

Virginia Middle School Engineering Education Initiative

SAVE THE SEA BIRDS ENGINEERING TEACHING KIT

An Introduction to Solar Energy, Force & Motion

Teacher's Guide

University of Virginia
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UNIT OVERVIEW

Introduction and Background

Students' alternative conceptions of energy, force, and motion begin at a young age and can easily persist into adulthood. We use the terms energy and force in non-scientifically ways in everyday language such that the scientific meanings are often obscured. What comes to children's minds when they think about energy, force, and motion? Perhaps a friend forcing them to do something, or perhaps having enough energy to get through a school day. In addition to the many non-scientific uses of the words, children often form their own scientific theories about the way the world works. They think that forces are necessary to keep objects in motion, that stationary objects are devoid of forces, and do not understand that forces come in pairs. They think that when a force is used up, motion stops. Energy is often confused with force, and energy is seen as a fluid or ingredient which flows from one place to another to "make things work." They think energy can be used up, and that it is required for motion. Without explicit interventions designed to target these alternative conceptions, chances are that they will persist into adulthood.

This Engineering Teaching Kit (ETK) is designed to help students with science concepts related to energy, force, and motion as well as teach them the basics of engineering design. They also come away with a sense of how engineers are people who design solutions to problems.

In the case of the *Save the Sea Birds* ETK, the broad context is oil pollution and its effect on sea birds. Students learn that crude oil is mined in the Middle East, West Africa, and Asia as well as here at home. It is pumped from underground on dry land as well as under fresh and salty bodies of water. Half of the crude oil pumped from the ground is turned into gasoline to fuel cars. Nearly 40% is turned into diesel fuel and jet fuel to power airplanes and trucks. The rest is used for heating and cooking. The environmental impacts of oil mining are broad. One critically severe impact occurs when crude oil accidentally leaks into water. Oil tankers can leak, as evidenced by the Exxon Valdez spill in 1989 off the shores of Alaska, but offshore oil rigs can explode, as evidenced by the 2010 BP Deepwater Horizon disaster in the Gulf of Mexico. The ecological impact of these oil spills is severe. Marine life is especially affected- fish, mammals, plants and sea birds as well as small creatures at the bottom of the food chain. Students are asked, "What can we do here at home to reduce our demand for crude oil? What could we do to prevent an oil spill from ever happening again? If 90% of crude oil is used for transportation, what environmentally friendly sources of energy are there for transportation? What can we do to save the sea birds?" Students learn about how solar energy has been used to create electricity for many things, including cars and airplanes. At this point, these cars and airplanes are for demonstration purposes, and not effective for transporting more than one person at a time. However, engineers may be able to improve the technology so that it is a feasible method of providing energy for realistic transportation. If so, the need to drill deep under the oceans will not be necessary, and the Sea Birds will be spared. In the *Save the Sea Birds* ETK, students are tasked with the challenge of creating solar-powered transportation for as many people as possible on a small scale.

Design -based science learning reflects the social constructivist theory of learning by having students work collaboratively in groups to solve problems and construct solutions, but learn certain skills through the modeling of their teacher. When students are involved in engineering design-based activities, they are not being told what to do- they are creating and innovating, making decisions with their peers based on their underlying knowledge. The role of the teacher is to guide students through their decision-making processes and model new skills to be learned.

Through engineering design activities, students should be able to create their own knowledge of scientific principles through active manipulation and testing of materials and ideas. But because students come to school with their own understandings about the world and how it works, their understandings may not resemble those of scientists. The teacher must provide the opportunities for students to challenge and internally modify their prior beliefs. Therefore, social constructivists see that the role of the teacher is to help learners construct their knowledge through scaffolding and coaching. Social constructivists see that learners construct meaning through active engagement, not passive listening. Learners use and apply their knowledge to carry out investigations and create artifacts that represent their understanding. Learners work within a social context as they use language to express and debate their ideas. Learners engage in authentic tasks that are relevant to the student and connected with their lives outside of the school setting.

In design-based science activities, the teacher does not tell the students what to build. Instead, the teacher steps back and allows the students to take the primary lead in their own learning. Problem solving through authentic tasks that relate to students' lives should serve to increase student interest and deeper conceptual knowledge.

National Science, Technology, and Math Standards

The *Save the Sea Birds* Engineering Teaching Kit is based on standards derived from the National Science Education Standards, the Benchmarks for Science Literacy, National Council of Teachers of Mathematics, and Standards for Technological Literacy.

STANDARD	GRADE LEVEL	CONTENT RELATED TO <i>SAVE THE SEA BIRDS</i> ETK
<i>National Science Education Standards</i>	Grades 5-8	Physical Science Content Standard B <ol style="list-style-type: none"> 1. The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph. 2. Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways. 3. The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth.
		Science and Technology Content Standard E <ol style="list-style-type: none"> 1. Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. Technological solutions are temporary; technologies exist within nature and so they cannot contravene physical or biological principles; technological solutions have side effects; and technologies cost, carry risks, and provide benefits. 2. Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology. 3. Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics. 4. Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.
<i>Benchmarks for Science Literacy</i>	Grades 6-8	Science in Personal and Social Perspectives Content Standard F <ol style="list-style-type: none"> 1. Human activities also can induce hazards through resource acquisition, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.
		Chapter 4E <ol style="list-style-type: none"> 1. Energy cannot be created or destroyed, but only changed from one form into another. 2. Most of what goes on in the universe... involves some form of energy being transformed into another.

Chapter 4F

1. An unbalanced force acting on an object changes its speed or direction of motion, or both.

Chapter 4G

1. Electrical circuits require a complete loop through which an electrical current can pass.

Chapter 8C

1. Transformations and transfers of energy within a system usually result in some energy escaping into its surrounding environment. Some systems transfer less energy to their environment than others during these transformations and transfers.
2. Different ways of obtaining, transforming, and distributing energy have different environmental consequences.
3. In many instances, manufacturing and other technological activities are performed at a site close to an energy resource. Some forms of energy are transported easily, others are not.
4. Electrical energy can be generated from a variety of energy resources and can be transformed into almost any other form of energy.
5. Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the transfer of energy from these resources is weak and variable, systems are needed to collect and concentrate the energy.

*National Council
of Teachers of
Mathematics*

Grades 6-8

1. understand both metric and customary systems of measurement;
2. understand relationships among units and convert from one unit to another within the same system;

*Standards for
Technological
Literacy*

Grades 6-8

Standard 8

Design is a creative planning process that leads to useful products and systems. There is no perfect design. Requirements for a design are made up of criteria and constraints.

Standard 9

Design involves a set of steps which can be performed in different sequences and repeated as needed. Brainstorming is a group problem-solving design process in which each person in the group presents his or her ideas in an open forum. Modeling, testing, evaluating and modifying are used to transform ideas into practical solutions.

Standard 10

Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system. Invention is the process of turning ideas and imagination into devices and systems. Some technological problems are best solved through experimentation.

Supplies:

The materials listed in Table 1 are needed by the teacher regardless of how many classes he or she teaches. They can be used for each class. The materials listed in Table 2 are “per student group.” So, if a teacher has four classes with 7 student groups in each class, 28 student kits will supply one teacher with enough supplies. Some materials can be purchased from a grocery store, hardware store, craft store, or large shopping mart but many will have to be mail ordered. Suggested sites are provided below where necessary.

Table 1
Basic Teacher Supplies needed for *Save the Sea Birds* ETK

Quantity	Item
7	Mini solar race cars Steve Spangler Part# WROB-200
7	Desk lamp
7	Light bulbs, 100W
7	Multimeters
7	Calculators
1	Tote bin, to hold and store all supplies. Size depends on number of classes.
1	Small pull cart with wheels for holding concrete sea birds- can be made with Legos. See Table 8.
3 kg	Assorted rocks (smooth) to represent people or concrete sea birds. See Figure 4.
1	Edmund Scientifics Part# 3001004 Spring Scale, 3 kg/30 N
7	Edmund Scientifics Part# 3001000 Spring Scale, 250 g/2.5 N
7	Edmund Scientifics Part# 3001002 Spring Scale, 1 kg/10 N
1	Plastic shopping bag for massing rocks on spring scale
7	Plastic cups
1	Roll of cotton string
3	Pull-back toy race cars http://www.arborsci.com/pull-back-car plus sand paper and waxed paper for wheels.
7	Solar cell A assemblies (these can be used with each class) See Table 6
7	Solar cell B assemblies (these can be used with each class) See Table 7
7	D-cell batteries and battery holders
2	Super glue bottles
3 packs	Heat Shrink tubing from Radio Shack (Cat # 278-1611)

Table 2: Student supplies for each student group

Part Description	Source	Quantity
Plastic Shoe Box for storage	Home Depot	1
Motor A assembly	See Table 3	1
Motor B assembly	See Table 4	1
Lego Parts assembly	See Table 5	1

Table 3: Motor A Assembly

Component	Mfg	Part Number	Description	Color	Qty
7100 RMP motor assy	Lego	3020	Plate 2x4	Black	2
	Lego	3700	Technic Brick 1x2 with hole	Black	2
	Lego	3023	Plate 1x2	Black	2
	Lego	3039	Roof Tile 2x2, 45 deg	Black	2
	Lego	3660	Roof Tile 2x2, 45 deg, inv	Black	2
	Kysan	RE-280SA-2865	Motor, DC, 23.8 mm, 1.5-4.5V, 7100 RPM, 0.16A		1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Black	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Red	1
	Pololu	1001	Cross Adaptor for 2mm Shaft	Grey	1
					14

Table 4: Motor B Assembly

Component	Mfg	Part Number	Description	Color	Qty
3100RPM motor assy	Lego	3307	Brick with Bow, 1x6x2	Grey	2
	Lego	3700	Technic Brick 1x2 with hole	Grey	4
	Lego	3795	Plate 2x6	Grey	1
	Kysan	RF-500TB-14415	Motor, DC, 32 mm, 1-9V, 3100 RPM, 0.026A		1
	Pololu	1001	Cross Adaptor for 2mm Shaft	Grey	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Black	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Red	1

Table 5: Lego Parts Assembly per student group

Component	Mfg	Part Number	Description	Color	Qty	
Main Car Parts	Lego	3647	8-tooth gear	grey	1	
	Lego	3649	40-tooth gear	grey	1	
	Lego	3650b	24 Tooth Crown Gear	Grey	1	
	Lego	32270	Double Conical Wheel Z12 1m	Black	1	
	Lego	32269	Double Conical Wheel Z20 1m	tan	1	
	Lego	3713	bush for cross axle	grey	8	
	Lego	4265c	1/2 bush	grey	8	
	Lego	3673	connector peg	grey	8	
	Lego	6558	connector peg with friction 3M	blue	4	
	Lego	3706	Cross Axle 6M	black	4	
	Lego	3707	Cross Axle 8M	black	4	
	Lego	3708	Cross axle 12M	black	4	
	Lego	6538c	Cross Axle, Extension 2M	grey	4	
	Lego	3700	Technic Brick 1x2 with hole	Black	4	
	Lego	3701	Technic Brick 1x4 with holes	black	4	
	Lego	3702	Technic Brick 1x8 with holes	black	4	
	Lego	2730	Technic Brick 1x10 with holes	black	4	
	Lego	3895	Technic Brick 1x12 with holes	black	4	
	Lego	3703	Technic Brick 1x16 with holes	black	2	
	Lego	3020	Plate 2x4	White	2	
	Lego	3795	Plate 2x6	White	2	
	Lego	3034	Plate 2x8	White	2	
	Lego	6632	Technic Lever 3M	Black	1	
	Lego	56145	Rim Wide with cross 30/20	grey	2	
	Lego	55981	Rim Wide 18/14 w Hole 4.8	grey	6	
	Lego	56891	Tyre Balloon Wide 37x18R	black	2	
	Lego	44309	Tyre Normal wide 43.2x22	black	2	
	Lego	30391	Tyre Normal wide 30.4X14	black	4	
						94

Table 6: Solar Cell A assembly

Component	Mfg	Part Number	Description	Color	Qty
0.4W Solar Cell Assembly	Velleman	SOL4	2V/200mA Solar cell , 3.0" x 3.7"		1
	Lego	3001	Brick 2x4	White	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Black	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Red	1
					4

Table 7: Solar Cell B Assembly

Component	Mfg	Part Number	Description	Color	Qty
0.75W Solar Cell Assembly	Kelvin	260193	1.5V/500mA Solar cell, 62 x 120mm		1
	Lego	3001	Brick 2x4	White	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Black	1
	Radio Shack	278-1156	Wire with Covered Alligator Clip	Red	1
					4

Table 8: Parts List for Cart (1 per teacher)

Component	Description	Part Number	Source	Quantity
Pull Cart	Cross Axle, Extension 2M	4512363	Lego	4
	Cross Axle 8M	370726	Lego	4
	Brick 1x12 with holes	4211860	Lego	6
	Bushing for cross axle	4211622	Lego	12
	Plate 6x12	302826	Lego	2
	Tyre, Normal Wide, 43.2x22	4184286	Lego	4
	Rim, Wide with Cross 30/20	4297210	Lego	4

Steve Spangler Science <http://www.stevespanglerscience.com>

Edmund Scientifics <http://scientificsonline.com>

Kysan Electronics <http://store.kysanelectronics.com>

Jameco www.jameco.com

Pololu www.pololu.com

Kelvin www.kelvin.com

Lego Pick a Brick <http://shop.lego.com/en-US/Pick-A-Brick-ByTheme>

Brick Link <http://www.bricklink.com>

Radio Shack www.radioshack.com

***Note to teacher:** While you may be tempted to jump into the design activity and skip over the demonstrations, please do not. The demonstrations provide the cognitive scaffolding necessary for students to link the design challenge with the complex science of force, energy, and motion. They present students with cognitive dissonance through discrepant events; the opportunity to face their conceptions about force and motion and refine any incorrect ones is imperative for the success of this ETK. Without the demonstrations and discussions that surround them, students will take away a fun activity that may or may not help them understand what engineers do. With the demonstrations, students will take away much more- including increased conceptual understanding about force, motion, energy, friction, etc.

Preparations of Materials:

Solar Cell Assemblies

Prepare the solar cells by attaching little alligator clips to the end of each wire. Pull back the plastic insulation and feed the wire through the little hole. Twist tight, and then slide the plastic insulation back into place. There is no need to solder. If the solar cells have no wires, then solder half a test lead with alligator clip onto each terminal.

Glue Lego pieces to the backs of the solar cells. You could first sand off the Lego bumps prior to gluing but it is not necessary. See Figure 1. In order to glue the brick securely, super glue works, or E6000 Jewelry adhesive works well and can be ordered online from www.DickBlick.com .

Motor Assemblies

Prepare the motors by super gluing lego pieces to each motor to create a motor mount. Feed shrink tubing onto each half of a test lead, then solder test leads with alligator clips to the terminals on each motor. Blow dry the shrink tubing so it shrinks around the soldered joint. See Figure 2.

Lego Parts Assemblies

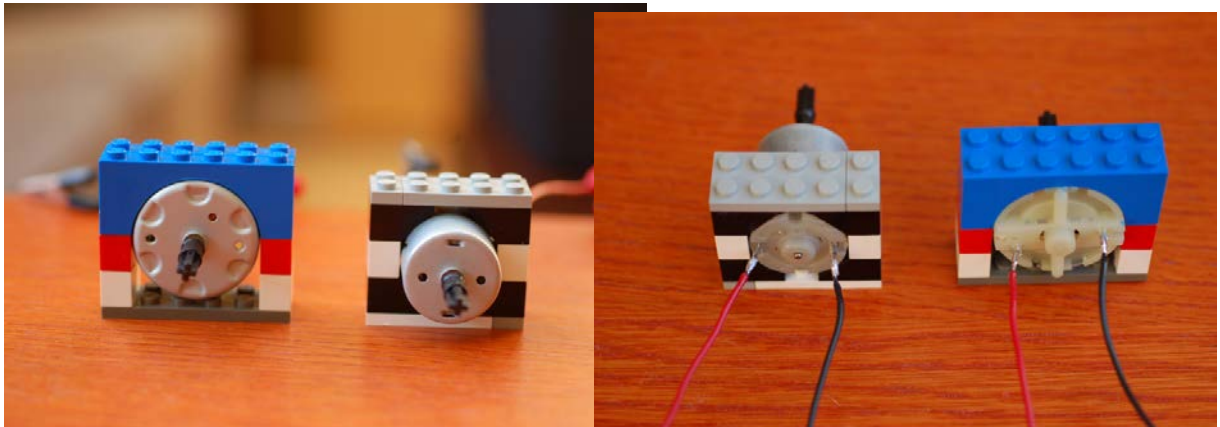
Sort Lego pieces so that each group has sufficient supplies to build one car. See Figure 3 for picture of suggested supplies listed in Table 5.

Cart Assembly

You will also need to build a cart that the solar vehicle will pull. The cart will be loaded with rocks or concrete sea birds, so it needs a sufficient surface area. See Figure 4 for an example of what kind of cart you can build, and Figure 5 for an example of what types of rocks work well- smooth and varied in sizes.



Figure 1. Solar cell with sanded-down Lego pieces glued to back.



**Figure 2
Solar cells and motors with connectors**

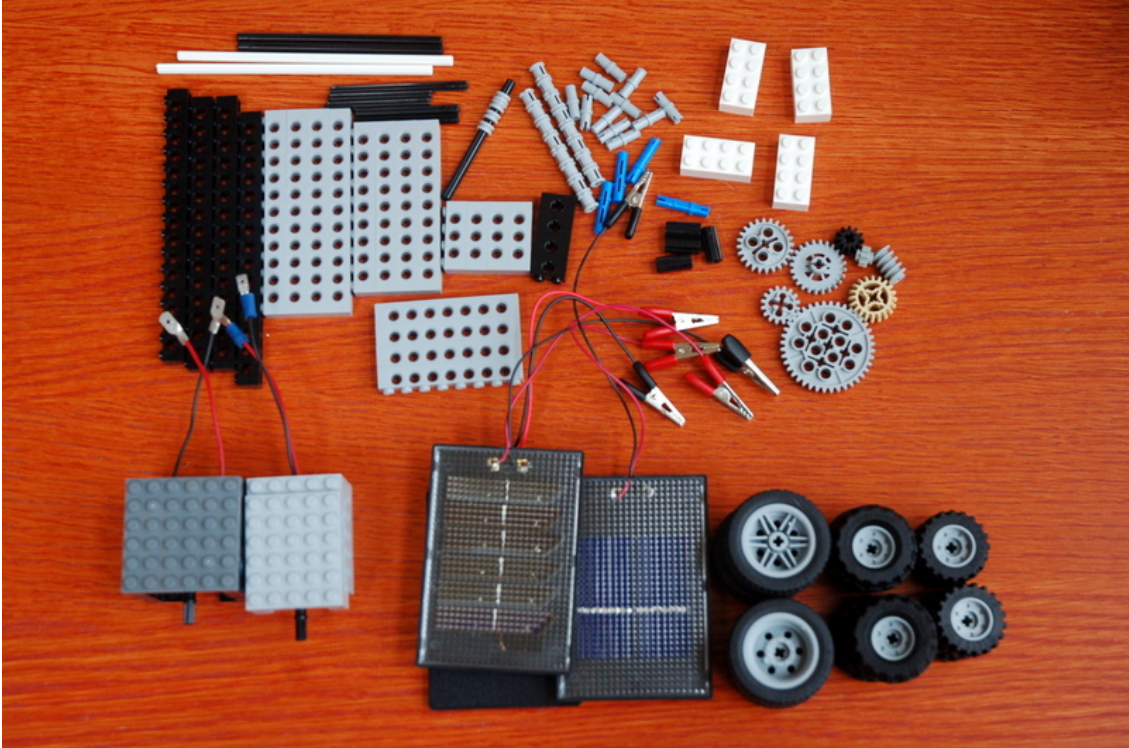


Figure 3
Suggested Legos for each solar car

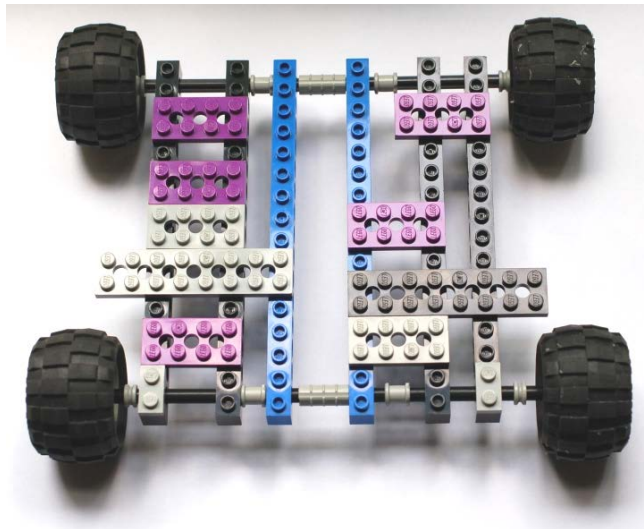


Figure 4
Cart for pulling rocks



Figure 5
Rocks

Overview of the Unit with Main Activities and Objectives for each Day

Day 1 – Introduction to Engineering/ Environment/ Energy

Objectives:

- The first objective is to introduce students to the impacts that oil spills have on the environment, especially concerning sea birds. Discuss with students why we drill for oil. As students discuss the ultimate goal of never having another oil spill in water again, lead them to the idea that an alternative source of energy for transportation could be solar energy.
- The second objective is for students to witness and discuss a series of demonstrations related to energy transformations so that they form a concrete understanding of what energy is, how it is used, and how it is transformed.
- The third objective is for students to begin a storyboard-type poster for the unit.

1. [Pre-assessment on energy and motion](#) (10 minutes)
2. [Introductory PowerPoint lecture](#) on Gulf of Mexico oil spill. (20 minutes)
3. [Introductory PowerPoint lecture](#) on engineering (10 minutes)
4. Introduction to the storyboard poster. (5 minutes)
5. Demonstration 1 – Miniature solar car (10 minutes)
6. Documenting learning on story board (10 minutes)

Day 2 – Light Energy to Electrical Energy

Objectives:

Today's objectives are for students to:

- visualize what electrical voltage and current are and
 - determine how to configure solar cells for the maximum electricity production.
 - In the process, they will learn how to use a multimeter, how to configure solar cells in series and parallel, and calculate the amount of electrical energy produced by solar cells.
1. Review the context - creating solar vehicles to reduce the need for oil and gasoline, thus positively impacting pelicans and other sea birds (10 minutes)
 2. Watch video showing how solar cells work. (5 minutes)
 3. Demonstration 2 –Electric circuit with battery and bulb (10 minutes)
 4. Demonstration 3 –Electric circuit with series solar cells (5 minutes)
 5. Demonstration 4 –Electric circuit with parallel solar cells (5 minutes)
 6. Students work in teams to investigate electricity production of solar cell configurations (25 minutes)
 7. Document learning on story board (10 minutes)

Day 3 – Electrical Energy to Mechanical Energy

Objectives:

Today's objectives are to

- experiment with different motors to determine the force they can produce,
 - understand that a force is a push or pull and that it can either help or hinder motion, and that
 - gears can be used to increase or decrease the force produced by a motor.
-
1. Review Day 2- electric circuits with solar cells (5 minutes)
 2. Show video on how combustion engines exert a force. (5 minutes)
 3. Demonstration 5- How can a motor exert a force? (10 minutes)
 4. Explore spring scales to measure force of different motors (10 minutes)
 5. Create gear train that increases force and measure change in force. See handout, "[How Gears Help Drive the World.](#)" (25 minutes)
 6. Document learning on story board (10 minutes)

Day 4 – Friction

Objectives: Today's objectives are to

- understand that friction is a force that helps or hinders motion,
 - experiment with different types of friction, and
 - experiment with different tires in order to determine which tires have the most sliding friction.
-
1. Review Day 3- forces exerted by motors (5 minutes)
 2. Demonstration 6- Cars with different wheel materials. (10 minutes)
 3. Build a car with interchangeable stationary tires and measure sliding friction (10 minutes)
 4. Put rocks on non-rolling car and measure increase in frictional force. (20 minutes)
 5. Build a car body with movable wheels as basis for solar car (15 minutes)
 6. Document learning on story board (10 minutes)

Day 5 – Engineering design, building, and testing

Objectives:

- Today's first objective is to have students design and construct solar-powered vehicles that move.
 - The second objective is for students to connect the cart to the solar car and see how many people (rocks) it can pull.
 - The third objective is for students to analyze their designs to determine what features work best and which do not.
-
1. Review Day 4- friction (5 minutes)
 2. Students design and build first iteration of solar car (20 minutes)
 3. Students test cars. This can be done in classroom with shop light or outside on sunny day. (20 minutes)
 4. Analyze and discuss results (15 minutes)
 5. Document learning on story board (10 minutes)

Day 6 – Revision and Final Testing

Objective: To make improvements and repeat the testing process.

1. Revisions (20 minutes)
2. Final testing (20 minutes)
3. Wrap-up discussion (15 minutes)
4. Post assessment (10 minutes)

Supplemental Information

Students will be working in groups. Ideally, groups of three or four work well. Either allow students to pick their own groups, or assign them based on what you know about how your students get along and work together. Single gender groups may help all students be more successful. Since students will be working with the same group members for the duration of this ETK, it is best if the students like one another and work well together. Have students sit together with their group members from the beginning of this unit.

UNIT DETAILS

Day 1 – Introduction to the Unit/ Lesson on Energy

Objectives

- Students will be able to describe engineers' role in society.
- Students will be able to explain why humans drill for oil.
- Students will be able to explain how oil drilling has affected the environment.
- Students will be able to brainstorm ways engineers might be able to reduce the need to drill for oil.
- Students will be able to define energy as something that makes things happen or move.
- Students will be able to list different types of energy.
- Students will be able to describe how solar energy can transform into electrical energy and then into kinetic energy.
- Students will be able to list the pros and cons of solar transportation.
- Students will be able to compare different solar cells and describe their properties.

Preparation:

- Photocopy the [Force, Motion, and Energy Assessment](#) for students.
- Study and practice the [Day 1 PowerPoint presentation](#) and the [Engineering](#) presentation. Print off notes for yourself if you need them.
- Set up an LCD projector and screen with speakers attached to your computer.
- Construct the mini solar race cars ahead of time so that each group has one with a shop light.
- Purchase large poster sheets or those that have a sticky strip on top (like large Post-It easel notes). Make sure you have one for each group, plus a few extras.

Step 1: Assess student's prior knowledge about energy, force and motion with the Force, Motion, and Energy Assessment. Collect the assessments, score them, but do not return or discuss them with students. This instrument is based on misconceptions research. The assessment will provide you with information about your students' misconceptions about energy, force and motion.

Step 2: Deliver PowerPoint presentation on sea birds, and oil spills, then the PowerPoint presentation on engineering. Beforehand, read through all the notes provided for each slide, and research each highlighted engineer for more information through the links provided. The goal is to get the students to be able to make the connections between the plight of sea birds, oil spills, energy consumption, alternative sources of energy for

transportation, and the role of engineering in society. Be sure to involve students in a continuous discussion through the discussion prompts provided.

Step 3: Introduce the concept of the story board. A story board is like a comic strip in that it tells a story through drawings and words divided up into sections that flow on into another. Each time students learn a new concept, do an experiment, create a design, or test a design, it should be recorded on the story board for teachers and students to see and comment on. Ideally, the storyboard is on the wall for easy viewing. See Figure 6 for a sample storyboard. Students will add to their storyboards in groups each day.

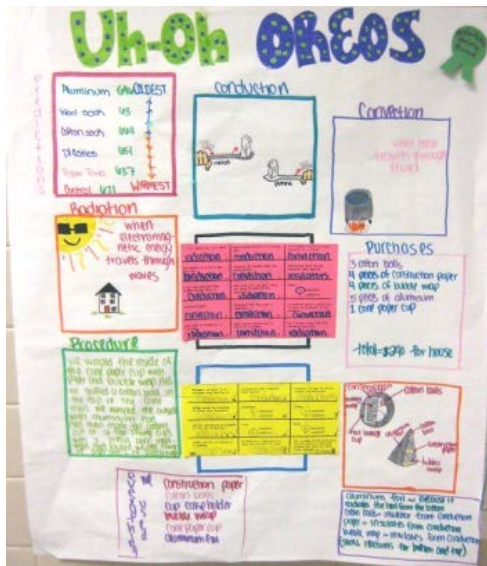


Figure 6
Sample Story Board

Step 4: Miniature solar car and matchbox car demonstration

Show students the miniature solar car, a matchbox car, and desk lamp. Ask them to predict what will happen when you shine the light on the cars. Through discussion, get students to understand that energy from the light is transforming into motion for the solar car. Ask, what kind of energy do things have when they are moving? Ask why the matchbox car does not move when light is shined on it? What happens in the solar car that does not happen in the matchbox car? Ask students what energy is? Most will not know. Tell them that it's ok- that scientists are not sure what energy is either. But scientists know what energy can do. This simple definition works well:

Energy is the ability to make something happen or change.

What has energy? Ask students and they will provide you with great insight into their preconceptions about energy. Keep using the same simple definition.

Can the solar car go uphill? Create a ramp with books and see if the solar car can climb up the books. When the car is at the top of the ramp or hill and not moving, ask students if it has energy? Many students will think that

zero motion = zero energy

Tell students that energy is the ability to make something happen or change. Can a car at the top of a ramp make something happen or change? If the table is tilted, could the car roll back down the ramp and knock over a domino? If so, then the car has energy just because it is high up and can roll down. Ask students where the car at the top of the hill got its energy from? Remind them that energy was put into the car from the light source, and the car moved. Its kinetic energy became potential energy. Many students will think that the car has the

potential to have energy

Be sure to tell them that potential energy is a special kind of stored energy, like the energy stored in a battery or stored in a wind-up car. When released, it has the potential to make something happen or change.

People have many different ideas about what energy is. It's a common word in our language and is used in a variety of ways from "energy drinks" to "nuclear energy." Naturally, there is some confusion about what energy is. Even scientists aren't sure what energy is, they just know what it can do (Feynman, Leighton, & Sands, 1989). So, what do children think about energy? Watts (1983) identified seven different frameworks children have about energy.

Framework 1: Human centered. People have energy and are energetic. When they do active things, they are using energy. If a person pushes a box up a hill, the person has energy but not the box. When people do not have energy, they are tired.

Framework 2: Object centered. Objects can store energy which allows them to work, and which can be depleted or recharged. For example, batteries store energy.

Framework 3: Energy as a dormant ingredient. Objects have energy in them, but it is not useful unless something triggers it to come out. For example, there is energy in food but it "comes out" only when the food is eaten. Energy drinks would fall into this category.

Framework 4: Energy is motion. Energy is not seen as the *cause* of the motion, but as the motion itself. For example, energy is the act of people moving or a sled sliding. If something is moving, energy is present. If something is not moving, it does not have energy.

Framework 5: Energy is a product. Energy is seen as something that is created, then dissipates or fades. Heat energy falls into this category, as children see that heat energy is created by a chemical reaction then goes away. They do not understand the conservation of energy, thinking that energy gets "used up."

Framework 6: Energy is functional. It does work for us, it makes life easier. For example, cars and kitchen appliances have energy because they do work for us, but clouds do not have energy because they do not do any work for us.

Framework 7: Energy is a fluid. It flows. It comes out of wires. It is the "juice" you put into a toy electric car to make it go. It is transported or conducted into one thing and out of another.

Several researchers have noted that children often confuse the terms, “force”, “energy”, and “work” or realize they are related concepts but do not understand how. Some children confuse friction and gravity with energy, and think that potential energy is the potential to *have* energy (Driver et al., 1994).

Step 5: Pass out the mini solar racers and desk lamps to student groups. On a sunny day, this activity can take place outdoors without the lamps. Tell students to play with the cars in order to learn what the cars can and cannot do. What happens when the light source is blocked or turned off? Does the car always go the same speed? Let this be a time of open exploration.

Have students record their observations and the definition of energy on their story board.

Day 2 – Light Energy to Electrical Energy

Objectives

- Students will be able to define voltage as a measure of the force pushing electrons in a circuit.
- Students will be able to define current as a measure related to the number of electric charges passing a point in a circuit each second.
- Students will be able arrange two solar cells in a series circuit and measure the voltage and current produced when light shines.
- Students will be able arrange two solar cells in a parallel circuit and measure the voltage and current produced when light shines.
- Students will be able to calculate the amount of energy produced each second in various solar cell configurations.

Preparation:

- Set up six stations around the room with desk lamps.
- Place a multimeter, two solar cells, and alligator clip wires at each station.
- Photocopy the [Multimeter Directions](#) sheets for each station. Modify for your own multimeters if you are using a different type.
- Photocopy the [Solar Cells Investigation](#) worksheet for students.

Step 1: Review the context of this unit - creating solar vehicles to reduce the need for oil and gasoline, thus positively impacting sea birds and other aquatic life affected by oil spills. Review the concept of energy and introduce electrical energy as one type. How do we know how much energy is present in an electric circuit? How can we measure it? First, students should have a conceptual understanding of what electricity is and how voltage and current are two different ways of measuring electricity. Many students will

be familiar with voltage, but not current. They may think that more voltage = more energy, but the activities presented today will show them that both voltage and current are important in knowing how much energy is present in a particular circuit.

Voltage is a measure of the force pushing electrons in an electric circuit. A high voltage shock from static electricity really hurts! There is a lot of force pushing those electrons into your finger when you touch the door knob. However, there may not be much energy if the current is low.

Current is a measure indicating how many electric charges pass by a point in a circuit each second. Fortunately, a high voltage shock from static electricity does not contain many electrical charges. The current is low, so the shock does not damage you. In an electric outlet, however, the current is quite high.

Energy in an electric circuit is the product of Voltage and Current. Energy/second (Joules/sec) = Voltage (Volts) x Current (Amperes).

Even if the voltage is high, there may not be much energy if the current is low. Ideally, solar cells work best if they produce enough voltage and current to yield usable energy. The voltage impacts speed of a motor the most, while the current impacts torque, or the twisting force the motor can exert.

Read *How Stuff Works Electricity* for more explanations about current and voltage:
<http://science.howstuffworks.com/electricity4.htm>

Step 2: Show student a video that explains how solar cells work. Here three possible sources of the same video:

<http://www.youtube.com/watch?v=x2zjdxrisc>

<http://video.google.com/videoplay?docid=-4265212146969344136>

<http://www.youtube.com/watch?v=AmWrGPKcMNM>

Step 3: Demonstrate for students how to create a circuit with a battery and a motor. How much voltage can the battery push electrons with? How fast does the motor spin? Where do you see or hear or feel energy making something happen or change?

Step 4: Now, demonstrate a circuit which gets its electric energy from a solar cell. Shine a light on the solar cell such that the motor spins. How much voltage can the solar cell push with? How fast does the motor spin? Where is energy being transformed from light into electricity and then into motion and sound?

Have students complete a section of their story board with the definitions of electric energy, voltage, and current.

Help students come to the understanding that voltage and current are both important for measuring the amount of energy produced by a solar cell. Make sure that all students understand the concept of voltage and current before proceeding to the next step.

Step 5: Students are now ready to work in groups to investigate three different types of solar cells. See Figure 7. While each one produces a different voltage, they each produce the same amount of energy. How can this be? Have students measure the voltage and current, calculate the energy produced each second, and then examine the solar cells carefully to make an inference about how they can each produce the same amount of energy. Pass out the Solar Cells Investigation worksheet.

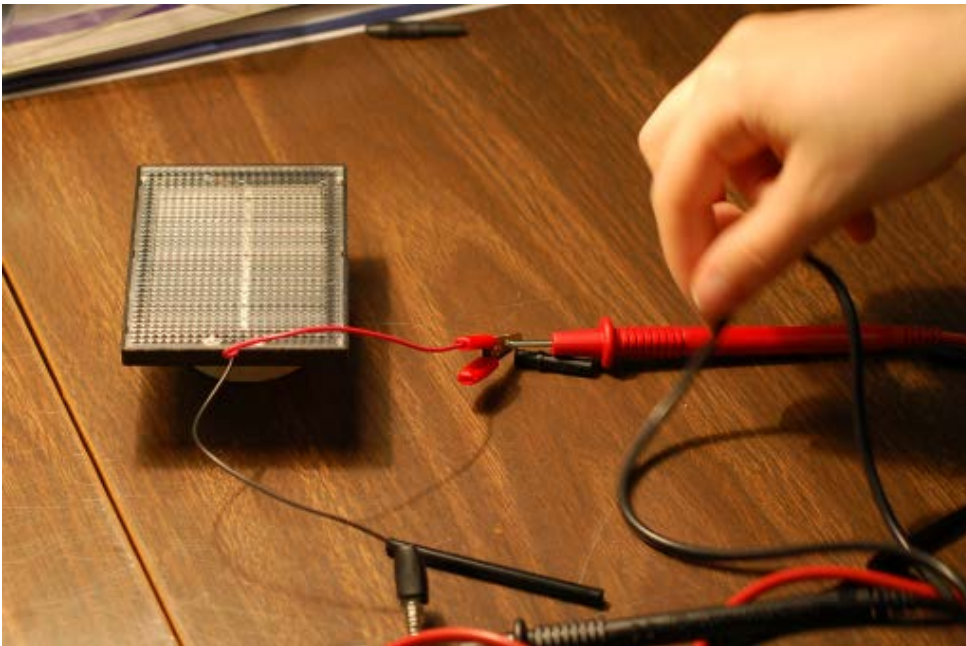


Figure 7. Testing voltage and current of solar cell

Finish up this class with a review of what electricity is and how electricity is measured. Allow students time to complete their story boards if needed.

Day 3 – Electrical Energy to Mechanical Energy

Objectives

- Students will be able to define a force as a push or a pull.
- Students will be able to create a gear train that increases force output of a motor.

Preparation:

- Create kit of Lego pieces for each group.
- Print off copies of [How Gears Drive the World](http://www.youtube.com/watch?v=Kr_xiusqtUM)

Step 1: Show students video on how a combustion engine works to create a force.
http://www.youtube.com/watch?v=Kr_xiusqtUM and

<http://videos.howstuffworks.com/howstuffworks/190-how-engines-work-video.htm> are two good choices.

Ask students for observations and inferences. Ask how the force on the piston is translated into force that makes the car move?

Step 2: Set up Motor demonstration- How much force can a motor exert? Ask students about their prior knowledge of forces. Do they understand that a force is just a push or a pull? Magnets can create forces, and this force causes the motor to spin. When the motor spins, it can put a force on something else connected to the shaft. See Figure 8.

There has been much research into children's conceptions about force, and it is a confusing scientific concept because of how frequently the word is used in everyday language for non-scientific purposes. A child is forced to eat her vegetables. A forceful person is powerful. There are military forces overseas fighting wars. May the force be with you! Driver et al. (1994) have consolidated the various research studies on children's conceptions of the science of "force" into a set of common ideas. These are:

1. If something is moving, a force must be acting on it in the direction it is moving to keep it moving.
2. If something is not moving, then it has no forces acting on it.
3. A moving object stops when the force acting on it is "used up."
4. The more force acting on an object, the more motion it has.
5. If the force acting on a moving object stays constant, its speed will be constant.

Children do not readily understand that forces come in pairs and think of a force as a solitary thing possessed by one object. They may recognize that a book on a table puts a force on the table, but fail to recognize that the table also puts a force on the book. They do not necessarily recognize friction as a force but rather see it as something different, for example, something that causes electricity. The concept that force is required for motion is so widespread and tenacious that studies indicate between 82% and 85% of high school students possess this concept, while 75% of university students also possess this concept even after instruction (Palmer & Flanagan, 1997).

While this demonstration will not address all the misconceptions students have about forces, it will familiarize them with observing and measuring forces, and seeing that forces come in pairs. Secure a motor to a table top and attach a Lego wheel (without tire) to the shaft so it can wind up a string. See Figure 9. Secure the string to the wheel. Attach a cup to the end of the string so the motor can lift different amounts of weight. Use a battery (or solar cell with light) to make the motor turn. Use rocks or marbles or even Unifix cubes until you find a load that the motor cannot raise. When this happens, decrease the weight a little bit. See if you can find the maximum weight the motor can raise. See how much weight the motor can lift by measuring the weight of the cup with a spring scale. Use the metric unit for weight, Newtons.

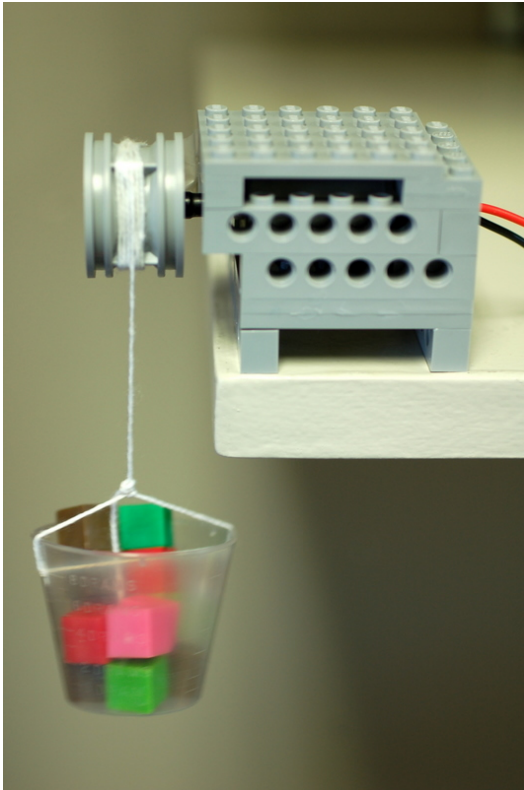


Figure 8. Motor with Lego wheel.

Ask students, “How much force could the motor put on the string? What forces did the string experience? What forces did the cup of rocks experience? When the cup of rocks was raised all the way and not moving, what forces were acting on it? As the force of the rocks increased, what happened to the motion of the cup of rocks? If you have different motors, you can compare them at this time to see which one can exert the most force.

Step 3: Pass out a motor assembly, battery in holder, several gears, a string, cup, rocks, select Legos and wheel to each group of students. Pass out the worksheet, “[How Gears Help Drive the World](#).” Challenge them to figure out a way to make their motor able to exert more force. They should create a simple gear train with a small gear on the motor and a larger gear meshed with it. The larger gear should have the wheel, string and cup assembly attached. See Figures 9 and 10. However, see if they can figure this out themselves. Ask, “What did you do to make your motor more forceful?” Have them try and figure out for themselves why gears increase the force output of a motor. Ask, “What did we lose when we increased the force?” More force = less speed, so the geared-up motor spins at a slower rate and pulls the cup of rocks slower. Ask students where they experience gears in everyday life. They may mention bicycle gears or car gears and relate

to slowly pedaling up a hill and exerting less force on the pedals; but remind them that the bike is exerting more force on them as they climb a hill.

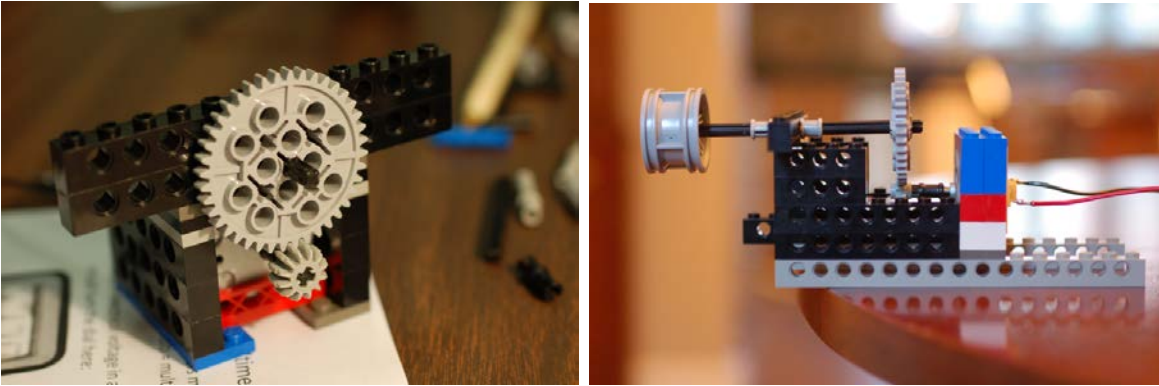


Figure 9. Small gear on motor, large gear attaches to spool.

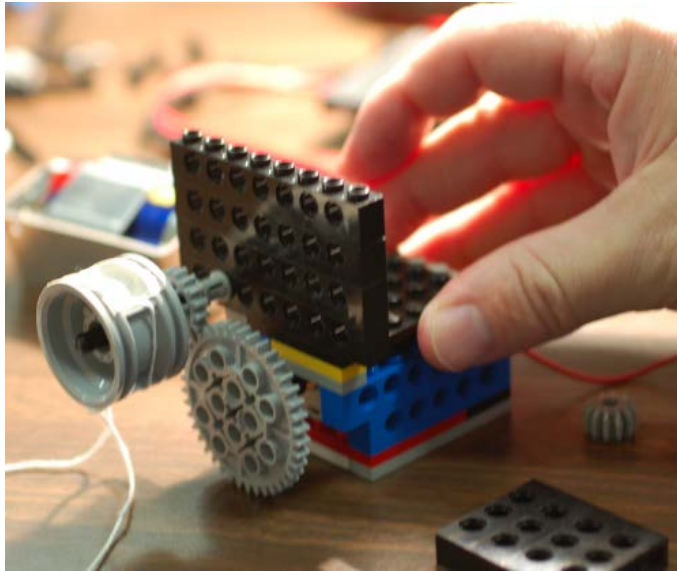


Figure 10. Large gear on motor, small gear attaches to spool.

Step 4: Have students document their activities and achievements on their story board.

Day 4 – Friction

Objectives

- Students will be able to define friction as the force between two surfaces that resists motion.
- Students will be able to demonstrate different types of friction.
- Students will be able to explain that the heavier something is, the more sliding or rolling friction it has.
- Students will be able to measure that some materials have more friction than others.
- Students will be able to explain how friction can be used to help motion.

Preparation:

- Cut little strips and glue sandpaper to the back wheels of one pull-back car, glue waxed paper to the back wheels of the other pull-back car. Let dry and test.
- Build a sample car with stationary wheels so students can imitate it.
- Gather materials so that each group has a set of different tires, spring scales, rocks, and Legos to build one locked-wheel car.
- Photocopy the [What is Friction](#) handouts.

Step 1: Determine student's prior conceptions about friction. Is friction a good thing? A bad thing? Is friction a force? What is friction good for? What would the world be like if we had no friction? Would walking be difficult? Would it be hard for cars to move? Ask students why hiking boots are different from bowling shoes? Ask if they know why skateboarding shoes have special soles? Many students will think of friction as something to eliminate, but help them see that friction helps with motion. Many will not understand that friction helps people walk and cars move forward, and that the frictional force is in the direction of the motion of the person or car, but opposite the direction that the wheel or foot tends to move. In what direction is friction acting in this demonstration? See Figure 11.

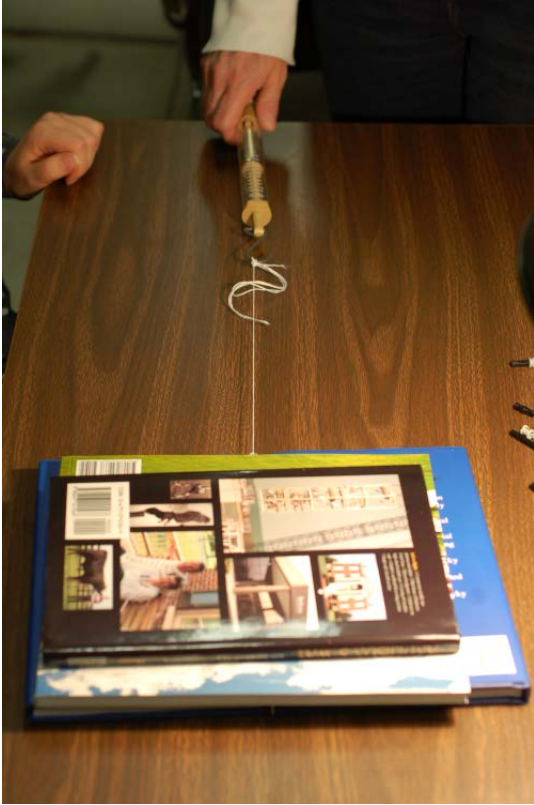


Figure 11. Pulling books with spring scale.

Step 2: Show students the three pull-back race cars. See Figure 12. One has sand-paper wheels, one has waxed-paper wheels, and one has rubber tire wheels. Tell students you are going to pull back on each car the same. Have them predict the motion of each car. Results will vary depending on the surface you use. Be sure to push down hard enough so that the wheels actually wind up when you pull back on the car. Many students will predict that the sand-paper car will go the farthest because the wheels have more friction. However, if you race these cars on a flat surface, this will not be the case. After racing the cars to see which one goes the farthest, engage students in a discussion about why friction helps cars go.

The car wheel has to push back on the road in order for the road to push on the wheel and cause it to move forward. In the same way, your foot has to push back on the ground for you to walk. Forces come in pairs. Your foot pushes backwards on the ground. The ground pushes forward on you. If the wheel or your foot cannot push back, if it slips and slides, the ground will not push back on the wheel or the car. What is this force called that the ground is pushing with? Friction! Without friction, cars and people can't get moving!



Figure 12. Race cars with different wheel surfaces.

Step 3: However, friction is not always easily determined by the roughness of a material. Very smooth materials can have extreme amounts of friction when moved against other smooth materials. Demonstrate this by pressing two pieces of Plexiglas together. You should be able to let go of one piece of Plexiglas while the other remains stuck to the first. This is due to friction! This Engineering Tool Box website lists the coefficients of friction for various material combinations. The higher the coefficient, the more friction there is. Plexiglas and Plexiglas together have a coefficient of 0.8 while a brick pulled across wood only has a coefficient of 0.6.

Step 4: Pass out the What is Friction? handouts and have students work in groups to test the different wheels for their ability to create a frictional force. See Figure 14 for sample wheels.

Put wheels on a cross axle, and thread it through a Lego piece that does not allow the axle to turn. See Figure 13. Pull on the wheel assembly with a spring scale to determine the force of friction.

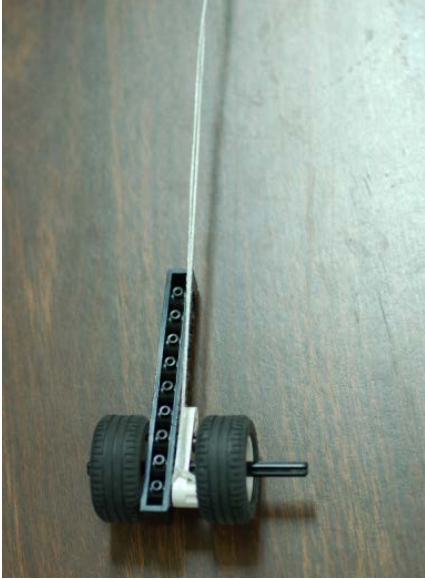


Figure 13. Pulling wheels that do not turn to check friction.

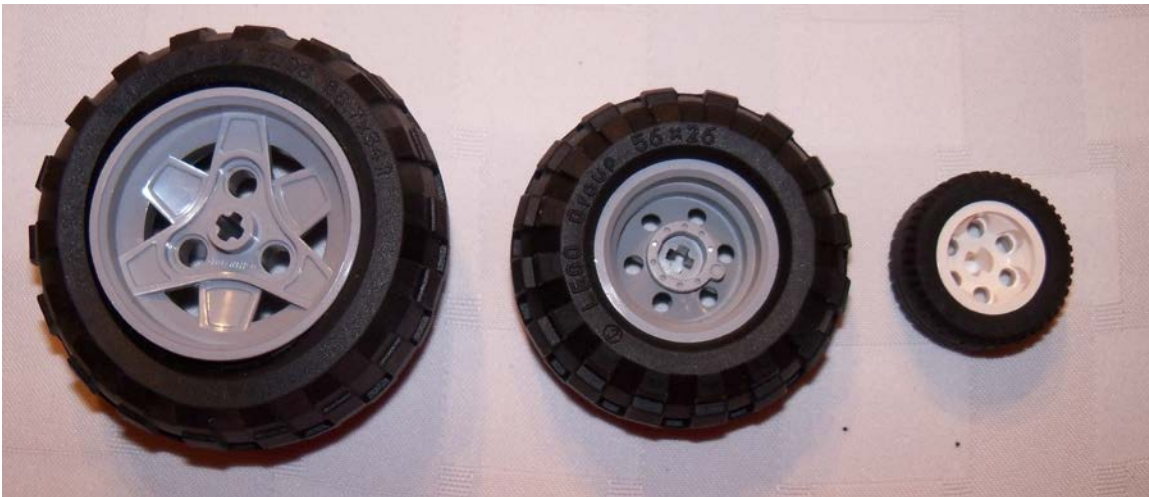


Figure 14. Three different wheel types.

Step 5: Pass out the remaining parts students will need for the design challenge. Encourage them to think about what they have learned in terms of solar cells, gears, and friction. Discuss the design challenge and have students draw their initial design on their storyboard:

Putting it all Together – Save the Sea Birds!

Design Challenge:

You are challenged to design and build a solar-powered vehicle that is able to pull a significant amount of weight since the car's primary mission will be to move people through town and replace cars and buses. Using solar-powered mass transportation eliminates the need for gasoline, diesel fuel, and pumping crude oil out from underneath the oceans. This will eliminate the possibility of oil spills affecting marine life, and save the Sea Birds from destruction. The best design is the one that pulls the most weight.

Official Rules:

1. Your design must be solar powered.
2. Your design must use a motor.
3. Your design must use only the materials provided.
4. The car must move.

Give students plenty of time to plan their design. It's important that the teacher discuss design decisions with students. Without giving away what WE know is best, it's important to pull creative and logical thinking out of the students. You might want to ask:

- How will the force created by the motor get transferred to the wheels?
- Do you want the most voltage, current, or energy produced each second?
- How can you increase the force that the motor can exert?
- Do you want wheels with more friction or less friction?

Make sure that students document their experiments on a story board square, drawing their design, and labeling the materials they plan to use, and indicating which tires they will use.

Day 5 – Engineering design, building, and testing

Objectives

- Students will be able to connect solar cells to a motor, and the motor to wheels to make a car move when light is shining.
- Students will be able to evaluate the effectiveness of their designs with regards to its ability to pull a load in a rolling cart.

Preparation:

- Make sure each group has a kit with all their materials in it: Lego pieces, solar cells motor(s), connectors, gears and wheels. Provide multimeters for diagnosing problems.
- Put smiley or people stickers on each rock so that the rocks represent passengers in a solar-powered vehicle. See Figure 15.



Figure 15. Rocks with smiley faces.

Step 1: Give students plenty of time to work on their designs and vehicle construction. Circulate around to ask probing questions as students work. Make sure all students are on task. Help students divide tasks if they have trouble working together

Step 2: Students should be drawing each iteration of the design in a story board square.

Step 3: Eventually, students will want to test their designs. For this first iteration, perhaps have them test the designs in the classroom so they can test independently. The first designs usually cannot pull much weight. Students invariably leave out gears on the first iteration. Let this happen- someone will eventually remember to use gears, and everyone will jump on the bandwagon. See example car in Figure 16 and note that gears are not used effectively! Three solar cells are required to get the car moving! See Figure 17 for an example of a well designed vehicle.



Figure 16. Sample solar vehicle with three wheels and three solar cells



Figure 17. Working solar vehicle with small gear on motor and larger gear connected to gear assembly on front wheels axle

Algebra Connection: Have students calculate the velocity of their car. Mark off a meter-long length on the floor and provide timers. As students add weight (people) to the trolley, have them calculate the velocity again. Having data like this gives your students the opportunity to graph different variables and look for linear relationships. Is there a relationship between the weight of the load and the velocity? This might provide the opportunity to discuss slope and linear equations and the value of interpolating and extrapolating data points.

Step 4: The most important part of the class period is the discussion. Gently and tactfully, have the class analyze the vehicles that did the best job at pulling the most weight. Also, have the class analyze the vehicles that did not perform as well. From this discussion, students can learn what features were most effective at creating force, increasing friction,

and delivering the most electrical energy to the motor. As you discuss the design features, be sure to point out which features promoted and which hindered success.

Step 5: Have students record the modifications they would like to do on their design tomorrow in class. Have them record these ideas in one story board square, and perhaps draw a sketch of the new and improved design.

Day 6 – Revision and Final Testing

Preparation: Print out awards for filling in at the end of class. [An award template is provided in this ETK](#)

Objective: To make improvements and repeat the testing process.

1. Revisions (20 minutes)
2. Final testing (20 minutes)
3. Wrap-up discussion (15 minutes)
4. Post assessment (10 minutes)

Step 1: Once again, provide guidance as students revise their designs.

Step 2: Ideally, perform the final testing outside on a sunny day. Sidewalks are a suitable surface. Have each team test their design in order, calculating the time to traverse 1 meter and the weight pulled by the vehicle. Have students record their final design and results on a story board square. See Figure 18 for examples of well-designed vehicles.

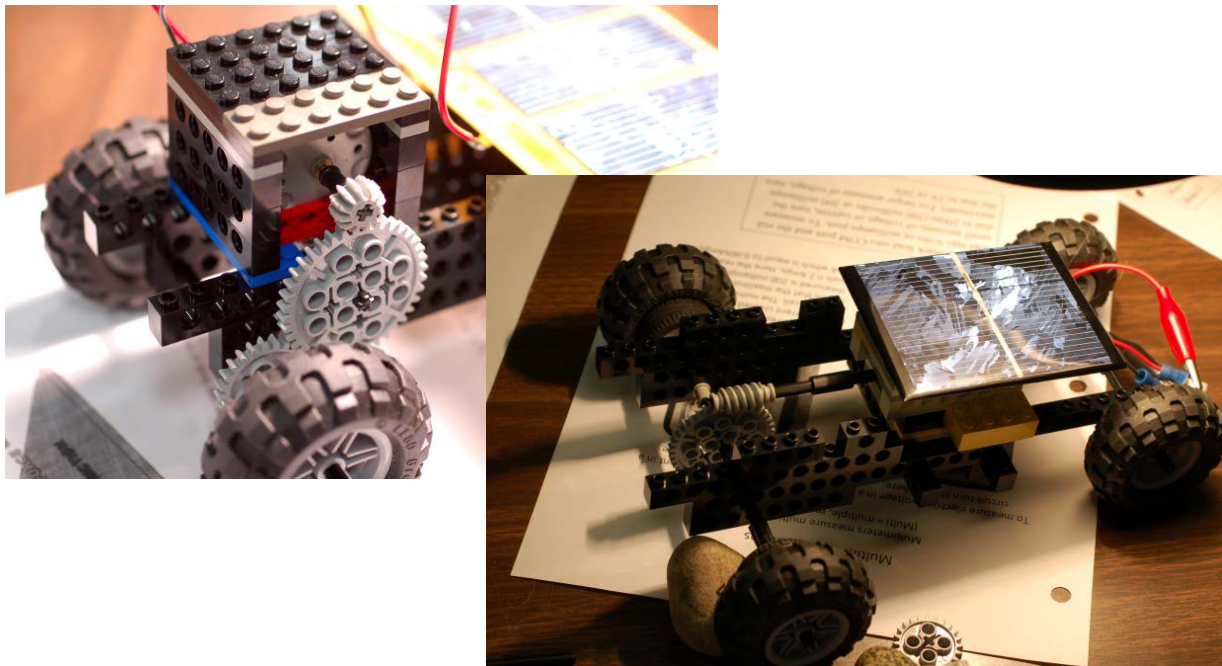


Figure 18. Well designed vehicles

Step 3: Guide students in an interpretive discussion about how they applied the concepts of energy, force, and motion to the design and construction of their vehicles. Ask students if they think solar-powered vehicles are realistic. Discuss the solar-powered vehicles already in existence: satellites, the Mars rovers, solar cars used in university competitions, and the new solar-powered airplane which flew for over 24 hours straight in July 2010. Use the PowerPoint presentation, Solar-Powered Transportation to facilitate discussion.

Step 4: Ask students what they liked and disliked about this unit. Use this information to help you plan future units which combine engineering design with science.

Step 5: Distribute awards for fun. [An award template is provided in this ETK](#). There are awards in several categories, including an award for the “People’s Choice” which is determined by popular vote. See Figure 19.



Figure 19
Award sample

Step 6: Complete the unit with the post-assessment on misconceptions about energy, force, and motion.