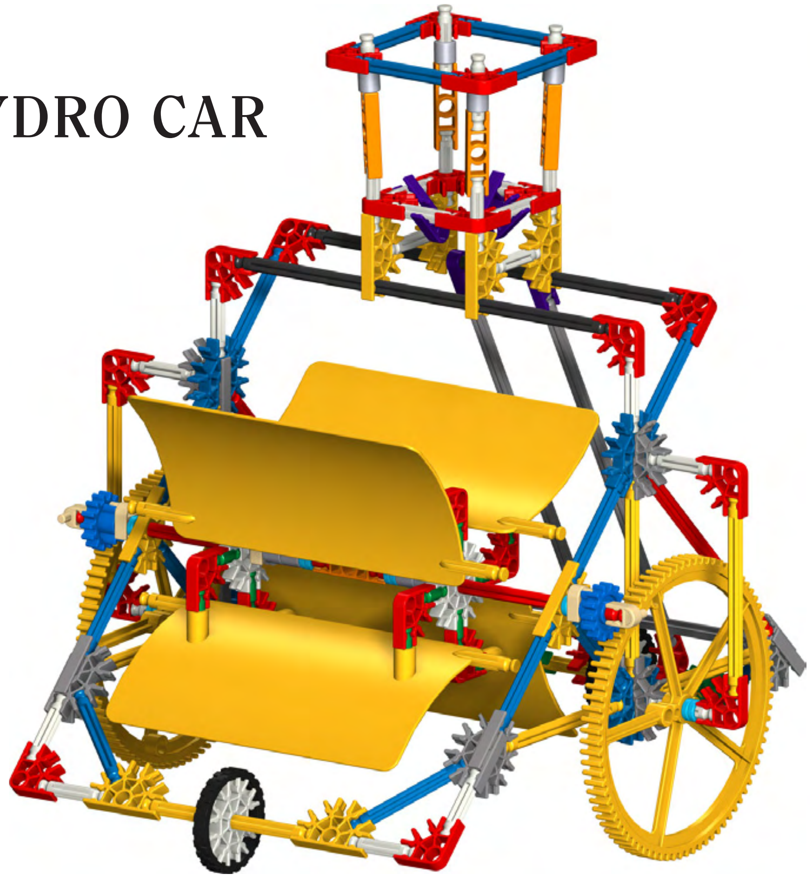
Extensions:

Complete these activities:

1. Use your experimental data and calculate the rate of water use for your car. The best label for this number would be the distance traveled (centimeters) per 1000 ml of water.
________________________________ cm/ 1000 ml of water

2. Is this type of water powered vehicle practical? Why or why not?

Lesson 5: HYDRO CAR



Investigation 1:

1. Build the Hydro Car model using the building instructions provided.
2. Water dropping on the paddles causes them to turn and move the car. Observe the model closely and gently push the paddles with your fingers. The following questions will guide as you explore the hydro car.

- Is it easy or hard to push the paddles?

  (It is easy to push the paddles.)

- Will several drops of water be powerful enough to turn the paddles and cause the car to move?

  (While the paddles move easily, students should realize that several drops of water are not enough to turn the paddles.)

- How much water might be needed to turn the paddles ten times?

  (Answers will vary. Less than 10 gm (10 ml) water moves the paddles. But the water runs off so you need to continually keep 10 or more grams of water on a paddle to keep the car moving.)

- How far will the car travel if the paddles turn ten times?

  (Approximately 70-75 cm.)

3. Collect a bottle of water and experiment by dropping (or pouring) the water on the paddles. The square frame on top of the model will support a commercial funnel or a funnel of your own design made from heavy duty foil. Your challenge is to determine which of the funnels enables the car to move the furthest with one bottle of water. You will need to have several funnels of different sizes. Collect your data in the chart below. What funnel appears to work best? How did you judge which funnel worked the best?

Make sure you use the same amount of water and that you pour the water from the same height for each trial. You should run several trials with each funnel.

Funnel size Diameter (cm)	Distance traveled (cm)
Funnels vary from class to class.	*Answers will vary.*

- On a separate sheet of graph paper make a graph of the data. Provide an appropriate title for your graph. After you have analyzed your graph describe what you have discovered. Write your findings.

(Answers will vary. The graph should be a bar graph and the title could be, 'The Effect of Funnel Size on the Distance a Hydro Car Travels' or something similar.)

- When all of the groups in the class have completed this activity you will compare your data findings with theirs. If your group finds your data varies significantly from other groups, discuss the experiment with the other groups and propose reasons for any differences.

(Remind students that they will have to save their data and results until other groups have completed the activity.)

Conclusions:

What funnel appears to work best?

(Answers will vary.)

How did you judge which funnel worked the best?

(Students who connect the amount of water used and the funnel size with the distance traveled have a good understanding of this investigation.)

Investigation 2:

1. In the first investigation you found that water can turn the paddles and move the hydro car. In this experiment, the challenge is to move the car as far as possible with 500 ml of water.

2. Use your observations and results from the first experiment to suggest a procedure that will result **in your model traveling as far as possible.** Run several tests before you decide on a procedure. Write the procedure you will follow in the space below.

   (Answers will vary but students need to carefully select the funnel size that adds water just fast enough to move the paddles. In this way, water is used as efficiently as possible. Students will decide upon a pouring strategy and the best funnel for the task based on their previous investigations with the hydro car.)

3. Design a data table to display the number of trials you attempted and the results of each of these trials. Place the data table in the space below

   (Student tables will vary. Ensure that the students have designed a data table with one column for the trial number, one column for the distance the car traveled and one row for the average distance traveled.)

4. How far did your car travel during your best trial?

   (Answers will vary.)

Extensions:

Complete these activities.

1. Use your experimental data and calculate the rate of water use for your car. The best label for this number would be the distance traveled (centimeters) per 1000 ml of water.
   ______________________________ cm/ 1000 ml of water

   (Answers will vary. If the students used 500 ml of water and the car traveled 32 cm, they should arrive at a rate of 64 cm/1,000 ml of water.)

2. Is this type of water powered vehicle practical? Why or why not?

   (Answers will vary but students should realize that a water powered vehicle that depends on pouring water is totally impractical. This type of vehicle may never work in the real world but falling water can and is being used to power electrical generators that produce power for electric cars.)

Water (Hydro) Power - Lesson 6:
GRIST/FLOUR MILL

Time Frame:
3 x 40 minute sessions

Student Objectives:
Students will demonstrate the ability to:

- Observe and describe how water can power a machine
- Infer how a grist/flour mill operates
- Make and test improvements that improve the efficiency of a mechanical system

Materials:

➤ The K'NEX Education Renewable Energy Set
➤ Masking tape
➤ Brightly colored dots (Stickers)
➤ Measuring containers for water
➤ Empty plastic bottles
➤ A collection of funnels
➤ Heavy Duty Foil
➤ Water
➤ Sponges

Engagement:

Provide students with pictures of grist/flour mills or a collection of PowerPoint™ slides with images you have collected from the internet. Select images of mill stones and entire mills for the students. Have a group of students build the Grist/Flour Mill model to aid this discussion.

- How does a grist/flour mill work?
- How can the mill design be improved?
- Does this machine use hydro power efficiently? Explain your thinking.

Allow time for students to brainstorm ideas and then write several of their suggestions on the board or chart paper. (Provide some time for the students to complete research into grist/flour mills before continuing.) Once a list of suggested answers has been developed move on to the second question. Students may suggest design improvements that seem farfetched at this point. Their understanding will improve as the lesson progresses. Build upon their ideas and make them aware that they are going to build and optimize a grist/flour mill system as a part of this activity.

Explore:

1. Years ago there were flour mills (or grist mills) lining almost every creek and stream. These mills used water to turn a water wheel for power. The water wheel was connected by way of belts and gears to a heavy, rotating stone that sat on top of a stationary stone. Farmers would bring their grain to the mill and pour the grain under the rotating stone. The rotating stone ground the grain against the stationary stone, turning it into flour, which was forced out along the edges of the stones. After grinding, farmers had flour to sell or take back home for baking bread, pies, cakes, and muffins. Students will examine their model and try to imagine a solid stone that would turn around on another stone. How do you think the grain was poured into the system so that it could be ground between the stones? (You might try looking this up on Google! For a sample picture of a mill stone, look at: http://www.wellsweepgallery.com/gallery/sculpture/sculpture_05.html)

> (NOTE: At the time of publication, these websites were operational and useful resources for information relative to flour mills. Please visit this and all websites before sharing them with students to ensure that the content is still appropriate.)

2. Students will describe why there are grooves in grist stones like the one shown on the website above. They will also provide suggestions to explain why the grooves form a pattern. A video of an antique flour mill in operation will be very useful as you help students understand the stones, operation and challenges of a flour mill. For example: http://www.flickr.com/photos/1rod/3630570876/ provides several videos and commentary about how milling was done.

Explain:

3. Allow students time to examine the Grist/Flour mill model. What do the yellow horizontal gears represent in this model? Why is it necessary for the lower gear to remain stationary? If this model were an operating flour mill, describe how it would use water power to provide the force to grind wheat to form flour.

4. Trace the path of energy from the falling of the water to the turning of the stone. Use a flow chart to complete this task.

5. A series of questions will guide students as they examine the grist/flour mill system. How many turns of the water wheel are needed to turn the top stone once? What is the gear ratio between the red and yellow gears on the grist/flour mill? In your own words explain what this ratio means. (This is a geared down system, and the gear ratio is approximately 2.5:1. That means the system multiplies force to move the top stone with greater force.) How would the operation of the grist/flour mill be different if the gear ratio represented a geared up system? (A gear ratio of 2.5:1 in a geared up system would mean the system would try to move the grinding stone more quickly. This would require a great deal more energy than the falling water could provide.)

Elaborate:

6. How much water is needed to turn the top stone (gear) twice if the water is poured from a height of 10 centimeters above the top of the water wheel? Students will design an experiment to answer this question. Have students write out the procedure they will use before beginning to experiment. Students should place the Grist/flour Mill into the green tub for testing, to aide in containment and reuse of water.

Teacher Note: Review each of the plans that the various groups will use to complete the activity and gather their data. Ask students how many trials they will use to determine how much water is needed to turn the top stone twice. Is one trial enough? Are two or three trials too many? Ask them to defend their decisions.

7. What can you do to improve this machine to make it more efficient?

   Students will think of as many improvements as they can and list them on their Student Response Sheet.

   The following directions will guide the students' investigations.

   Make changes to your model to improve its performance. Make these changes one at a time. Record your data for these improvements in the chart that is provided. Your group will need to establish a 'standard' for comparison. (You already know how much water it takes to turn the stone twice. Let that value establish your standard.) Enter the amount of water from the previous investigation on the chart and use that amount of water for each trial. You will compare the results to the standard after you have made changes to the model in each of the trials that you attempt.

(Sample Data Provided as an Example)

Amount of Water ________ ml	Number of Rotations of yellow gear	Change that was made to the model ____________ ____________
Trial 1: Standard	**2**	No change- This data represents the original model.
Trial 2:	**3.5**	We added foil to the blades of the water wheel to make sure no water went through the blades
Trial 3:	**3**	We made the blades of the water wheel longer
Trial 4:	**Etc.**	

a. Describe which changes improved the efficiency of the machine. Why do you think these changes were effective?

b. Which trial worked best? Provide evidence that supports why this trial worked best.

Evaluate:

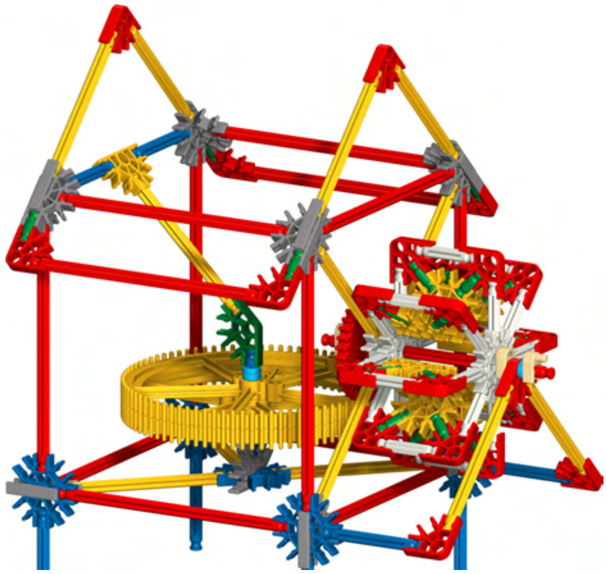
c. One or more of your trials may have improved the efficiency of your model. (An operational definition of efficiency in this activity might be: Efficiency is improved by getting more movement of the yellow top gear with the same or less volume (or mass) of water. Cite the results of your trial to support what you have described. Then describe how your data can be interpreted to support your claim.

Teacher Note: Students may suggest any of the following changes or others that they expect to work: vary the height from which the water drops; change the gearing of the yellow stone; alter the shape, number and design of the paddles.

Extensions:

1. Have students examine pictures of water wheels and mill designs and offer comments on effective and ineffective elements of these systems. Have students prepare an engineering design study report on an antique mill design or picture.
2. What are advantages of having water go over the wheel compared to going under the wheel? Challenge students to craft an experiment that might provide data for this variable. (This aspect of water wheels can be researched on the Internet and/or with school reference materials as well.)
3. Today's flour is made by steel rotating drums. What are advantages and disadvantages to this innovation?

Lesson 6: GRIST/FLOUR MILL



1. Years ago there were flour mills (or grist mills) lining almost every creek and stream. These mills used water to turn a water wheel for power. The water wheel was connected by way of belts and gears to a heavy, rotating stone that sat on top of a stationary stone. Farmers would bring their grain to the mill and pour the grain under the rotating stone. The rotating stone ground the grain against the stationary stone turning it into flour which was forced out along the edges of the stones. After grinding, farmers had flour to sell or take back home for baking bread, pies, cakes, and muffins. Examine your model and try to imagine a solid stone that would turn around on another stone.

- How do you think the grain was poured into the system so that it could be ground between the stones? The internet or library will provide information that will assist with your answer. Also, check with your teacher for suggestions. Feel free to include a drawing with your answer.

2. Using information provided by your teacher, research mill stones. Why do you suppose there are grooves on the bottom of the stone?

3. Examine the grist/flour mill model.

- What do the yellow horizontal gears represent in this model?

- Why is it necessary for the lower gear to remain stationary?

- If the model were an operating flour mill, describe how it would use water power to provide the force to grind wheat.

4. Use a flow chart to trace the path of energy from the falling water to the turning of the stone.

5. How many turns of the water wheel are needed to turn the top stone once?

- What is the gear ratio between the red and yellow gears on the grist/flour mill? Describe how you determined the gear ratio.

- In your own words explain what this ratio means. Is the system geared up or geared down?

- If the gear ratio was approximately the same in a geared up system how would the operation of the grist/flour mill be different?

6. How much water is needed to turn the top stone (gear) twice if the water is poured from a height of 10 centimeters above the top of the water wheel?

Discuss how your group will complete this investigation before you begin. Write out the procedure you will use. Place the Grist/flour Mill into the green tub for testing to aide in containment and reuse of water.

7. What can you do to improve this machine to make it more efficient? Think of as many improvements as you can and list them below.

Make changes to your model to improve its performance, one at a time. Record your data for these improvements in the chart that is provided. Your group will need to establish a "standard" for comparison. You already know how much water it takes to turn the stone twice. Let that value establish your standard. Enter the amount of water from the previous investigation on the chart and use that amount of water for each trial. You can compare the results to that standard after you have made changes to the model in each of the trials.

Amount of Water ________ ml	Number of Rotations of yellow gear	Change that was made to the model
Trial 1: Standard	**2**	No change- This data represents the original model.
Trial 2:		
Trial 3:		
Trial 4:		

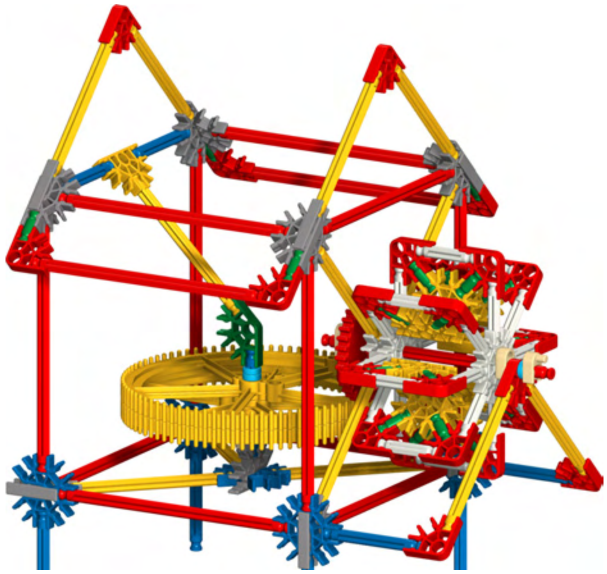
a. Describe which changes improved the machine. Why do you think these changes were effective?

b. Which trial worked best? Provide evidence to support your answer.

One or more of your trials may have improved the efficiency of your model. An operational definition of efficiency for this activity might be: Efficiency of the system is improved if the yellow gear completes more than two rotations with the use of the same amount of water or less water than was used in the standard trial.

c. Describe how one of your trials improved the efficiency of your model.

Lesson 6: GRIST/FLOUR MILL



1. Years ago there were flour mills (or grist mills) lining almost every creek and stream. These mills used water to turn a water wheel for power. The water wheel was connected by way of belts and gears to a heavy, rotating stone that sat on top of a stationary stone. Farmers would bring their grain to the mill and pour the grain under the rotating stone. The rotating stone ground the grain against the stationary stone turning it into flour which was forced out along the edges of the stones. After grinding, farmers had flour to sell or take back home for baking bread, pies, cakes, and muffins. Examine your model and try to imagine a solid stone that would turn around on another stone.

- How do you think the grain was poured into the system so that it could be ground between the stones? The internet or library will provide information that will assist with your answer. Also, check with your teacher for suggestions. Feel free to include a drawing with your answer.

  (Answers will vary. The students should be able to discover that the grain was poured into an opening in the center of the top stone.)

2. Using information provided by your teacher, research mill stones. Why do you suppose there are grooves on the bottom of the stone?

   (As the grain was ground into flour, the flour would slide into the grooves. More grain coming in from the middle of the stone added pressure that moved the flour along the grooves. The rotating stone added a centrifugal force which helped move the flour along the grooves. The grooves of some stones were curved in the direction of motion to further move the flour to the edge of the stones.)

3. Examine the grist/flour mill model.

- What do the yellow horizontal gears represent in this model?

(The yellow gears represent the mill stones.)

- Why is it necessary for the lower gear to remain stationary?

(The stationary stone provides a surface for the top stone to rub the grain against.)

- If the model were an operating flour mill, describe how it would use water power to provide the force to grind wheat.

(The paddles represent the water wheel. The K'NEX model works in the green tub and water is poured onto the paddles from above. The rotating water wheel turns a gear which in turn turns the yellow gear.

4. Use the flow chart to trace the path of energy from the falling water to the turning of the stone.

(Moving water [kinetic energy] ⟶ moving water wheel [mechanical energy] ⟶ gear rotation [mechanical energy] ⟶ mill stone rotation [mechanical energy].)

5. How many turns of the water wheel are needed to turn the top stone once?

(By experimentation the students will find that the water wheel turns about 2.5 times for each turn of the yellow gear [stone].)

- What is the gear ratio between the red and yellow gears on the grist/flour mill? Describe how you determined the gear ratio.

(There are 84 teeth on the yellow gear and 34 teeth on the red gear. Therefore the gear ratio is computed by dividing 84 by 34. The resulting answer is 2.47. When written as a ratio it is phrased as 2.47:1. This matches the value for the previous answer.)

- In your own words explain what this ratio means. Is the system geared up or geared down?

(To spin the mill stone one time, the water wheel needs to go around about 2.5 times. This is a geared down system.)

- If the gear ratio was approximately the same in a geared up system how would the operation of the grist/flour mill be different?

(In a geared up system the relationship of the gears would be just the opposite. The red gear would have to be 2.5 times larger than the yellow gear. Such a system would require a great deal of force to operate. As a result, there would probably not be enough water power to turn the stone.)

6. How much water is needed to turn the top stone (gear) twice if the water is poured from a height of 10 centimeters above the top of the water wheel?

Discuss how your group will complete this investigation before you begin. Write out the procedure you will use. Place the Grist/flour Mill into the green tub for testing to aide in containment and reuse of water.

(Answers will vary. Students must state how they will count complete turns of the yellow gear and include a technique to measure the volume of water that they will use. Students should indicate that they will attempt several trials and that they will average their results.)

7. What can you do to improve this machine to make it more efficient? Think of as many improvements as you can and list them below.

(After doing the activity in the previous question, students will probably recognize it is difficult to pour water onto the paddles and that a great deal of water is wasted. Most improvements that students offer will deal with this issue: For example, cover the paddles so water doesn't go through the holes, channel the water with a funnel or chute so it lands right on top of a paddle, etc. Students might suggest a larger paddle wheel.)

Make changes to your model to improve its performance, one at a time. Record your data for these improvements in the chart that is provided. Your group will need to establish a "standard" for comparison. You already know how much water it takes to turn the stone twice. Let that value establish your standard. Enter the amount of water from the previous investigation on the chart and use that amount of water for each trial. You can compare the results to that standard after you have made changes to the model in each of the trials.

Amount of Water ________ ml	Number of Rotations of yellow gear	Change that was made to the model
Trial 1: Standard	**2**	No change- This data represents the original model.
Trial 2:		*Answers will vary.*
Trial 3:		*Answers will vary.*
Trial 4:		*Answers will vary.*

a. Describe which changes improved the machine. Why do you think these changes were effective?

(Answers will vary. This question asks students to analyze their design and their data. A quick check of the students' charts will clearly indicate which data sets improved the performance of the model when compared to the standard.)

b. Which trial worked best? Provide evidence to support your answer.

(Answers will vary. This question asks students to rank their experiments. Ranking can be done just with the data or by including anecdotal observations along with the data.)

One or more of your trials may have improved the efficiency of your model. An operational definition of efficiency for this activity might be: Efficiency of the system is improved if the yellow gear completes more than two rotations with the use of the same amount of water or less water than was used in the standard trial.

c. Describe how one of your trials improved the efficiency of your model.

(Answers will vary. Example: When we covered the paddles on the water wheel with foil, they didn't allow water to pass through them and be wasted. We were able to turn the yellow top gear three times with the same amount of water that originally could only turn the gear two times. Thus, our trial improved efficiency.)

Wind Power

Introduction:

This unit studies the topic of renewable energy as students investigate lessons related to solar power, wind power, and water power. Students will investigate the science behind these energy sources and the technologies that help to make them useful. This series of lessons deals with wind power. As the need for energy is constantly increasing, countries have turned to alternative sources for that energy. One of the alternative energy sources that appears to have great promise is wind. Wind farms have been sprouting up everywhere.

See:
http://www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/?stc=usccc021710

http://www.windpoweringamerica.gov/wind_maps.asp

http://motherjones.com/blue-marble/2009/12/largest-wind-farm-united-states-be-built-oregon

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

Through the investigation of wind powered models, we can provide students with practical information about this form of energy and the opportunity to explore and investigate this renewable energy source on their own.

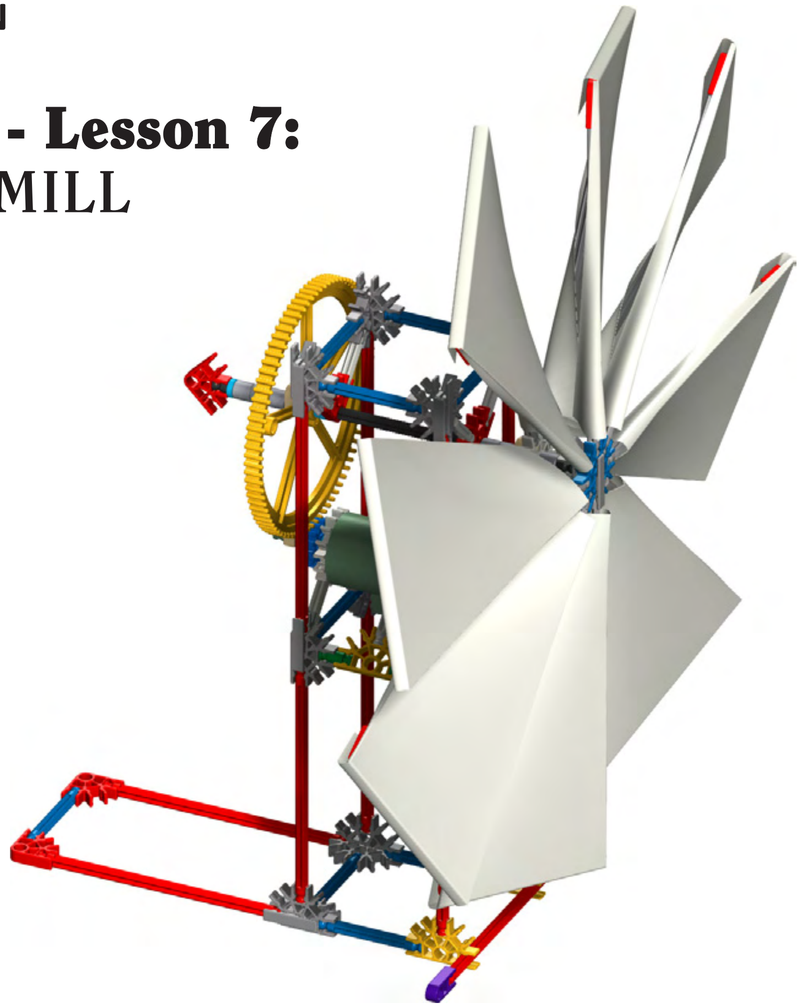
This particular unit is written in a 5E instructional model. The elements of the 5E model are Engage, Explore, Explain, Elaborate and Evaluate (see BSCS for more explanation at: http://www.bscs.org/pdf/bscs5eexecsummary.pdf)

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 will explore energy efficiency as energy is converted from one form to another. Additionally, as they calculate the energy in wind powered systems, students will use experimental data in conjunction with their physical science knowledge to demonstrate their understanding of energy and its transformations from one form (kinetic) to another (potential or electrical)

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 used today. The story of windmills includes the Dutch who use wind power to grind grain and pump water as well as farmers around the world who use the power of the wind to pump well water for their animals and/or crops. Contemporary wind farms and personal windmills are making a small but steadily increasing impact in the amount of electrical energy available in the United States and other countries.

Wind Power - Lesson 7:
WINDMILL



Time Frame:
3 x 40 minute sessions

Student Objectives:
Students will demonstrate the ability to:

- Discover the most efficient blade combination for a power generating windmill
- Design and carry out one or more experiments to investigate variables associated with windmill performance
- Design and test a strategy to determine the power output of a windmill directly or indirectly

Materials:
- The K'NEX Education Renewable Energy Set
- Templates for two styles of windmill blades (Are the first 2 cutouts at the end of this Teacher's Guide after the glossary section. Directions to put them on are found in the instructions booklet.)
- A 20-24 inch box fan with 3 speeds is recommended
- Stopwatches
- Meter sticks or metric tapes
- Graph paper

For Extension Activities:
- String
- Small masses (metric masses, washers, coins, metal nuts, etc.)

Investigation 1: How can you determine the number of blades your windmill will need to spin at top speed?

Engagement:

Provide several pictures of windmills or show PowerPoint™ slides of windmill images that you have collected from the internet. These images will heighten interest and provide a frame of reference for discussion.

Have a group of students construct the Windmill model for reference during this engagement activity.

- Does the number of blades affect how fast a windmill spins? Provide several ideas about this possibility and describe why you believe these ideas are correct.
- How can you measure the speed of spinning windmill blades?

Teacher Note: Before examining the affect of the number of blades on a windmill, ask students to list other factors that might make the windmill turn faster or slower.

Students might suggest a number of variables such as:
- The height of the blades above the ground.
- The heavy parts have momentum and inertia to overcome and therefore lighter and fewer blades might work better.
- Blade shape and aerodynamics may affect the speed of the blades. E.g. propellers might work better than paddles.
- Bigger blades may catch more air and turn the blades faster.

When students build the model they may suggest that the gears and motor that are attached to the system are slowing down the system. The motor is actually acting as an electrical generator in this application. The students are correct; the system does slow down the turning blades. Later activities will examine the generator and its operation. The second investigation that the students complete will use information students gathered during their first investigation so it is important that the students explore the windmill with the gears and generator in place during Investigation 1. An excellent extension activity would be to have students complete the first investigation using the model with the gear system removed.

Explore:

1. Students will construct the K'NEX Windmill model following the instructions provided. There are two different blade designs that the students can use for their exploration. Allow them to select the design that they would like to explore. Provide time for the students to investigate their model before they attempt to design an experiment to answer the question above.

   This experiment is an exercise in controlling variables and understanding rotational forces. Students should discover the optimum number of blades that will produce the greatest windmill speed. Also, students will learn that if the blades are unbalanced on the hub of the windmill the windmill with vibrate quite dramatically. Students will be making many changes to the model. It is important that they return the model to its original configuration before moving on to further experiments. For example, students should:

- Make sure the spacers in the rotating parts are aligned properly.
- Ensure that the frame is tight.
- Verify that all components spin freely with no binding.

The windmill should to be placed at the same distance and angle from the fan during each trial so that the only variable is the number of blades.

There is an extension on the base of the windmill model that was designed to support textbooks that will keep the model in place during experimentation.

Students should cover the framework of the blades with paper for this activity. The Teacher's Guide includes two templates for blade covers that can be made from single sheets of paper. Students will use a bright red marker to color one of the blade covers to serve as the counting blade for rpm (revolutions per minute) studies.

Examine and Explain the Windmill:

2. Procedure: Student groups will be directed to design an experimental strategy that will enable them to determine the number of blades that will produce the greatest windmill speed. For example, some groups might elect to begin with eight blades like the original model and remove blades one by one. Other groups might decide to keep the system balanced by taking away two blades at a time. Each design strategy can be tried so that students discover the optimum number of blades. At the same time, they will discover that the arrangement of the blades is very critical to the performance of the windmill. The key element of concern throughout the process is to ensure that students change only one variable at a time as they experiment. Given the geometry of the model, it is easy to investigate 2, 4, 6, and 8 blades. Students will find that odd numbers (e.g. 5 and 7) of blades will produce unbalanced conditions and the model will not perform well. Ask students to experiment with as many numbers of blades as time allows or, students can be assigned a sequence of blade arrangements to test.

Collecting Data on the Spinning Windmill:

As students experiment with the various combinations of blades, they will need to gather and record data in an organized fashion. The table below provides one example of what a data table might look like. The table is set up so students collect data for 30 seconds three times before averaging the number of turns of the blades in 30 seconds. The average is then multiplied by two to determine the number of turns (rotations) in one minute (rpm).

# of Blades	Trial 1 Turns/30 sec	Trial 2 Turns/30 sec	Trial 3 Turns/30 sec	Average Turns/30 sec	Multiply x 2	Average Speed in (rpm)

Elaborating on the Data:

3. The following questions may be helpful in guiding your students' thinking as they present, analyze and interpret the data that they have collected.

a. Using the data that you have collected, graph your findings. The number of blades is the independent variable and is placed on the x-axis of the graph. The speed is the dependent variables and is placed on the y-axis of the graph.

b. What information does your graph indicate?

c. Which number of blades provided the fastest spinning windmill based on your data?

d. Which worked better, odd or even numbers of blades? Why? What observations or evidence helps explain this answer?

e. What other variables could you test to determine their impact on windmill speed?

Evaluation:

Write a letter to the 'Super Fast Windmill Company' that explains how many blades they should use on their very best windmills to make them as fast as possible. Be sure to include evidence from your experiments that support your conclusion.

Investigation 2: How much electrical energy does your best windmill design produce with a high, medium and low speed fan?

Explore:

1. Using the blade configuration the students found turned the blades the fastest in the last investigation, they will be introduced to the generator that is attached to their windmill model, and be challenged to design an experiment that will enable them to determine how much electrical energy their best windmill design is able to produce. It is suggested that you provide students with an opportunity to complete an internet search that introduces them to generators and the systems that commercial windmills use to convert wind energy into electricity. The K'NEX windmill model system is an excellent example of how wind energy can be used to produce electricity. Additionally, the performance of the model helps students to realize that when the model is tasked with producing electricity, the mechanical systems that assist in the energy conversion add friction that slows the operation of the model.

2. Have students must borrow a Shuttle Ride or Crank Man model from another group to generate electricity with the windmill model, and use that electricity to power the other model.

3. Students will attach the motor on the borrowed model to the generator on the windmill model, with the wire provided. They will then spin the windmill with their hands to see what happens. Have students answer the following questions as they investigate.
   - What happens to the model you connected to the windmill when you turn the windmill blades?
   - What happens if you let the models stop moving and then turn the windmill in the opposite direction?
   - What happens if you spin the windmill model fast?
   - What happens if you spin the windmill slowly?
   - How many times does the second model turn in 15 seconds if you spin the windmill 20 times quickly? (Have one of your group members hold the windmill as you turn the blades.)
4. The students can now begin to design an experiment that will answer the question above. The questions below will guide them as they decide on a procedure and develop their data table.
   - How far will you place the windmill in front of the fan?
   - Which type of blade will you use on your windmill?
   - How many blades will you use on your windmill?
   - How many speeds are there on the fan you are using?
   - What will you measure to determine how much electricity your windmill is producing?
   - What is the independent variable in your experiment?
   - What is the dependent variable in your experiment?
   - How long will each trial last as you collect data?
   - How many trials will you complete with each fan speed? Why?
   - How will you organize and present your data?
   - Will you average your results? Why?
   - Will you graph your results? What type of graph will you use?
   - When the results are compared for the different speeds of your fan, what do you think they will show?
5. When students have answered all of the questions above they should write their procedure on a separate sheet of paper and gather the materials they will need for their experiment.

Explain and Elaborate:

6. The students will write their results on the Student Response Sheet.

7. The students will then answer questions to demonstrate their understanding of the activity and their results.

- Which fan speed produced the most electrical energy? How do you know?
- Do you see any pattern in your data when you observe the graph you prepared? Describe the pattern. What does the pattern mean to you?
- Write a single sentence that describes the relationship between the speed of the fan and the amount of electricity the windmill produces.

Evaluate:

8. Have students describe how the results of their experiment would have been different if they had chosen the other model (Crank Man or Shuttle Ride). They should realize that the Crank Man is a more complex system that will require additional energy to operate. As a result, if they used the Crank Man for their experiment they would say the experiment would be different with the Shuttle Ride because the ride would spin much faster than the Crank Man cranks. If, on the other hand, they used the Shuttle Ride for their experiment they would say the Crank Man would have cranked slower than the Shuttle Ride spun.

Possible Extensions: The windmill model provides the opportunity for a variety of other investigations.

What is the maximum distance the windmill can be placed from the wind source and still turn consistently?

Questions to guide experimentation:

- How far can you place the windmill from the fan and still have the blades turn when the fan is set on High?
- How far can you place the windmill from the fan and still have the blades turn when the fan is set on Medium?
- How far can you place the windmill from the fan and still have the blades turn when the fan is set on Low?
- Is there any relationship or pattern that you can identify in your data?
- Is there a relationship between the distance the windmill is from the fan and the speed of the windmill?
- Why isn't this information pertinent to windmills that are placed in nature?

Is there a blade angle that causes the windmill to spin fastest?

Questions to guide experimentation:

- How fast does the windmill model spin when the blades on the windmill are flat?
- How fast does the windmill model spin when the blades on the windmill are fixed at a slight angle?
- How fast does the windmill model spin when the blades on the windmill are fixed at a sharp angle?
- Describe the angle of the blades on commercial windmills you have seen.
- How do these observations compare with the information you found during your investigation?

Teacher Note: This investigation will require that students redesign the hub and blades of their windmill. Allow time for students to explore their options and to make appropriate changes to their model.

Additional Activities to Consider:

a. The axle on the windmill is attached to a gear system.

- Do the gears speed up the system or make the system move with greater force?
- What is the gear ratio of the gear train? Is it geared up or geared down?

b. The gear system is attached to an electric generator.

- How does the generator affect the speed of the windmill?
- When the generator is used to power another model, does that affect the speed of the windmill?

c. Ask students to remove the gear from the axle of the windmill. The axle is now able to spin much more freely. Students can repeat any of the investigations that were completed above with the blades spinning more freely.

- The question is, "Do the discoveries made earlier still hold with a free spinning windmill?"

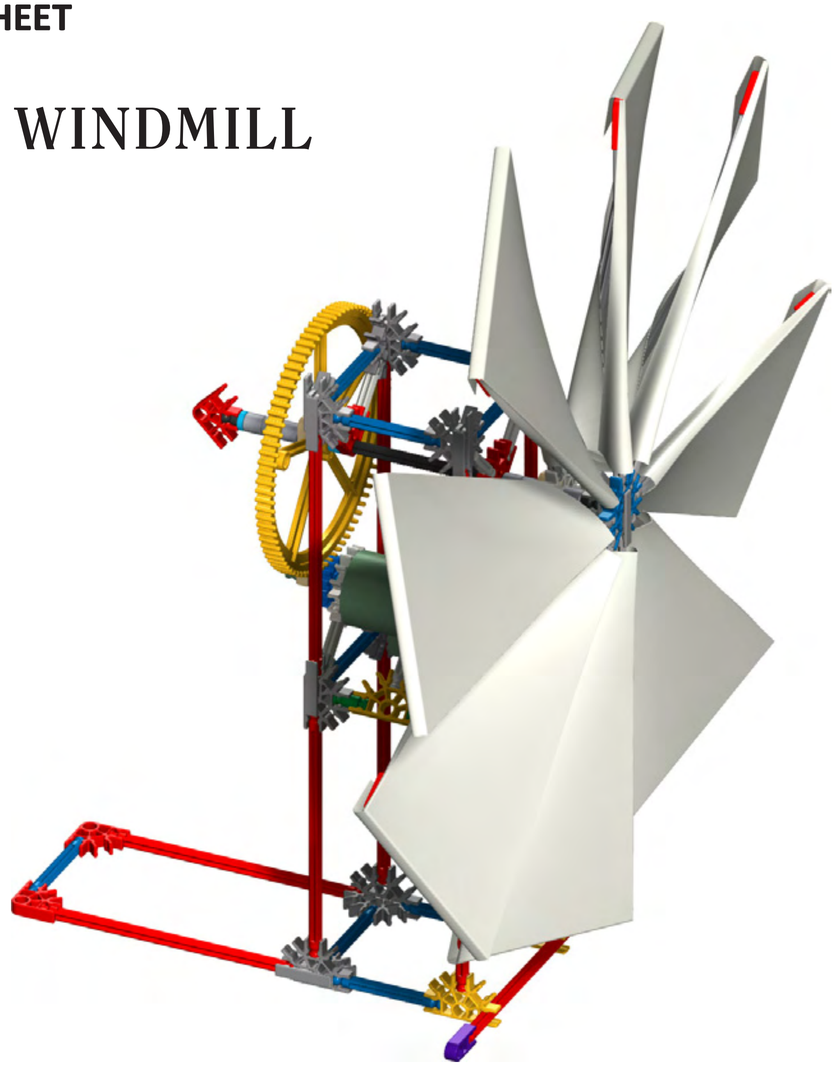
d. Ask students to fix a length of string (a meter or two) to the axle of the windmill. Attach a small weight to the end of the string (a metal washer or small item).

- Is the windmill system able to drag the weight across the table when a fan powers the windmill?
- How heavy a weight is the system able to move?

e. Set up the windmill system so that the windmill lifts the weight. This weight (which is a force) times the distance lifted is a measure of work that is done. Students can determine through experimentation the maximum work available at the axle of the windmill.

- How is work defined? What are the units of work?
- How does this activity clarify the definition of potential and kinetic energy that was introduced earlier?
- How might we use this information to better understand the electrical energy that is produced through this system? How can we measure electrical power?

Lesson 7: WINDMILL



Investigation 1: How can you determine the number of blades that your windmill will need to spin at top speed?

Construct the K'NEX Windmill model following the instructions provided. There are two different blade designs that can be used for the windmill model. Your group may select either of these blade designs. Use the template provided to prepare blade covers for the windmill. Use a bright marker to place a large dot near the end of one of the blades. This will make it much easier for your group to count how many times the blades turn during these investigations.

Design a procedure that will allow you to answer the question above. Before designing a procedure, use a fan and observe the spinning windmill to determine how to count turns of the blades. Investigate both the speed of the fan and the distance the fan is from the windmill in order to find a speed where you can accurately count turns of the blades.

Write an experimental procedure that will allow you to answer the question on a separate sheet of paper. Share the procedure your group has decided upon with your teacher before beginning your experiment.

Use the following table to collect and organize your data.

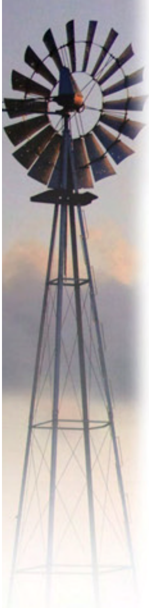
# of Blades	Trial 1 Turns/30 sec	Trial 2 Turns/30 sec	Trial 3 Turns/30 sec	Average Turns/30 sec	Multiply x 2	Average Speed in (rpm)
					x 2	
					x 2	
					x 2	
					x 2	

a. Using the data that you have collected, graph your findings. The number of blades is the independent variable and is placed on the x-axis of the graph. The speed of the blades is the dependent variable and is placed on the y-axis.

b. Which number of blades provided the fastest spinning windmill based on your data?

c. Did your windmill work better with an even number of blades or an odd number of blades? Why?

d. What observations or evidence helps explain this answer?



e. What other variables that affect the speed of a windmill could you examine?

f. What is your recommendation for the number of blades to use if someone wanted to build the fastest windmill? What evidence can you cite that supports this conclusion?

Investigation 2: How much electrical energy does your best windmill design produce with a high, medium and low speed fan?

1. Have students use the blade configuration they found turned the blades the fastest in the last investigation. The solar motor that is mounted on your windmill is acting as a generator. Normally, electricity from a solar panel causes the motor to turn gears that power many K'NEX solar models. When conditions are reversed and the motor is turned mechanically by your hand or in this activity a windmill, the motor produces an electrical current that will operate another model that has a solar motor. You will complete some activities to explore this generator system and then your group will design an experiment to answer the question above.
2. To complete this investigation, you will need to borrow a Shuttle Ride or Crank Man model from another group.
3. Attach the motor on the model you borrowed to the generator on the windmill model using the wire provided. Spin the windmill with your hands and observe what happens. Answer the following questions as you investigate.
   - What happens to the model you connected to the windmill when you turn the windmill blades?
   - What happens if you let both models stop moving and then turn the windmill in the opposite direction?
   - What happens if you spin the windmill model fast?
   - What happens if you spin the windmill slowly?
   - How many times does the second model turn in if you spin the windmill 20 times quickly? (Have one of your group members hold the windmill as you turn the blades.)

4. Design an experiment that will answer the bulleted questions on the previous page. The questions below will guide your group as you decide on a procedure and develop your data table.

- How far will you place the windmill in front of the fan?
- Which type of blade will you use on your windmill?
- How many blades will you use on your windmill?
- How many speeds are there on the fan you are using?
- What will you measure to determine how much electricity your windmill is producing?
- What is the independent variable in your experiment?
- What is the dependent variable in your experiment?
- How long will each trial last as you collect data?
- How many trials will you complete with each fan speed? Why?
- How will you organize and present your data?
- Will you average your results? Why?
- Will you graph your results? What type of graph will you use?

- When the results are compared for the different speeds of your fan, what do you think they will show?

5. Write your procedure, data chart and graph on a separate sheet of paper. Gather the materials you will need for the experiment. List your results below.

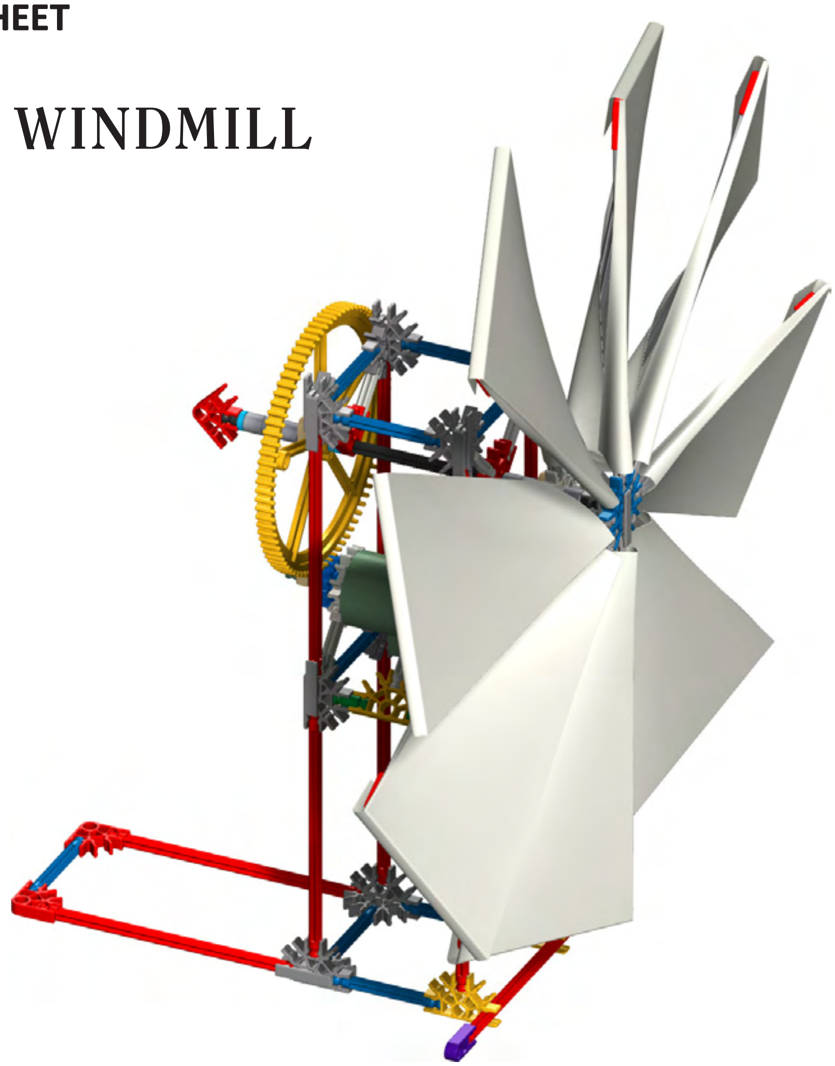
6. Answer the following questions:

- Which fan speed produced the most electrical energy? How do you know?

- Do you see any pattern in your data when you observe the graph you prepared? Describe the pattern. What does the pattern mean to you?

- Write a single sentence that describes the relationship between the speed of the fan and the amount of electricity the windmill produces.


Lesson 7: WINDMILL



Investigation 1: How can you determine the number of blades that your windmill will need to spin at top speed?

Construct the K'NEX Windmill model following the instructions provided. There are two different blade designs that can be used for the windmill model. Your group may select either of these blade designs. Use the template provided to prepare blade covers for the windmill. Use a bright marker to place a large dot near the end of one of the blades. This will make it much easier for your group to count how many times the blades turn during these investigations.

Design a procedure that will allow you to answer the question above. Before designing a procedure, use a fan and observe the spinning windmill to determine how to count turns of the blades. Investigate both the speed of the fan and the distance the fan is from the windmill in order to find a speed where you can accurately count turns of the blades.

Write an experimental procedure that will allow you to answer the question on a separate sheet of paper. Share the procedure your group has decided upon with your teacher before beginning your experiment.

(The procedure should indicate the variable the students will test, the technique they will use to test that variable, the data they will collect. It should also explain how they will analyze their results. If the procedure is not complete or clearly stated, ask that students revise their procedure.)

The following table may be helpful as you collect and organize your data.

(This is a sample of data obtained in a classroom setting)

# of Blades	Trial 1 Turns/30 sec	Trial 2 Turns/30 sec	Trial 3 Turns/30 sec	Average Turns/30 sec	Multiply x 2	Average Speed in (rpm)
8	37	39	38	39	x 2	78
6	41	42	44	41.5	x 2	83
4	42	44	41	41.5	x 2	83
2	31	35	34	33.5	x 2	67

a. Using the data that you have collected, graph your findings. The number of blades is the independent variable and is placed on the x-axis of the graph. The speed of the blades is the dependent variable and is placed on the y-axis.

b. Which number of blades provided the fastest spinning windmill based on your data?

(Answers will vary. Some groups found 2 blades to be the fastest. The above data shows that 4 and 6 were the fastest.)

c. Did your windmill work better with an even number of blades or an odd number of blades? Why?

(An even number of blades spun smoothly with less vibration. The system is balanced with an even number of blades.)

d. What observations or evidence helps explain this answer?

(It was not easy to use an odd number of blades due to the structure of the hub used for this activity. Also, when odd numbers of blades were used, the model vibrated. An even number of blades were balanced on the hub, allowing the model to run smoothly without vibration.)

e. What other variables that affect the speed of a windmill could you examine?

(Students may suggest: the size of the blades – both length and width, the shape of the blades, etc.)

f. What is your recommendation for the number of blades to use if someone wanted to build the fastest windmill? What evidence can you cite that supports this conclusion?

(Answers will vary. Ensure that the students support their recommendations with logical arguments. The answer to this question is an example of optimization. Students are recommending the option that will allow the windmill to operate at maximum efficiency.)

Investigation 2: How much electrical energy does your best windmill design produce with a high, medium and low speed fan?

1. Have students use the blade configuration they found turned the blades the fastest in the last investigation. The solar motor that is mounted on your windmill is acting as a generator. Normally, electricity from a solar panel causes the motor to turn gears that power many K'NEX solar models. When conditions are reversed and the motor is turned mechanically by your hand or in this activity a windmill, the motor produces an electrical current that will operate another model that has a solar motor. You will complete some activities to explore this generator system and then your group will design an experiment to answer the question above.

2. To complete this investigation, you will need to borrow a Shuttle Ride or Crank Man model from another group.

3. Attach the motor on the model you borrowed to the generator on the windmill model using the wire provided. Spin the windmill with your hands and observe what happens. Answer the following questions as you investigate.

   - What happens to the model you connected to the windmill when you turn the windmill blades?

     (The model moves as the windmill blades turn.)

   - What happens if you let both models stop moving and then turn the windmill in the opposite direction?

     (The second model turns in the opposite direction.)

   - What happens if you spin the windmill model fast?

     (The second model turns fast.)

   - What happens if you spin the windmill slowly?

     (The second model slows down.)

   - How many times does the second model turn in if you spin the windmill 20 times quickly? (Have one of your group members hold the windmill as you turn the blades.)

     (Answers will vary. The answers depend on the speed the windmill is turned and the model that the group borrows.)

4. Design an experiment that will answer the bulleted questions on the previous page. The questions below will guide your group as you decide on a procedure and develop your data table.

- How far will you place the windmill in front of the fan?

  (Answers will vary.)

- Which type of blade will you use on your windmill?

  (Answers will vary.)

- How many blades will you use on your windmill?

  (Answers will vary.)

- How many speeds are there on the fan you are using?

  (Three speeds in most cases.)

- What will you measure to determine how much electricity your windmill is producing?

  (The number of times the second model cranks or turns in 30 seconds or a similar answer.)

- What is the independent variable in your experiment?

  (The speed of the fan is the independent variable.)

- What is the dependent variable in your experiment?

  (The speed of the second model is the dependent variable.)

- How long will each trial last as you collect data?

  (Thirty seconds or some other short time frame is appropriate.)

- How many trials will you complete with each fan speed? Why?

  (Three. Generally, three trials are acceptable in classroom investigations.)

- How will you organize and present your data?

  (The students' data tables will vary.)

- Will you average your results? Why?

  (Yes, to avoid the impact of error with some trials.)

- Will you graph your results? What type of graph will you use?

  (Yes, a bar graph will be used.)

- When the results are compared for the different speeds of your fan, what do you think they will show?

  (Answers will vary depending on the students' prior knowledge.)

5. Write your procedure, data chart and graph on a separate sheet of paper. Gather the materials you will need for the experiment. List your results below.

(Answers will vary but they will be in terms of how many cranks or spins the second model they used was able to produce.)

6. Answer the following questions:

- Which fan speed produced the most electrical energy? How do you know?

  (High speed, it caused the second model to turn the fastest.)

- Do you see any pattern in your data when you observe the graph you prepared? Describe the pattern. What does the pattern mean to you?

  (The graph only had three points but they produced 3 bars that got progressively taller as they moved from low to high speed.)

- Write a single sentence that describes the relationship between the speed of the fan and the amount of electricity the windmill produces.

  (Answers will vary. The faster the speed of the fan, the more electrical energy the generator is able to produce.)

Wind Power - Lesson 8: SAIL CAR

Time Frame:

3 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Adjust the sail angle to maximize distance traveled.
- Suggest, make and test other sail designs to improve sail car performance.
- Complete and report a series of trials with different sail designs that create a car that sails further than their initial trial.
- Reflect on the design process and note the importance of observation, record keeping and careful measurements.

Materials:

- The K'NEX Education Renewable Energy Set
- Template for the sail of the sail car (Is the third cutout at the end of this Teacher's Guide after the glossary section. Directions to put them on are found in the instructions booklet.)
- Masking tape or blue painter's tape
- Miscellaneous K'NEX pieces
- Selection of fabrics (coarse, fine, porous and of different sizes) for sail making
- Selection of thin cardboard, thin plastic sheets, poster board, etc. for sail making
- Stapler
- Glue
- Thin string or strong thread
- Paper clips, rubber bands
- Meter stick or tape measure
- Stopwatch

Investigation 1: How does the Sail Car respond to wind?

Teacher Note: This activity can be done outside on a paved playground area but it is recommended that it be completed indoors. The car does not necessarily travel straight when pushed by a gust of wind. Indoors, preliminary tests saw sail cars able to travel up to 18 meters down a school hallway using a 24 inch box fan as a wind source. While 20-24 inch box fans work very well, smaller fans (properly shrouded for safety) work as well for experiments. Aspects of the physics of sailing are illustrated in the following investigations. Teachers and their students might examine research on the physics of sailing (one useful site is http://www.animations.physics.unsw.edu.au/jw/sailing.html)

Engagement:

Provide a photo of a sail car, a collection of PowerPoint™ slides with images you have collected from the internet and/or use a pre-built Sail Car model. Ask students to observe the model and then have them answer the questions listed below. Keep a record of their insights on the board or chart paper.

- How does this sail car work?
- Have you seen other devices or machines that work like this? Describe them. (Ice boats and wind surfing boards)

Explore:

1. Students will construct the sail car following the instructions provided. As they give the car a gentle push they will determine that it rolls fairly straight and very easily. Students may find it necessary to make adjustments in order to ensure that the sail car moves easily in a straight line.

2. Ask students to try to sail their car down wind (move in the direction the stream of air is coming from the fan). Ask students questions to help them focus their attention and improve their powers of observation. For example: Does the car seem to go in a straight line? Does the car move at a uniform speed as it moves away from the fan? Does the car sail further if it is released directly in front of the fan or if it is released one meter in front of the fan? How far does the car travel?

   Students will use pieces of tape to mark off a 2 meter section of the floor in front of the fan. The 2 meter section should begin one meter in front of the fan. (In preliminary tests this was a good starting point. When students get closer to the fan, they block some of the air which alters the experiment.) How long does it take the car to travel the 2 meters when it is released from the first piece of tape? Do you think the sail car is going as fast as the air, faster than the air or slower than the air? Students will experiment with the sail car to see if you can make it travel faster across the 2 meter section of the floor. Some suggestions will be provided to direct students' investigations but encourage them to think beyond the suggestions and to brainstorm ideas on their own with their group. They may:

a. Change the speed of the fan.

b. Change the height of the fan off the floor.

c. Change the angle of the wind stream.

d. Change the way they release the sail car, etc.

Remind students to change only one variable at a time as they experiment.

3. A blank data table will be provided for students to use as they describe the variables they selected, their observations, and the results of their sail car experiments:

Experimental Variable	Experimental Variable
Trial 1	**Time:**____________ **sec**
Trial 2	**Time:**____________ **sec**
Trial 3	**Time:**____________ **sec**
Trial 4	**Time:**____________ **sec**

Elaborate:

4. Students can combine the best results of their trials to offer a suggestion as to: What combination of factors (wind speed, wind direction, fan height off the floor, etc.) worked to produce the fastest time through a 2 meter distance?

Evaluate:

5. Ask students to respond to this question in a written or oral fashion. Based on the data and observations you have collected; what factors most influence the speed of the sail car as it moves across the two meter distance?

Investigation 2: How far can your Sail Car travel?

Explore:

1. Provide the students with a long section of a hallway or open room for their experiment (this investigation has been done successfully in a school hallway). Also, provide the groups with a supply of cloth, paper, and cardboard that they can use for sail material. In order to perform experiments to answer the question above, they may need to change the size and composition of their sail material.

2. Student groups will make whatever changes they would like to their car, with the materials provided, to enable it to travel as far as possible using the high speed setting on the fan.

3. The following experimental conditions will be constants for all groups that complete this activity.

- The fan will be set at high speed.
- The fan will be elevated 10 cm off of the floor.
- The car will be released at a distance of one meter in front of the fan.
- The car will travel in the same space used by each of the other groups.
- Each test of the car will include three trails and the results will be averaged.

Elaborate:

4. Students will report the changes they made to the car and Indicate why they made each of the changes. They will also describe the procedure they used to test how far the car traveled and design a chart to display the results of their trials. The average distance traveled by their car during its best test will be used when the results of all of the groups are compared.

5. Students will complete the following sentence.

If ____________________________________ would have been available to use on our car it would have traveled even further than our best trial because ______________________
____
____

Hopefully, students will identify well thought out ideas that they feel would improve the performance of their car. Possibly they will suggest materials that you can actually provide for them. If so, you may provide them with the opportunity to test their car with the new material.

Evaluate:

6. This is an opportunity for the students to relate what they have learned in the classroom to the real world. Emphasize the importance of this question and encourage students to devote sufficient time to their answer.

Would a sail car be of practical use on the road? Support your answer with data and observations from your experiments. How are modern cars designed to take advantage of air and wind?

Extension Activities:

1. Does the size of the sail make a difference? Students can craft squares of paper with different areas and test them.
2. Does the height of the sail above the car affect the performance of a sail car? This requires changing the car's construction to provide at least three different heights to test.
3. Does the orientation of the sail impact the performance of a sail car? The default angle of the sail is 900. Students can angle the sail to other settings by adjusting the mast. Students should test at least three different angles.
4. Does the position of the sail affect the car's performance? The sail car looks somewhat like a dragster with big wheels on the back, small wheels on the front and the sail located just in front of the rear wheels. Moving the sail to different positions on the gray side rails of the car requires some engineering and the use of additional K'NEX pieces.
5. How does varying the fan speed affect the performance of the sail car?
6. Do different sail materials affect the speed of the car?
7. Would a car with 4 small wheels work better than the car in the instruction booklet?

Evaluation:

Would a sail car be of practical use on the road? Support your answer with data and observations from your experiments. How are current cars designed to take advantage of air and wind?

Teacher Note: Students might think of aerodynamics to lessen the drag of air (sometimes called atmospheric drag). Many cars have features like air dams and wings to change the flow of air around, under and/or over the car. Students might not think of the air going through the radiator to keep the car engine at the proper temperature. Newer cars have a smooth undercarriage to reduce the drag of air. Open windows raise the resistance to the wind as do roof racks and other add-ons.

Lesson 8: SAIL CAR

Investigation 1: How does the Sail Car respond to wind?

1. Use the instruction booklet provided to construct the sail car model.
2. Set up a fan and turn it on. Test the Sail Car by allowing it to go down wind (in the direction the fan pushes the air). Does it travel straight?

Use pieces of tape to mark off a 2 meter section of the floor in front of the fan. The 2 meter section should begin one meter in front of the fan.

a. Hold the car one meter in front of the fan with the front wheels on the first piece of tape. Use a stopwatch to time the car as it travels over the 2 meter course. Gather data from several trials before reporting your results. How long does it take the car to travel 2 meters?

b. Do you think the sail car is going as fast as the air, faster than the air or slower than the air? Why?

c. Experiment with the sail car to see if you can make it travel faster across the 2 meter section of the floor. Your group may make the following changes in an attempt to increase the speed of the sail car.

- Change the speed of the fan.
- Change the height of the fan off the floor.
- Change the angle of the wind stream.
- Change the way you release the sail car.
- Change the amount of bow in the sail.
- Change other conditions to test their impact on speed.

3. Remember to change only one variable at a time as you experiment. A blank data table is provided for your group to describe the activities you decide upon and results of your sail car experiments.

Experimental Variable	Experimental Variable
Trial 1	**Time:**____________________ **sec**
Trial 2	**Time:**____________________ **sec**
Trial 3	**Time:**____________________ **sec**
Trial 4	**Time:**____________________ **sec**

4. Since you know which individual factors speed up the car, you also know what combination of factors should produce the fastest possible time through 2 meters. Test that combination of factors using several trials and report your results in the space provided below. Does combining all of the successful factors produce a time faster than all of the individual trials? Explain why.

5. Based on the data and observations you have collected; what factors most influence the speed of the sail car as it moves across the two meter distance?

Investigation 2: How far can our Sail Car travel?

1. Using this space and materials provided, make whatever changes you would like to your car with the materials to enable your sail car to travel as far as possible. Save your results so you can compare your furthest distance with the other groups.

2. The following experimental conditions will be constants for all groups as they complete this activity.

   - The fan will be set at high speed.
   - The fan will be elevated 10 cm off of the floor.
   - The car will be released at a distance of one meter in front of the fan.
   - The car will travel in the same space used by each of the other groups.
   - Each test of the car will include three trails and the results will be averaged.

3. On separate sheets of paper report the changes you made to the car and indicate why you made each of the changes. Describe the procedure you used to test how far the car traveled and design a chart to display the results of your trials. The average distance traveled by your car during its best test will be used when the results of all of the groups are compared.

4. Complete the following sentence.

If ______________________________________ would have been available to use on our car it would have traveled even further than our best trial because ____________________

____

5. Would a sail car be of practical use on the road? Support your answer with data and observations from your experiments. How are modern cars designed to take advantage of air and wind?

Lesson 8: SAIL CAR

Investigation 1: How does the Sail Car respond to wind?

1. Use the instruction booklet provided to construct the sail car model.

2. Set up a fan and turn it on. Test the Sail Car by allowing it to go down wind (in the direction the fan pushes the air). Does it travel straight?

   (Generally, the car travels straight.)

   Use pieces of tape to mark off a 2 meter section of the floor in front of the fan. The 2 meter section should begin one meter in front of the fan.

a. Hold the car one meter in front of the fan with the front wheels on the first piece of tape. Use a stopwatch to time the car as it travels over the 2 meter course. Gather data from several trials before reporting your results. How long does it take the car to travel 2 meters?

   (Answers will vary based on the speed of the fan.)

b. Do you think the sail car is going as fast as the air, faster than the air or slower than the air? Why?

   (The car moves slower than the air. Students may say they can feel the air moving past the car as they follow it over the 2 meter course. They may also say that the car is slowing down even though they can still feel the air moving.)

c. Experiment with the sail car to see if you can make it travel faster across the 2 meter section of the floor. Your group may make the following changes in an attempt to increase the speed of the sail car.

- Change the speed of the fan.
- Change the height of the fan off the floor.
- Change the angle of the wind stream.
- Change the way you release the sail car.
- Change the amount of bow in the sail.
- Change other conditions to test their impact on speed.

3. Remember to change only one variable at a time as you experiment. A blank data table is provided for your group to describe the activities you decide upon and results of your sail car experiments.

Experimental Variable	Experimental Variable
Trial 1 *Speed of fan: high*	*The car traveled faster.* **Time:** 3.5 **sec**
Trial 2 *Height of fan: 10 cm off the floor*	*Answers will vary.* **Time:** ______ **sec**
Trial 3 *Turning the fan at a 45 degree angle*	*The car traveled slower.* **Time:** 4.9 **sec**
Trial 4 *Use a sail that is twice as big*	*The car traveled faster.* **Time:** 3.2 **sec**

4. Since you know which individual factors speed up the car, you also know what combination of factors should produce the fastest possible time through 2 meters. Test that combination of factors using several trials and report your results in the space provided below. Does combining all of the successful factors produce a time faster than all of the individual trials? Explain why.

   (While answers vary, this is an optimization challenge. Students need to combine the successful variables to see if they can attain a time that is faster than all of their individual trials. They should record a time that is faster than any of the individual trials.)

5. Based on the data and observations you have collected; what factors most influence the speed of the sail car as it moves across the two meter distance?

   (Answers will vary. The answers should be consistent with the data they collected.)

Investigation 2: How far can our Sail Car travel?

1. Using this space and materials provided, make whatever changes you would like to your car with the materials to enable your sail car to travel as far as possible. Save your results so you can compare your furthest distance with the other groups.
2. The following experimental conditions will be constants for all groups as they complete this activity.
   - The fan will be set at high speed.
   - The fan will be elevated 10 cm off of the floor.
   - The car will be released at a distance of one meter in front of the fan.
   - The car will travel in the same space used by each of the other groups.
   - Each test of the car will include three trails and the results will be averaged.
3. On separate sheets of paper report the changes you made to the car and Indicate why you made each of the changes. Describe the procedure you used to test how far the car traveled and design a chart to display the results of your trials. The average distance traveled by your car during its best test will be used when the results of all of the groups are compared.

   (Answers will vary. Ensure that the students have: listed each of the changes they made to their car, described why they made each of the changes, designed a logical display chart for their data, completed three trials for each design they test, and computed the averages for all of tests.)

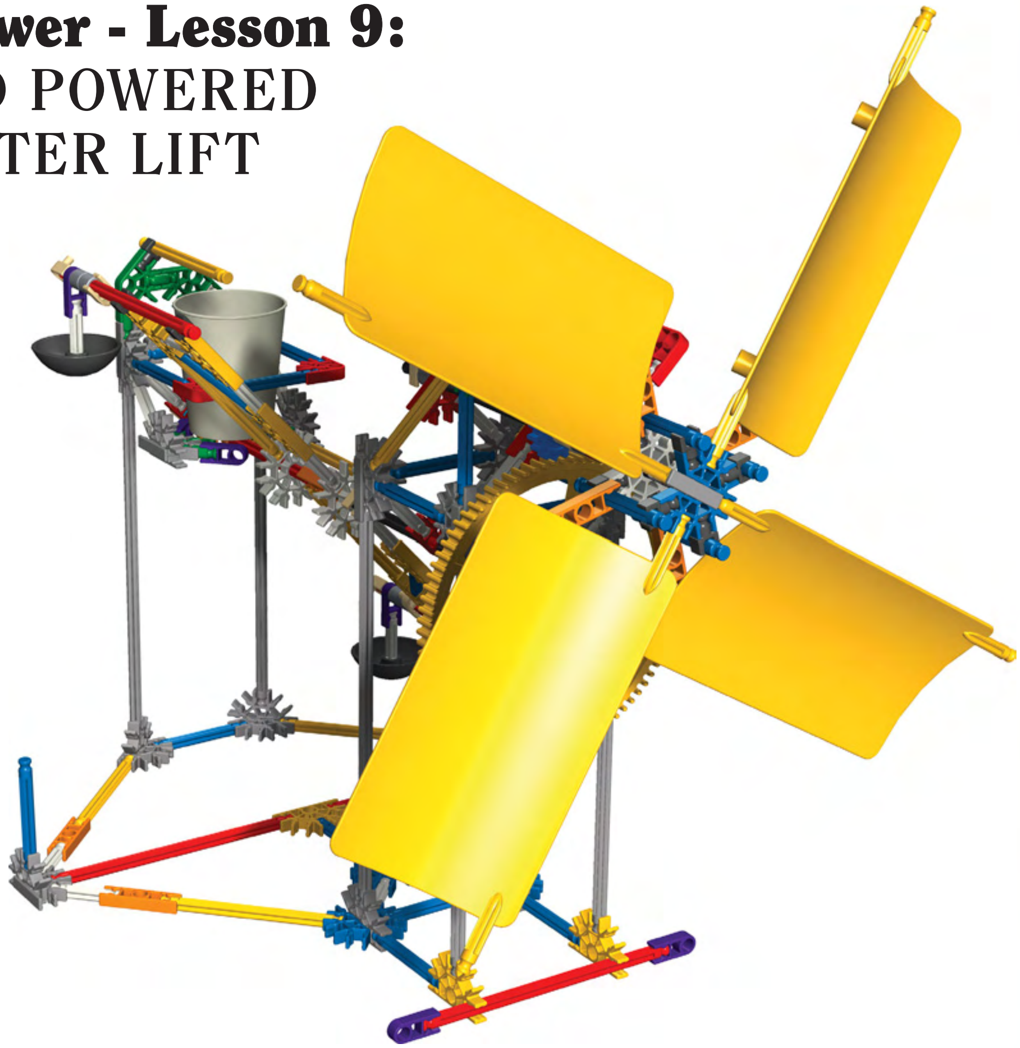
4. Complete the following sentence.

If __**(Answers will vary. [i.e., thin sheets of plastic])**__ would have been available to use on our car it would have traveled even further than our best trial because __**(Answers will vary. A reasonable answer might read: the thin plastic could be cut into shapes that catch the wind better than the fabric we used for our sail.)**__

5. Would a sail car be of practical use on the road? Support your answer with data and observations from your experiments. How are modern cars designed to take advantage of air and wind?

(No, a sail car would not be practical on the road but they would be great fun on a salt flat or a dry lake bed. The support for this statement will vary from student to student. Expect the answers to be logical and well thought out. Modern car designers are very concerned about air and wind. They design cars aerodynamically to ensure they are safe and they lessen the drag caused by air resistance and wind.)

Wind Power - Lesson 9:
WIND POWERED WATER LIFT



Time Frame:

3 x 40 minute sessions

Student Objectives:

Students will demonstrate the ability to:

- Observe changes in energy from one form to another.
- Relate kinetic energy to work.
- Calculate the approximate work output of a model.
- Suggest and implement improvements to a design.
- Optimize the operation of a wind powered system.

Materials:

- ➤ The K'NEX Education Renewable Energy Set
- ➤ Box fan (3 speed preferred)
- ➤ Water source
- ➤ Sponges
- ➤ Protractor
- ➤ Paper or plastic cups (3-6 oz size)
- ➤ Plastic measuring cup or graduated cylinder/beaker.
- ➤ Stopwatch

Investigation 1:

Engagement:

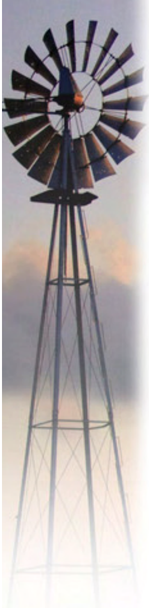
Provide students with pictures of windmills or a collection of PowerPoint™ slides with images you have collected from the internet. Select examples of windmills that are used to lift or pump water. Have a group of students make the Wind Powered Water Lift as shown in the instruction booklet to aid this discussion.

- How can a windmill lift water?
- What types of energy changes are used in the Wind Powered Water lift?
- How can we measure the amount of work that is done by a machine?

Maintain a record of student answers and suggestions. The answers to the questions will provide insight into the students' prior knowledge as it relates to energy, windmills, and the concept of work.

Explore:

1. In many parts of the world windmills lift water from shallow wells for irrigation and livestock. Windmills are common on farms throughout many countries. Additionally, some windmills in Holland lift seawater out of the countryside and back into the ocean since much of the country is below sea level. In this series of activities you will investigate the science behind the operation of these machines. Students will place their model in the green, parts storage tub so that the windmill blades remain outside the tub. They will be asked to examine their wind powered water lift and spin the blades. They will complete several directions and answer questions as they complete their examination. Does the model work best when turned clockwise or counter clockwise? Turn the blades of the windmill at an angle, place the model in front of the fan, and turn the fan on low speed.



Explain:

- How the blades operate?
- Where does the energy come from to make this model operate?
- At this point, students will add water to the green tub to a level that allows the two black scoops to pass through and pick up water from the bottom of the tub. They will need some time to operate the system and there will be some excitement and mess as they watch the cup at the top of the system fill with water.

Teacher Note: Help students if their model does not run smoothly. The first set of instructions focuses on the fins that catch the wind. However, there are least two other areas where adjustments may need to be made: 1. the rotation of the two black water scoops may scrape the sides of the basin (Students can adjust the position of the model to correct the scraping.) 2. the trip mechanism above the cup which acts to dump the water into the cup may need to be adjusted for peak performance.

Elaborate: Does the angle of the windmill blades affect how fast the blades turn?

3. Students will be directed to complete an experiment that will allow them to answer the question above. They will:

- Attach a colored sticker or a ribbon on one of the windmill blades so they can count the number of turns the blades make in 15 seconds.
- Place the fan about one meter from the water lift and experiment to find a fan speed that moves the windmill slowly enough that you can easily count its turns.
- Set the windmill blades at a 10 degree angle (move the outside edge of the blades back towards the machine) and run three trials to determine the average number of turns the blades make in 15 seconds.
- Turn the blades to a 20 degree angle and collect data again.
- Repeat data collection at a 30 degree angle.

Teacher Note: To measure the fin angles better, students can use a protractor and place several angles up to 30˚ on a sheet of paper (use dark lines). They will place this paper on the table directly under the plane of the blades. Students can look down from above and use that paper as a template to adjust the blades to the desired angle. While the construction of the blades suggests one orientation, the blades can be angled in the other direction as well. Both directions rotate the water scoops but students will soon discover that one of those directions dumps water into the cup with less waste. It is recommended that students make this discovery on their own through their adjustments and initial testing.

Students will complete the attached data table:

Angle of the fins	Average number of turns in 15 seconds
10 degrees	
20 degrees	
30 degrees	

Students can then respond to these questions.

- What variables did you keep the same for every trial during this experiment?
- Describe the blade angle that provided the highest number of turns in 15 seconds.
- Describe any relationship you found between the angle of the blades and the rate at which the blades spin? Write this as a conclusion for your experiment.

Investigation 2: What is the most water the water lift can move into the cup in one minute?

Explore, Explain and Elaborate:

Student groups will develop a series of procedures and data tables in order to answer this question.

- As students observed during the first investigation, there may be an optimal angle for the windmill blades.
- Students should next ask if there is an optimal fan speed and an optimal distance for the fan to be placed in front of the water lift model. These are two separate variables so students must design procedures to study them individually. The students will need to design separate experiments and data tables as they investigate each of these variables. When they have decided on a plan of action, they will share their ideas with you. Ensure that they are moving in an appropriate direction with their investigations and data collection.
- After students have determined the best fan speed and distance from the fan they can complete a final experiment to determine how much water the machine can move in to the cup in one minute.
- Students should provide a written description of their experiments, their data tables, and their results at the conclusion of their investigations.

Possible Extensions:

1. Examine the relationship between the spinning blades and the rotation of the water lifting cups. How many times do the fins turn in order to rotate the lifting scoops one time? Show this ratio as input : output. ________ : _______. Is this ratio an example of gearing up or gearing down? What are some of the advantages of this type of gearing? What are some of the disadvantages of this type of gearing?

2. How much work can the water lift do? In the previous investigation you optimized the water lift to find the amount of water that could be placed in a cup in a minute. **How much work was actually done by the water lift?** (Work is one of many terms defined in the glossary.) In the next series of steps you can determine the net output of the water lift. The following procedure takes students through the math and the formulas necessary to answer that question.

a. What was the amount of water that was lifted into the cup in a minute? ________ ml.

b. What is the mass of that water? For water the density is about 1 gm/ml. Therefore, the volume in ml is equal to the mass in grams. What is the mass of the water in grams? _________ g. What is the mass in kilograms? _________ kg.

c. Force is equal to the mass in kilograms x the acceleration constant (9.8 meters/sec2). What is the force of this amount of water? __________ kg (m/sec2) or Newtons.

d. Work (in Joules) is equal to the force (in Newtons) x the distance moved in meters. On your water lift model, measure from the bottom of the trough to the middle of the cup. This is the net height that the water was lifted. (You observed that the model lifted the water higher and then dumped the water into the cup. In this activity we are concerned with net work accomplished. This is also called output energy.

Height to the middle of the cup = ____________ cm.

What is this height in meters? _______________ m.

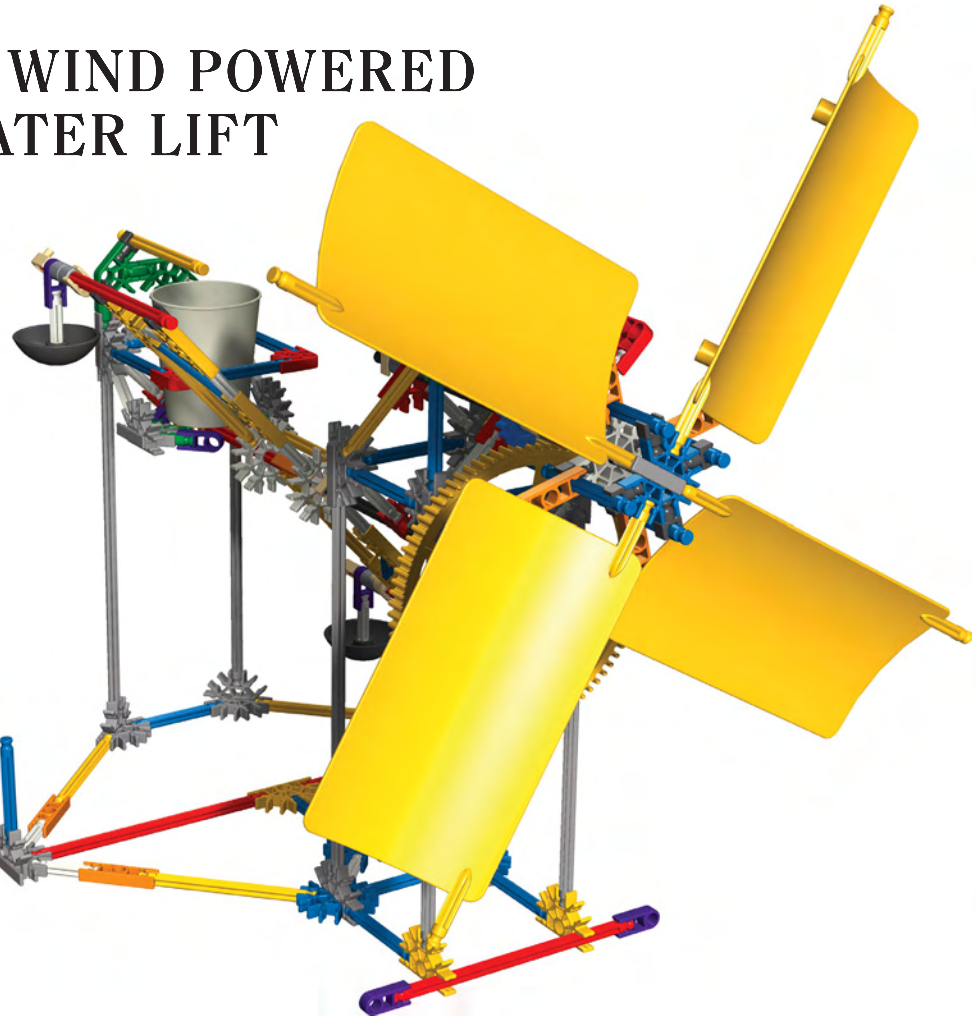
e. Work = Force x Distance

(Your answer in c.) X (Your answer in d.) = __________Joules

This number is the practical amount of work that the model can perform in one minute.

3. Examine the flow of energy in this system and describe the changes in energy that take place to move water into the cup. Do you think that this model efficiently uses wind energy?

Lesson 9: WIND POWERED WATER LIFT



Investigation 1:

1. Construct the Wind Powered Water Lift using the instructions provided.
2. Windmills lift water from shallow wells for irrigation and livestock, and are common on farms throughout many countries. Additionally, windmills in Holland lift seawater out of the countryside and back into the ocean since much of the country is below sea level. In this series of activities you will investigate the science behind the operation of these machines.

- Place the model in the green, parts storage tub so that the windmill blades remain outside the tub.
- Examine the wind powered water lift and spin the blades with your hand.
  - i. Turn the blades of the windmill on their axles so they are at an angle of about 30 degrees to the plane of the windmill.
  - ii. Place the model in front of the fan, and turn the fan on low speed.
  - iii. Does the water lift run smoothly? (If not, ensure the water scoops are not scraping the side of the tub and that all K'NEX connections are made correctly.)

iv. Explain how the blades operate the system.

v. Where does the energy come from to make this model operate?

vi. Add water to the green tub to a level that allows the two black scoops to pass through and pick up water from the bottom of the tub as the windmill turns. Experiment with the system as you turn the blades with your hand and make necessary adjustments so that the scoops dump a portion of the water they collect into the cup. Your wind powered water lift system is now ready for experimentation.

Does the angle of the windmill blades affect how fast the blades turn?

3. In order to answer this question your group will need to complete a series of experiments. As your group experiments you must keep careful records and report your results in the chart that has been provided below.

- Attach a sticker or a ribbon to one of the windmill blades. The marker will allow you to count the number of turns the blades make in 15 seconds.
- Place the fan about one meter from the water lift and experiment to find a fan speed that moves the windmill slowly enough that you can easily count its turns.
- The windmill blades can be moved forward and backwards. Move each of the blades backwards to the angles described below and collect data at each setting.
- Set the windmill blades at a 10 degree angle and run three trials to determine the average number of turns the blades make in 15 seconds.
- Set the blades to a 20 degree angle and collect data again.
- Repeat data collection one more time at a 30 degree angle.

- Write your data tables in your notebooks and place your average results in the chart below.

Angle of the fins	Average number of turns in 15 seconds
10 degrees	
20 degrees	
30 degrees	

- What variables did you keep the same for every trial during this experiment? List them below.

- Describe the blade angle that provided the highest number of turns in 15 seconds.

- Describe any relationship you found between the angle of the blades and the rate at which the blades spun? This description will form the conclusion of your experiment.

Investigation 2: What is the most water the water lift can move into the cup in one minute?

Develop a series of procedures and data tables in order to answer this question.

- As you discuss how your group will approach this problem use the information from your last experiment to help you decide on the angle to use for the windmill blades.
- Predict which fan speed you feel will fill the cup faster?

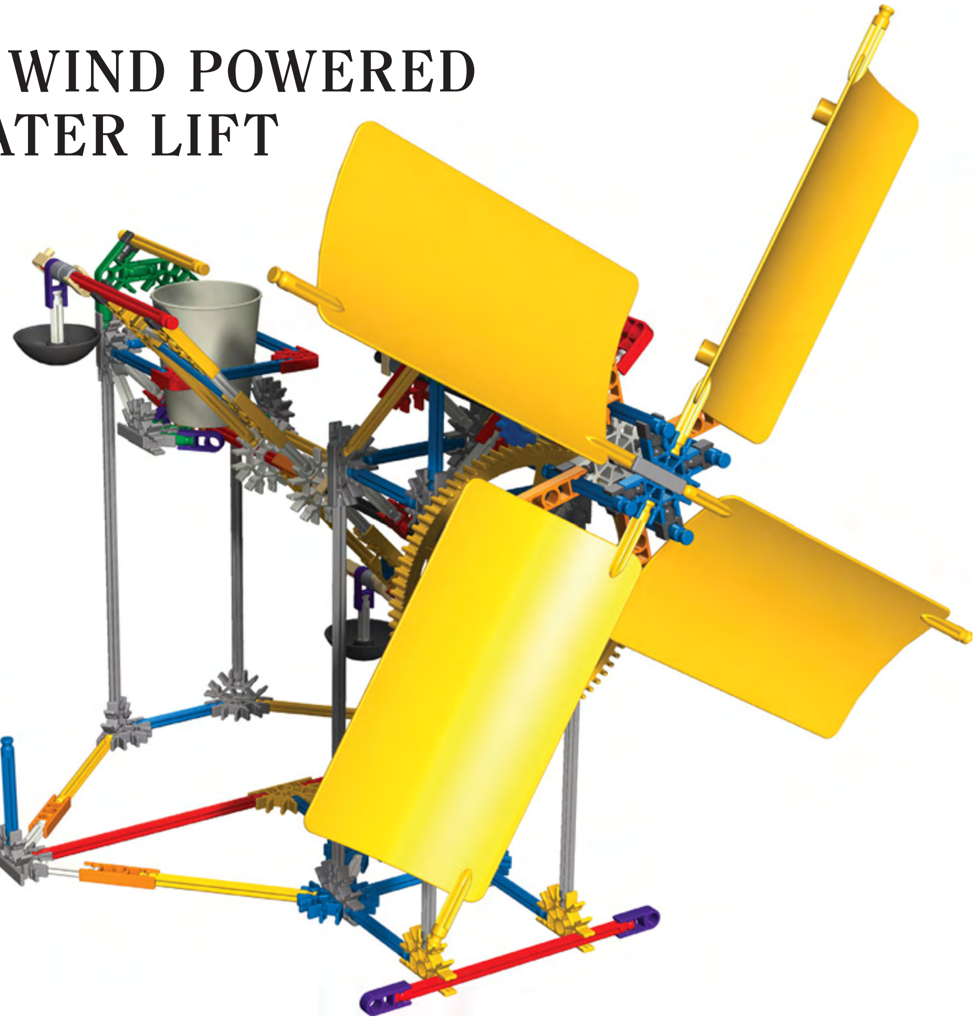
- Predict what you think will be the best distance to place the model in front of the fan?

- These are two separate variables and you must design procedures to study them individually. Design a separate experiment and data table as you investigate each of these variables. When you have decided on a plan of action, share your ideas with your teacher before you begin experimentation.

- Complete your experiments to determine the most water that the water lift can move into the cup in one minute. How much water did your wind powered lift system lift in one minute?

- Provide a written description of your experiments, data tables, and results on separate sheets of paper.

Lesson 9: WIND POWERED WATER LIFT



Investigation 1:

1. Construct the Wind Powered Water Lift using the instructions provided.
2. Windmills lift water from shallow wells for irrigation and livestock, and are common on farms throughout many countries. Additionally, windmills in Holland lift seawater out of the countryside and back into the ocean since much of the country is below sea level. In this series of activities you will investigate the science behind the operation of these machines.

- Place the model in the green, parts storage tub so that the windmill blades remain outside the tub.
- Examine the wind powered water lift and spin the blades with your hand.

   i. Turn the blades of the windmill on their axles so they are at an angle of about 30 degrees to the plane of the windmill.

   ii. Place the model in front of the fan, and turn the fan on low speed.

   iii. Does the water lift run smoothly? (If not, ensure the water scoops are not scraping the side of the tub and that all K'NEX connections are made correctly.)

iv. Explain how the blades operate the system.

(Answers will vary. Expect that students will mention the curved surfaces of the blades are pushed by the wind and they cause the entire system of gears and mechanical parts to turn.)

v. Where does the energy come from to make this model operate?

(Answers will vary. Students should identify that the energy comes from the wind. The wind is in motion and thus represents a source of kinetic energy that drives the mechanical systems that operate the water lift.)

vi. Add water to the green tub to a level that allows the two black scoops to pass through and pick up water from the bottom of the tub as the windmill turns. Experiment with the system as you turn the blades with your hand and make necessary adjustments so that the scoops dump a portion of the water they collect into the cup. Your wind powered water lift system is now ready for experimentation.

Does the angle of the windmill blades affect how fast the blades turn?

3. In order to answer this question your group will need to complete a series of experiments. As your group experiments you must keep careful records and report your results in the chart that has been provided below.

- Attach a brightly colored sticker or a piece of colorful ribbon to one of the windmill blades. The marker will allow you to count the number of turns the blades make in 15 seconds.
- Place the fan about one meter from the water lift and experiment to find a fan speed that moves the windmill slowly enough that you can easily count its turns.
- The windmill blades can be moved forward and backwards. Move each of the blades backwards to the angles described below and collect data at each setting.
- Set the windmill blades at a 10 degree angle and run three trials to determine the average number of turns the blades make in 15 seconds.
- Set the blades to a 20 degree angle and collect data again.
- Repeat data collection one more time at a 30 degree angle.

- Write your data tables in your notebooks and place your average results in the chart below.

Angle of the fins	Average number of turns in 15 seconds
10 degrees	*Answers will vary*
20 degrees	*Answers will vary*
30 degrees	*Answers will vary*

(This investigation allows students to place their data in their notebooks and to record their results in the table below. Ensure that you check their notebooks to verify that they have followed sound procedures in the charting and reporting of their data.)

- What variables did you keep the same for every trial during this experiment? List them below.

(Fan speed, distance from the fan to the model, the depth of water in the tub, etc.)

- Describe the blade angle that provided the highest number of turns in 15 seconds.

(Answers will vary. Ensure that the answer to the question matches the results listed in the results chart.)

- Describe any relationship you found between the angle of the blades and the rate at which the blades spun? This description will form the conclusion of your experiment.

(Answers will vary. Students may find that the greater the angle of the blades the more turns the water lifter made in 15 seconds. The key is to check the students' data to determine if they have described a relationship that is consistent with their results.)

Investigation 2: What is the most water the water lift can move into the cup in one minute?

Develop a series of procedures and data tables in order to answer this question.

- As you discuss how your group will approach this problem use the information from your last experiment that to help you decide on the angle to use for the windmill blades.
- Predict which fan speed you feel will fill the cup faster?

(Answers will vary. Students may find that slower speeds allow the system to lift water without splashing which would allow the cup to fill faster.)

- Predict what you think will be the best distance to place the model in front of the fan?

  (Answers will vary. The fan speed and the fan's distance from the model are experimental conditions that are related. Students will have to complete many trials to arrive at the optimal fan speed and fan distance.)

- These are two separate variables and you must design procedures to study them individually. Design a separate experiment and data table as you investigate each of these variables. When you have decided on a plan of action, share your ideas with your teacher before you begin experimentation.

- Complete your experiments to determine the most water that the water lift can move into the cup in one minute. How much water did your wind powered lift system lift in one minute?

  (Answers will vary.)

- Provide a written description of your experiments, data tables, and results on separate sheets of paper.

  (Answers will vary. Ensure that students have followed sound experimental procedures and common conventions for data collection and organization. Their written work may provide an excellent opportunity to discuss the scientific method.)

Glossary of Terms

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

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

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.

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 x 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.

Geared 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.

Geared 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.

Hydro Energy: Energy produced by water. This can include moving water, waves, tides and or density currents.

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.

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.

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.

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.

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.

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.

Pitch: The angle a propeller or wind vane makes with the plane of its spin.

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

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Protractor: A drafting tool that measures degrees.

Right Angle: An angle of 900.

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

Temperature: Temperature is a measure of the average kinetic motion of the atoms in a material. The metric unite of measurement for temperature is the Celsius scale. 00 Celsius is where water freezes, 1000 Celsius is where water boils. Therm is a common prefix used for temperature as in thermometer, an instrument that measures temperature or isotherm which is a line connecting places of equal temperature on a weather chart.

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 x d. In the metric system Force is measured in Newtons and distance (d) is in meters. Work (W) is in Joules.

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