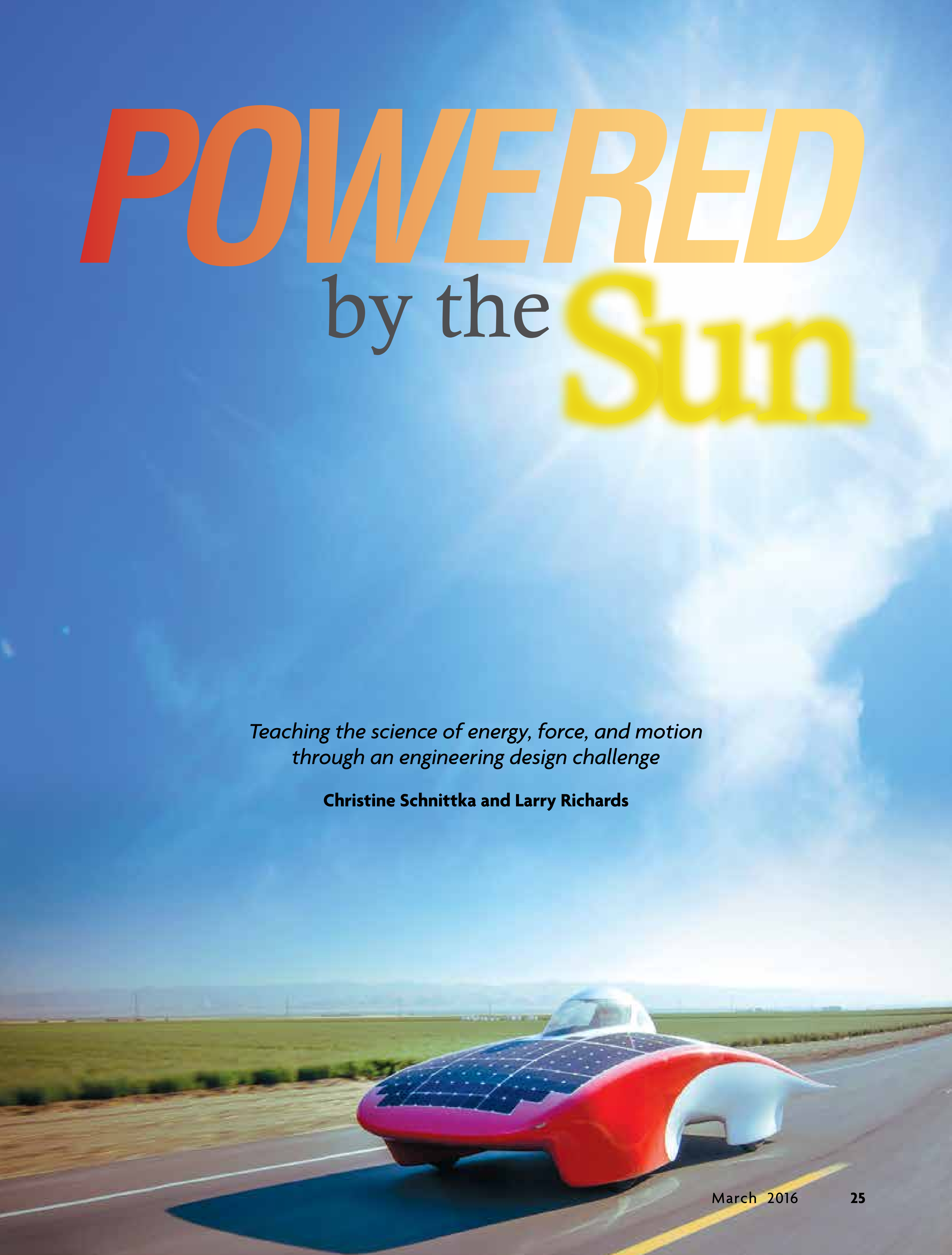

POWERED by the Sun

Teaching the science of energy, force, and motion through an engineering design challenge

Christine Schnittka and Larry Richards

Solar energy is clean, free, and abundant worldwide. The challenge, however, is to convert it to useful forms that can reduce our reliance on fossil fuels. This article presents an activity for physical science classes in which students learn firsthand how solar energy can be used to produce electricity specifically for transportation. The activity introduces students to solar-powered mass transit currently in use and then challenges them to create their own vehicle (Figure 1). When students create a successful solar-powered mass transportation vehicle, they use the engineering-design process to create designs that solve problems and carry out relevant scientific investigations (see box, p. 32, for connections to the *Next Generation Science Standards*).

Engaging students

Directly or indirectly, people and products are transported by fossil fuels that are mined or drilled from the Earth, then burned with many environmental consequences; there is a growing need for cleaner sources of energy. After describing this problem, give students a miniature toy solar car, a Matchbox car, and a shop light (Figure 2; see "On the web" for sources for materials and parts). Explain that energy from the light transforms into motion for the solar car. Share images of solar transportation—of say, the *Solar Impulse* or the *Türanor* (see sidebar, p. 29)—or let students browse the internet for images, videos, and news stories related to solar transportation. Plan on one class period for the pretest on energy and motion (included in the complete curriculum; see "On the web"); learning about solar trains, planes, boats, and automobiles; and the investigation with the toy solar and Matchbox cars described above.

FIGURE 1

Testing a solar car.

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FIGURE 2

Toy car and miniature solar car.

Testing the components

Next, students will prepare to design their own solar vehicles by devoting a few class periods to testing the various design components: the solar cells, motors, gears, and wheels.

Solar cells

Distribute the solar panels for students to examine. Ideally, one panel should be rated for high voltage and low current (5.0 V and 100 mA) and another for low voltage and high current (1.0 V and 415 mA). Have students compare them by measuring surface area, counting the number of cells within the panels, and observing the wires beneath the plastic surface. Challenge them to use a light source and multimeters to determine how much energy the solar cells produce (Figure 3). (See "On the web" for a video on how to use a multimeter.) Have students use the multimeters' direct current (DC) settings to measure voltage and current. Many will be familiar with the former but not the latter. Both are important for understanding how much energy a solar cell can produce. Have students test the solar cells in series and in parallel to see which configuration produces more power over time. The overhead

FIGURE 3

Testing a solar cell that produces .528 volts.

FIGURE 4

Data collected from solar cells.

Solar cell	Voltage (volts)	Current (amperes)	Energy per second (joules/second)	Power (watts)
A				
B				
A+B in series				
A+B in parallel				

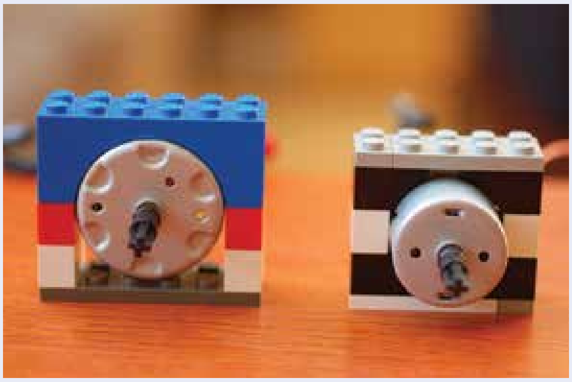
light in the classroom might be sufficient as a power source, but we find it better to conduct this activity outside in the sunshine or with shop lights in the classroom. (**Safety note:** When using shop lights, 150-watt incandescent bulbs are ideal but get very hot. Mount the shop lights so that students do not have to touch them and remind students to keep all hands and solar panels at least 50 cm away.) After testing, students might create a data chart similar to the one in Figure 4.

Electric motors

Distribute inexpensive electric motors typically used for hobbies and robotics. Ideally, one should be rated for high speed and low torque and another for lower speed and higher torque. We mount ours in Lego pieces glued together to make them easier to use (Figure 5) and mount special Lego-type pieces on the shafts as well (Figure 6). These are made especially for the 2 mm- or 3 mm-diameter motor shafts that we purchase from Pololu (see "On the web").

FIGURE 5

Two different motors in Lego motor mounts.



Torque can be defined as a twisting force. A higher-torque motor can move a heavier load than one with lower torque. When students connect a motor to a solar cell under light, they can compare how much twisting force each motor produces.

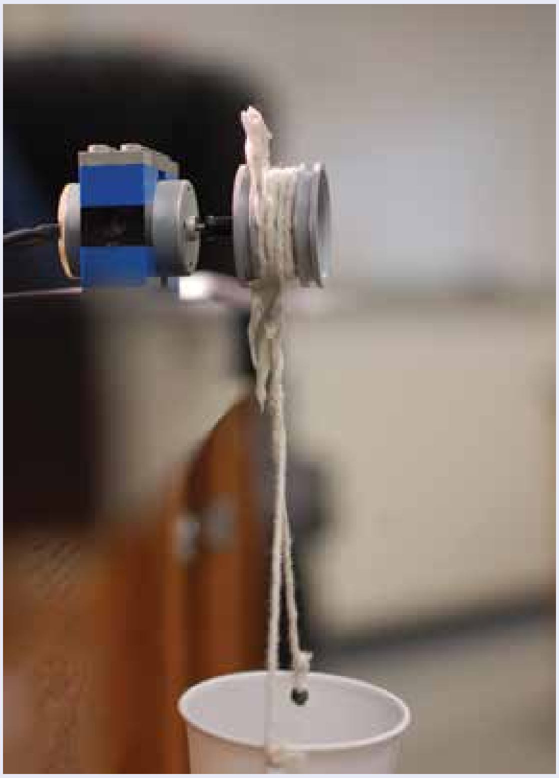
Our students compare motors by seeing how much weight each can lift in a bucket on a string. To do this, place the motor on the edge of a tabletop and attach a Lego wheel to the connector on the motor shaft so it can wind up a string (Figure 6). Secure the string to the wheel with a small piece of tape. Attach a cup to the string so the motor can lift different amounts of weight until students find a load it cannot lift. There should be a marked difference between the output force, or torque, of the two motors, and deciding between them is an important design decision.

Gears

Next, ask students if they can think of a way to enable the motors to pull more weight. If we need solar-powered vehicles that can carry cantaloupes across the country, for

FIGURE 6

Measuring torque: Motor with spool on its shaft lifting a load.



example, then we need electric motors that can exert a lot of torque. Here, someone is bound to suggest gears, which are great for multiplying the output force of a motor (Figure 7).

To test the gears, have students put a small one on the motor shaft and mesh it with a large one on a shaft that will lift a bucket. We use Lego parts and pieces for this, but if you have other parts available, you can make just about anything work. Have students test this configuration and then switch the gears so that the large gear is on the motor shaft and the small one is twisting up the bucket. Which one can lift more weight? Students will find that when speed is sacrificed, force is increased. Both configurations will do the same amount of work, but when the smaller gear is on the motor, the larger gear turns more slowly. Since work = force × distance, and the output distance is decreased, the output force is increased. Students can compute the gear ratio and compare it to the resulting increase in force. We use the GearSketch website to model gear pairs (see "On the web").

Wheels

Students might not think that wheels matter, but they do. Friction is the force that is required between the wheel and the ground for motion to happen; it's the force required between your foot and the ground for you to walk! Different wheel surfaces will produce higher or lower friction forces. Think about a car with wax paper wheels or one driving on an icy road—the car will spin out and not pull much force behind it. Demonstrate this with spring pull-back cars, which can be found at your local toy store (Figure 8). Cover the wheels in different materials, such as sandpaper or wax paper, and show students the effect friction has on motion.

Then, pass out a variety of wheels for testing. Students can use any method to test the wheels' friction, but we find it easiest to connect two wheels to a shaft so that they do not spin, and to hang a string with a cup to see how much weight it takes to overcome static friction and slide the wheels (Figure 9). Discuss how vehicle tires need friction.

FIGURE 7

Multiplying force: Motor with small gear meshed with large gear.

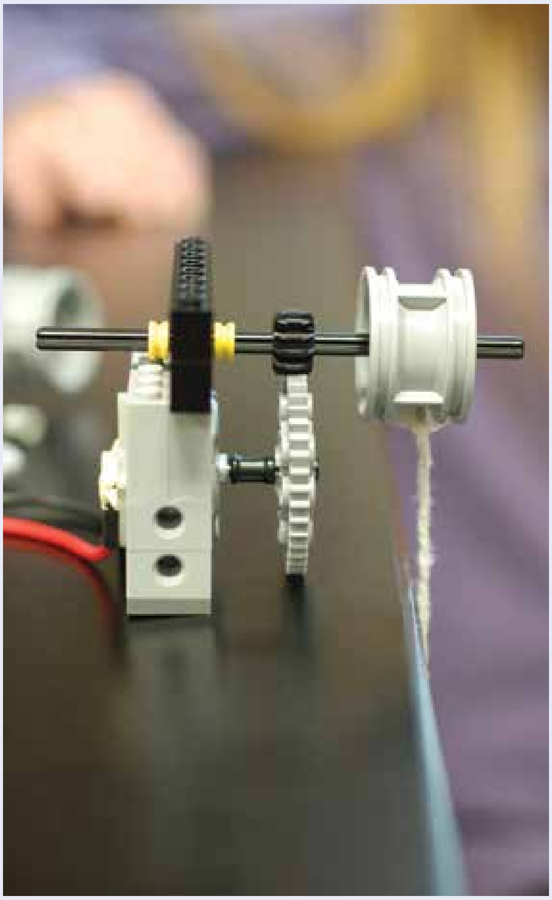
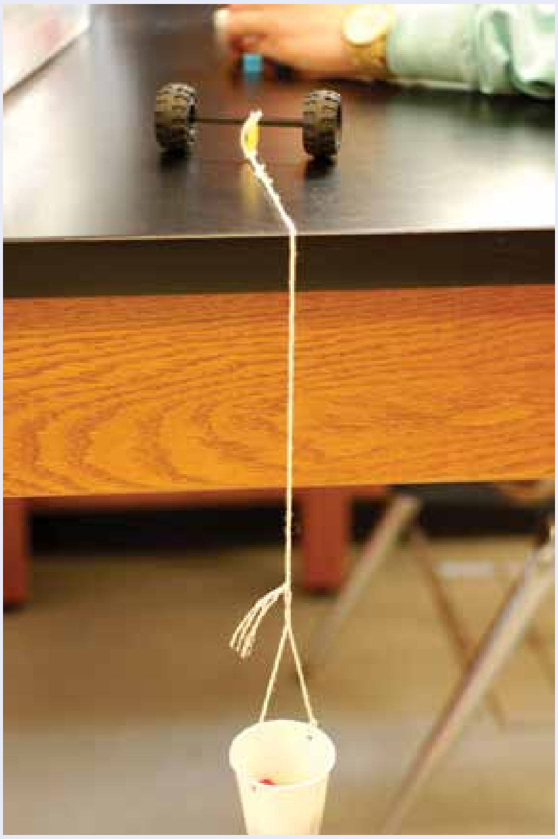


FIGURE 8

Comparing friction: Pull-back cars with different tire surfaces.

FIGURE 9

Testing static friction of wheels.



Solar power in transit.

Solar cars, trains, buses, and even airplanes move people and things around the world. In Belgium, for example, 16,000 solar panels form the roof of a train tunnel, helping supply power for that country's train network (Ridden 2011). A comfortable, air-conditioned bus called *Tindo* transports people in the city of Adelaide, South Australia, using only solar energy. The *Solar Impulse* flies across the United States without using a single drop of gasoline and is currently attempting an unprecedented around-the-world flight (see "On the web"). The solar-powered boat, *Türanor*, has circumnavigated the globe. And a solar-powered ferry moves commuters across the Sydney Harbor in Australia. Each of these efforts reduces the world's dependence on fossil fuels for transportation and makes a great example for classroom use.

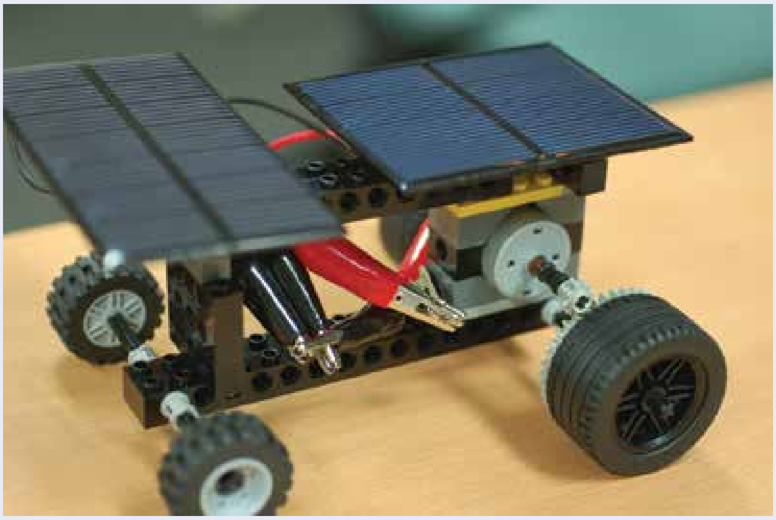
Truck drivers going up mountains, for example, do better with friction than without (e.g., think of snow and ice and the role of sand on a slippery road, or the role of chains or studs attached to winter tires).

The design challenge

Once your students have interpreted and analyzed data—another important component of the engineering-design process—it's time to put all the pieces together for the next step: model development and use. Encourage students to apply their knowledge of energy, force, and friction to their designs. You can conduct this segment outdoors on a sunny day or indoors with shop lights simulating the Sun. Most students need one or two class periods to design, build, and test their vehicles. Once students have a vehicle that reliably moves (Figure 10), it can be used to start pulling loads. To simulate mass transportation, placing the load in a plastic food storage container with wheels works well (Figure 11, p. 30).

FIGURE 10

A working solar vehicle.

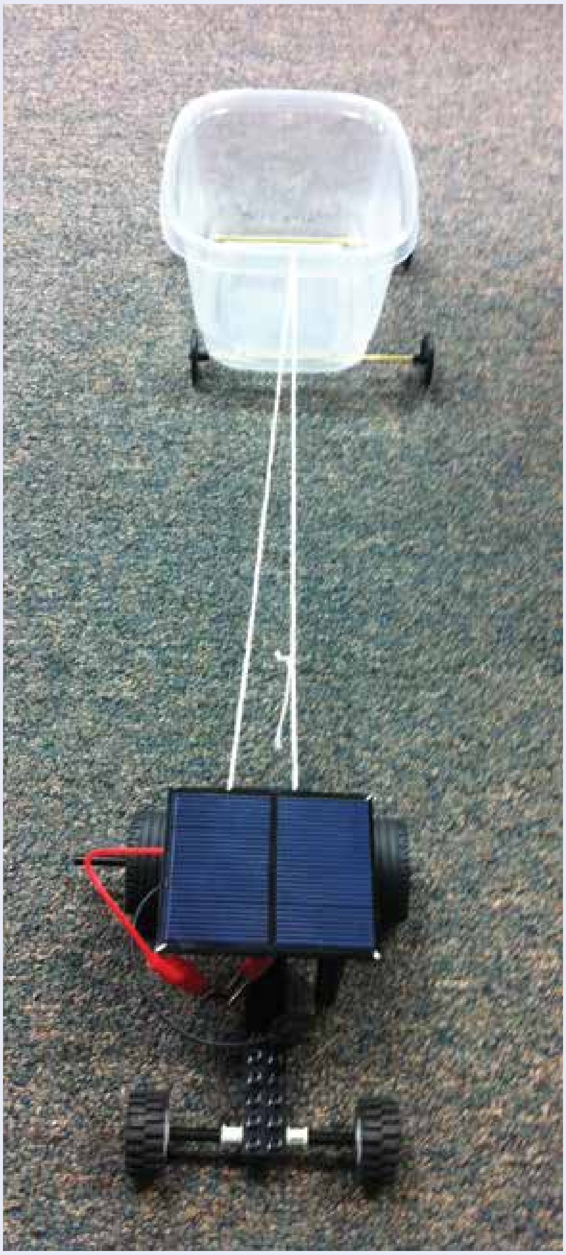


Testing the design

Connect the vehicles to the cart and load it with weights, such as rocks, brass weights, or plastic eggs filled with plaster. When all groups have tested their designs, have them share their design decisions with the class and let everyone go back to the drawing board. The goal is for every group to find a successful solution, which usually means not building a fast car but the one that can pull an adequate load. Depending on your solar cells, motors, and other parts, you can determine a target load weight and encourage each group to meet it. A vehicle made with the parts we typically use can pull up to 1 kg.

FIGURE 11

A solar vehicle pulling an unloaded plastic food container.



Assessment

Assessment of this activity can happen in many different ways. You can administer the pre- and posttest included in the full curriculum (see "On the web"), which assesses understanding of energy transformations, gears, voltage and current, torque, and friction (Schnittka 2009), but you can also have each group create a storyboard on a piece of poster board. Each square of the storyboard tells a part of the story as in a comic strip (Figure 12).

Students can draw their ideas, explain their design decisions, and record their results. Each time students work on the project, have them get out their storyboards. These can serve as a way for you to glance at ideas while walking around a busy room, and you can use the story squares as prompts for informal discussion. Students can use the boards to help explain their reasoning to the class during show and tell "pin-up" sessions. The design challenge itself is a form of authentic performance assessment.

Conclusion

Engineering design is an effective conduit to learning when the science is explicitly taught (Schnittka and Bell 2011; Schnittka et al. 2012). Competitions can actually discourage more students than they encourage, so making the design challenge a cooperative project in which everyone is capable of succeeding helps more students develop an affinity for science and engineering. Engineering comes naturally to youth, who often possess a passionate desire to remake the world around them. Try teaching science through the lens of engineering design and problem solving and watch how it can enrich your classroom. ■

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Acknowledgments

This curriculum was developed in part with the support of the National Science Foundation, grant #1247287. A link to the entire curriculum (in PDF or e-book format) can be found in the "On the web" section and is available at no cost to teachers.

Resources

Home improvement stores sell clamp lamps, multimeters, plaster, string, and other basic parts. We get motors and solar cells for the solar cars from companies such as Pololu; we ordered the mini solar cars from a different source (see "On the web"), Edmund Scientific, and Radio Shack. We purchase Legos directly from Lego's Pick-a-Brick feature online or from BrickLink (see "On the web"). If Lego parts are not affordable, the vehicle can even be built with scavenged wheels and axles.

FIGURE 12

Sample storyboard.

On the web

BrickLink: *www.bricklink.com*
Complete curriculum: *http://bit.ly/1OHkSYS*
GearSketch: *www.gearsket.ch*
Mini solar car source: *http://bit.ly/1RmfZDp*
Multimeter video: *http://bit.ly/1RDfRl6*
Pololu: *www.pololu.com*
Solar cells: *www.futurlec.com/Solar_Cell.shtml*. See parts SZGD6060-PET and SZGD10040-10
Solar Impulse: *http://bit.ly/1QNWvd0*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
HS-PS3 Energy
HS-ETS1 Engineering Design

Performance Expectations
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS.* Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.

HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Dimension	**Name and *NGSS* code/citation**	**Specific Connections to Classroom Activity**
Science and Engineering Practice	**Developing and Using Models** • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-3, HS-ETS1-2)	Students model the transfer and transformation of energy by designing and testing a solar-powered vehicle.
Disciplinary Core Idea	**PS3.A: Definitions of Energy** • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-3)	Student groups discuss and analyze the voltage and current generated by solar cells under different lighting conditions. Student groups discuss and analyze how gears are used to transfer energy and modify speed and torque.
Crosscutting Concepts	**Systems and System Models** • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. **Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS3-3)	Student groups modify their designs based on performance of the solar vehicle. They may change inputs in the form of solar cells or combinations of solar cells, or they may change the choice of gears or motors or tires to achieve the desired output. Students will use the engineering design process to design and modify technological systems that are key to modern energy transformations in our world.