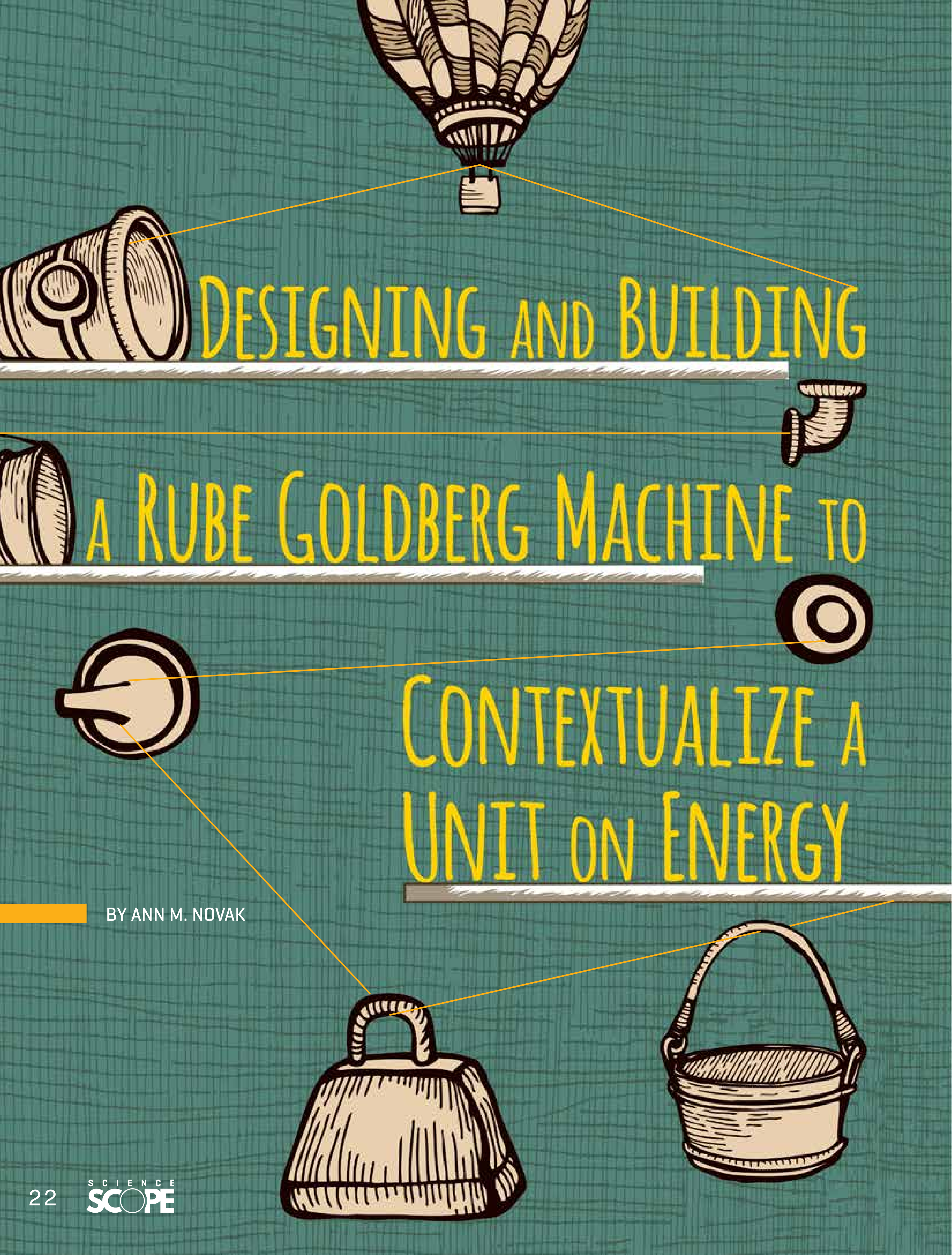


Designing and Building a Rube Goldberg Machine to Contextualize a Unit on Energy

BY ANN M. NOVAK

Many of us teach concepts that include different forms of energy, conservation of energy, and energy transfer. In this article, I first describe a unit overview with the driving question "Why does my cell phone charge when I plug it into an outlet?" In this lesson, students design, build, and diagram a Rube Goldberg machine that can accomplish a simple task, such as using a marble to turn on a light. By the end of the unit, they will be able to apply what they have learned about energy to answer the unit's driving question about charging cell phones.

This lesson has several goals. First, it contextualizes the curriculum and makes it meaningful and engaging to students. Second, the unit's driving question emerges from this lesson. Finally, the lesson serves as the unit's anchoring activity, which students revisit throughout the curriculum. All of the energy concepts of the unit are embedded in this introductory lesson, but none is explicitly discussed. Students can successfully build a Rube Goldberg machine without any understanding of the concepts. A *Rube Goldberg machine* is a contraption, invention, or device that is deliberately over-engineered to perform a very simple task through a chain reaction. In order to explain how their machines work, however, students will need to develop understanding of energy concepts. A "need-to-know" environment is thus created, and from this the various lessons of a unit emerge.

During the unit, students return to their Rube Goldberg machine diagram, bringing with them new understanding of energy concepts that allow them to develop a richer, more sophisticated energy "story" that describes how their Rube Goldberg machine works. Students use their emerging understanding of the energy concepts to more fully develop their diagrams; this process provides students with opportunities to use their understandings and assists them in gaining a deeper understanding of the ideas. Students' final Rube Goldberg machine diagrams account for all of the energy (energy conservation) in the system by documenting the types of energies, the energy transformations (conversions), and the energy transfers that occur during their machines' operation.

Unit overview

A Rube Goldberg machine that uses the driving question "How can I use a marble to light a bulb?" is used to illustrate the process that students undertake. In this machine, a marble at the top of the ramp rolls down and hits a small rubber ball at the bottom (1). The rubber ball bumps into the first domino (2), which causes the other 10 dominos to fall (3). The last domino falls on an aluminum foil strip (4), which hits the wires on the table (5) and completes a simple circuit that lights a bulb (6) (see Figure 1).

Little do students know that no matter which Rube Goldberg machine they build, it will include gravitational energy (GE), kinetic energy (KE), elastic energy (EE), thermal energy (TE), and sound energy (SE). In addition, groups' machines may or may not include chemical energy (CE), electrical energy (ELE), and light energy (LE). In order for students to fully understand how their machines work,

CONTENT AREA

Energy: energy transfer and the conservation of energy

GRADE LEVEL

6–8

BIG IDEA/UNIT

This article presents the context of students designing and building a Rube Goldberg machine as a way to contextualize a unit on energy.

ESSENTIAL PRE-EXISTING KNOWLEDGE

When something hits something else, it can cause it to move.

TIME REQUIRED

Three class periods; 45 minutes each

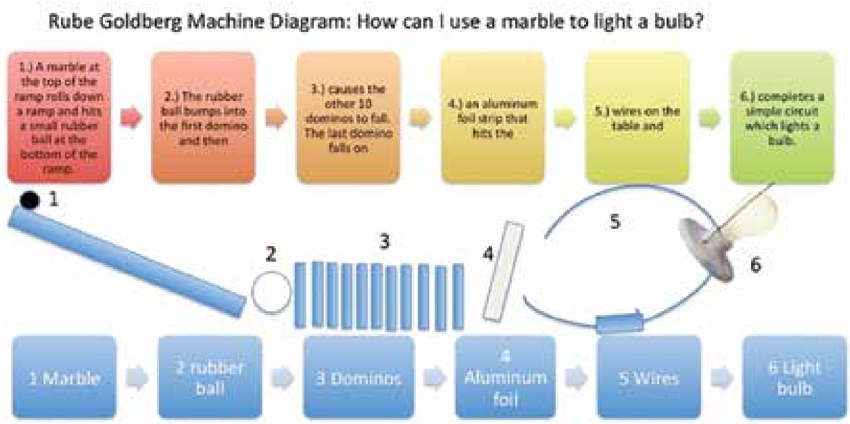
COST

Minimal

they will need to know about the various energies, how they transform (convert) and transfer to other energies, and ultimately that energy was not created nor destroyed, but that all of the energy can be accounted for when taking the entire system (their Rube Goldberg system) into account.

Students' Rube Goldberg machines now facilitate student groups' (three or four students per group) driving question for the unit (sub-questions), as well as the anchoring activity that is revisited throughout the curriculum as students engage with new ideas. Once students can answer their own driving question pertaining to their Rube Goldberg machines, they should possess foundational knowledge to accurately respond to the unit's driving question, "Why does my cell phone charge when I plug it into an outlet?" This becomes the unit's major learning performance and assessment. Furthermore, students should be able to answer questions such as "Why does the light go on when I flip the switch?" or any similar question.

FIGURE 1: Using a Rube Goldberg machine to demonstrate energy transfer



ALL IMAGES COURTESY OF THE AUTHOR

In several lessons following the initial lesson, the major learning goals are to help students understand that there are (a) different types of energy and (b) energy can be transformed from one type of energy to another. These lessons introduce students to kinetic, gravitational, and elastic energies through activities that use falling objects, pendulums, and bouncing balls. For example, a swinging pendulum incorporates cycles of gravitational energy transforming (converting) to kinetic energy and then back to gravitational energy. A bouncing ball transforms gravitational energy to kinetic energy as it falls from a higher to lower level, which converts to elastic energy as it compresses when hitting the floor. Subsequently, as the ball elongates, its elastic energy converts back to kinetic energy, and as it moves back into the air, its kinetic energy transforms back into gravitational energy. Students are introduced to energy conversion diagrams (Fortus et al. 2012) as a way to represent energy transformations. Students are also introduced to energy transfer diagrams that are used to represent (a) energy "moving" from one object to another and (b) energy gained or lost by an object (the object itself can represent a system or be part of a larger system).

Following this set of lessons (lessons that many of us already use), students return to their own initial Rube Goldberg machine diagrams to use their current understanding to explain how their machines work by updating their diagrams; they will represent their machines with energy transformation diagrams based on their emerging understanding of energy concepts. This updated diagram should include the energies learned thus far. Students should be able to identify energy types, the pathway of energy transfer, and various objects that have gained and lost energy. In addition, energies that decrease and energies that increase could be included using up and down arrows. Figure 2 illustrates a sample updated Rube Goldberg machine diagram.

For many students, KE, GE, and EE may be the only energy types represented in their machines. For other groups, they may not be able to explain the entire machine. This is fine for now but creates a "need to know" and will lead to lessons on chemical, electrical, and light energies. In Figure 2, notice the energy "story" for wires (5) and the light bulb (6) are incomplete. After these lessons, an optional activity is to challenge students to redesign their Rube Goldberg machines to incorporate all types of energies learned.

No matter what Rube Goldberg machine students have created, in the end, every student's machine will have "lost" all of its energy. Why did this happen? This will lead to further lessons on why some things stop, thermal energy (TE), and sound energy (SE). The learning goals of these lessons are to help students understand that (a) energy can be transferred from a system to its surroundings and (b) the total amount of energy can be accounted for and is conserved.

Following these lessons, students again return to their Rube Goldberg machine diagrams to document the types of energies and the energy conversions and transfers occuring during the machine's operation that account for all of the energy in the system; their energy transfer diagrams will need updating. Figure 3 represents a Rube Goldberg machine diagram that now includes energies "lost," thus accounting for all energy.

The unit concludes with students investigating how their energy transformation diagrams, based on their Rube Goldberg machines, can help them answer the unit's driving question, "Why does my cell

FIGURE 2: Updated Rube Goldberg machine diagram with various energies that light the bulb

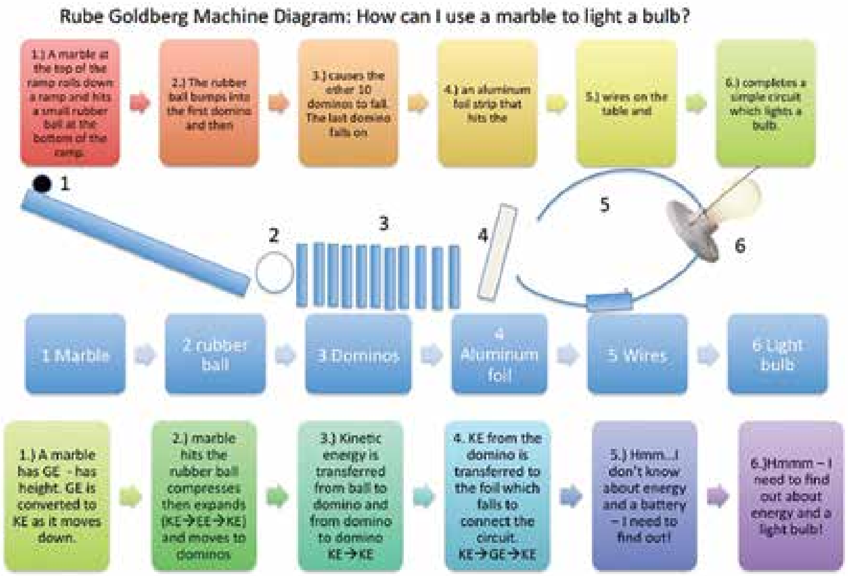
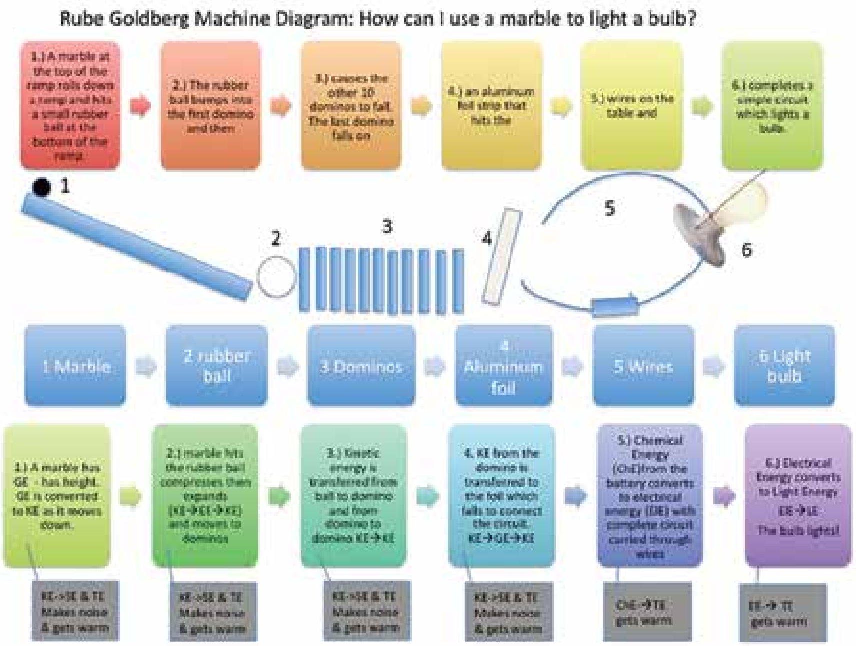


FIGURE 3: Updated Rube Goldberg machine diagram: All energies accounted for



phone charge when I plug it into an outlet?" Students should be able to deduce that, just like their Rube Goldberg machines, a series of energy transformations and transfers allows various energies to ultimately charge a cell phone. Students will then need to investigate various energy resources and how these resources generate electricity that eventually ends up in their homes. These will be the final lessons of the unit. Students should be able to create energy transfer diagrams to illustrate the chain of energy transformations that connect various energy resources to electricity. They should also be able to include energies that transfer out of the system, thus accounting for all of the energy. Figure 4 illustrates an energy transfer diagram using the resource coal to answer the unit's driving question.

FIGURE 4: Why does my cell phone charge when I plug it into an outlet?

Lesson plan

Title: Challenge! Can you design and build a Rube Goldberg machine that completes a simple task?

Content area/grade level: Seventh- or eighth-grade physics

Time: Three days

Lesson sequence

Tell students that you are going to begin a new unit by watching two videos. Ask students if they are familiar with Rube Goldberg machines.

The first video is a two-minute commercial made by Honda (see Resources). The second video represents the collaboration between the pop band OK Go and engineers from Syyn Labs, a Los Angeles-based arts and technology collective (see Resources). These videos are highly motivating to all students. To assess students' prior knowledge, inform them that these videos each contain lots of important science ideas (avoid saying energy ideas). Ask students whether they have any ideas of how these relate to science. (This can be done as a class discussion, or you may ask students to initially write out their own ideas on paper, then share with a partner, and then move to a class discussion. Papers may be collected and read to gauge students' prior knowledge). This process can last 5–15 minutes. If students bring up the idea of energy, inform them that, in fact, there are many important energy ideas represented in how a Rube Goldberg machine works and that energy is a major concept in all of science.

Tell students that their challenge, over the next several days, is to design and build their own Rube Goldberg machine that answers a question by com-

Materials for building a Rube Goldberg machine

- rubber bands
- marbles
- ramps
- paper towels
- wrapping paper
- toilet-paper rolls
- golf, tennis, or any other type of ball
- springs
- slinky
- batteries
- string
- tape
- vinegar
- baking soda
- safety goggles

pleting a simple task. For example, students can light a bulb, have a ball bowl down some pins, crack open an egg, etc.

Procedure

Assure students that the videos they just saw featured professionally created machines that have taken a great deal of resources, including many, many trials. The Honda video contains no video manipulation or computer graphics and took 606 takes before the whole thing worked. The OK Go "This Too Shall Pass" video shows a Rube Goldberg machine that took a month and a half to build. About 60 people worked on the project in all, including eight "core builders" who did the bulk of the design and building, along with another 12 or so builders who helped part time (see Tweney 2010 in Resources).

Students are not expected to create elaborate machines. They should try to incorporate four to six different steps in their machines. To get more ideas, students can spend 15 minutes looking up amateur Rube Goldberg machines online using key phrases such as "domino Rube Goldberg machines," or "amateur Rube Goldberg machines." If you have computers in your classroom or the availability of a computer lab, this can be done at school. Students may also do this as a homework assignment if your students have computer access at home. Another option is to explore various sites together as a class using one computer.

Introducing the design project: The challenge begins

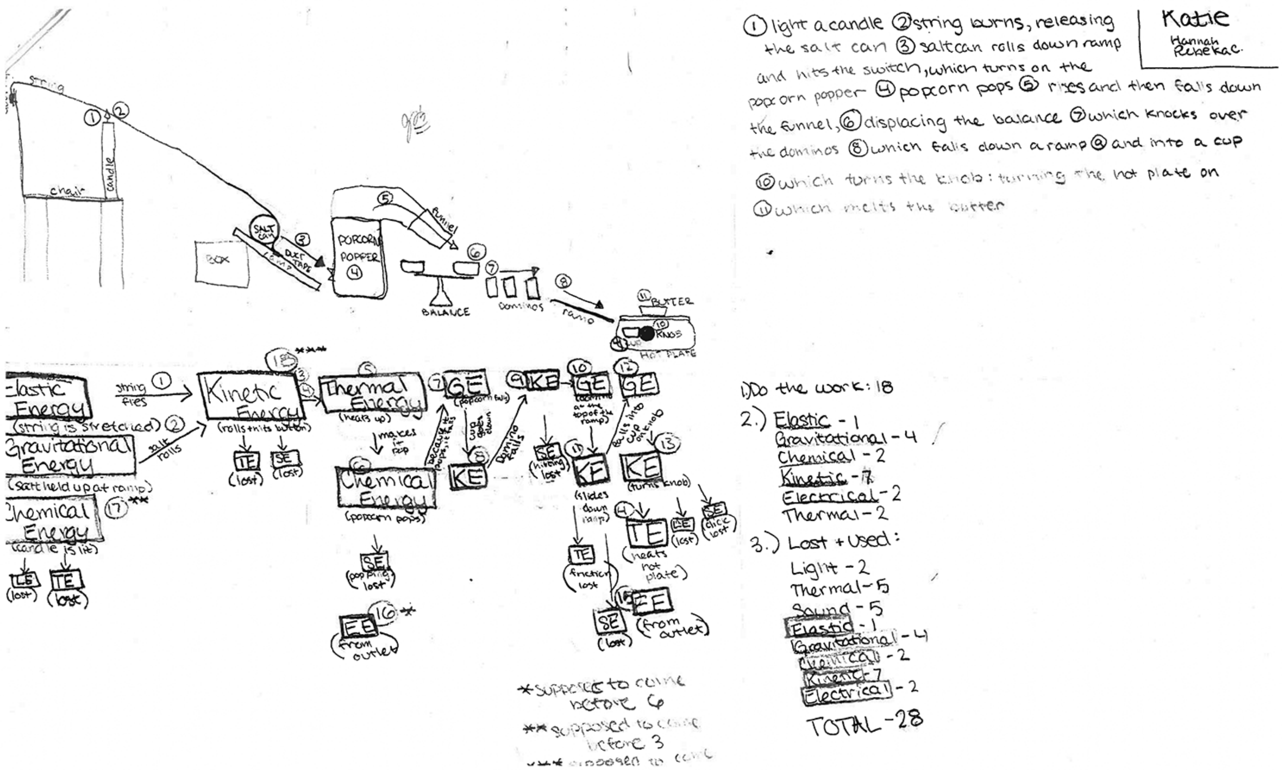
Prior to the lesson, the teacher should collect various materials for students to use (see Materials sidebar). Each student will also need paper to construct a Rube Goldberg machine diagram. Although any type of paper will work, 12″ × 18″ graph paper is ideal.

This lesson, and the unit in general, is accessible to all types of learners. It engages and challenges more and less advanced students. More advanced students may contribute ideas for more challenging Rube Goldberg components. However, my experience as a teacher shows that it is also common for students who seem to be less academically inclined to contribute sophisticated ideas, including how to engineer the successful building of various components. The successful building of the machine combines a wide variety of skills and talents. It appeals to a broad range of students because it requires and fosters creativity, problem solving, and collaboration. It includes manipulation of materials and student movement. The process may challenge students' patience and it should be stressed that this is part of what science is: thoughtful trial and error and persistence. All students can experience success in this unit.

Students should be divided into groups of three to five, depending on class size and space. In groups, students complete the following:

1. Plan the Rube Goldberg machine, including the simple task students want to accomplish and the various steps that will be taken to accomplish this task. This includes students assessing the feasibility of their design; a great idea isn't so great if materials are unavailable or if safety can be a potential issue. You will need to decide if it is acceptable for students to use candles, flash paper, and so on, and then provide students with appropriate guidelines to ensure a safe environment.
2. Figure out what materials students will need to accomplish this task, if these materials are available in class or if they can bring materials from home, and who will bring materials. Students should use everyday materials rather than purchase them. They can ask the teacher if certain materials are available from school.
3. Students need to construct an initial Rube Goldberg machine diagram. **Safety Note:** All students must wear safety glasses during the construction, testing, and demonstration of their Rube Goldberg devices. This will be done in student notebooks. In this initial diagram, students draw a picture of each object, in

FIGURE 5: Final Rube Goldberg machine diagram: How can I melt some butter?



order, and label and number each object. Additionally, students "Tell the Simple Story" (see Figure 1 for an example). The story can line up directly under or above the picture. Students collaborate to plan and design the machine, but each student draws an initial Rube Goldberg machine diagram (group members may work together on this as each member draws and writes). This will engage all students in the group and hold each group member accountable.

4. Groups spend one or two days building. In the area where you have placed various materials that students may choose for their Rube Goldberg machines, include materials that will be used in your energy lessons. For example, a pendulum (which uses gravitational and kinetic energies transforming back and forth) and a bouncing ball (which illustrates gravitational, kinetic, and elastic energies) will be used in future lessons. If students incorporate these into their machines, it allows you to make connections to those machines during these lessons. It also affirms and motivates students and creates a situation that allows them more visible opportunities to make connections between their machines and energy concepts.

   Inevitably, students will run into problems or have questions. While we never want to tell students what to do, this is another opportunity for teachers to suggest materials that will be used in future lessons.

5. Chances are that most or all of the groups' designs will be modified during the building time. Once groups' Rube Goldberg machines are successfully built, students will construct another Rube Goldberg machine diagram, this time on

larger graphing paper. Like their initial diagram, this will include a drawing of each object, in order, that is labeled. Likewise, students will "Tell the Simple Story" of how their machine works. They do this by writing about how the machine works using everyday language. As with the initial drawing, each member of the group is responsible for constructing his or her own diagram, although you may choose to have students work on this together. This process engages all students, assists them in developing ideas, and holds all students accountable. The updated diagram serves as formative assessment. See Figure 5 for an example of a final Rube Goldberg machine diagram.

6. As groups successfully complete their machines, they will present them to the class. **Safety Note:** Students making and observing the machine demonstrations must be wearing safety glasses. First, they explain, step-by-step, what will occur. Next, groups "run" their machine for the class. In some cases, they may need to run it a few times before it works. The class observes each presentation and can provide feedback to the groups; for example, they may provide suggestions for improvements or ask for clarification on how various parts work.

Summarize with students: Each group has a problem question from which they have built a Rube Goldberg machine. They have also created a Rube Goldberg machine diagram that tells a simple story of how it works. Inform students that there are lots of important science ideas related to energy represented in these two artifacts. Tell students that they will be investigating energy ideas over the course of the next few weeks, which will allow them to construct a sophisticated science "story" to explain how their Rube Goldberg machine works using energy ideas (see Figure 1). Once we can tell this story, students will then be able to answer the unit's driving question, "Why does my cell phone charge when I plug it into an outlet?"

More on differentiation

This lesson, as well as the entire unit, uses a method of teaching called "project-based science" (Krajcik and Czerniak 2013). "This teaching approach engages all learners—regardless of culture, race, or gender—in exploring important and meaningful questions through a process of investigation and collaboration" (Krajcik and Czerniak 2013). The Rube Goldberg curriculum is accessible to the most challenged students and is challenging to the most able students. It allows for student groups to explore their own question to design and build a Rube Goldberg machine so they find it interesting and meaningful. The unit also provides students with opportunities to participate in scientific and engineering practices that require social interactions and scientific discourse (NGSS Lead States 2013). ●

REFERENCES

Fortus, D., H. Abdel-Kareem, H. Jin, J.C. Nordine, and A. Weizman. 2012. Why do some things stop while others continue going? In *Investigating and questioning our world through science and technology (IQWST)*, eds. J.S. Krajcik, B.J. Reiser, L.M. Sutherland, Greenwich, CT: Activate Learning.

Krajcik, J., and C. Czerniak. 2013. *Teaching science in elementary and middle school: A project-based approach*. New York: Lawrence Erlbaum Associates.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

RESOURCES

Honda commercial—*http://bit.ly/2c8bxLm*

OK Go video—*http://bit.ly/2cnWryU*

Tweney, D. 2010. How OK GO's amazing Rube Goldberg machine was built. *Wired. http://bit.ly/2bZDnrx*

Ann M. Novak (*anovak@greenhillsschool.org*) has taught middle school science for over 20 years at Greenhills School in Ann Arbor, Michigan. She has a PhD in science education.

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

- 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, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standards

MS-PS3: Energy:
www.nextgenscience.org/dci-arrangement/ms-ps3-energy

MS-ETS1:
www.nextgenscience.org/dci-arrangement/ms-ets1-engineering-design

Performance Expectations

MS-PS3-5: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
www.nextgenscience.org/pe/ms-ps3-5-energy

MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
www.nextgenscience.org/dci-arrangement/ms-ets1-engineering-design

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Planning and Carrying Out Investigations	Students design and construct a Rube Goldberg machine that completes a simple task.
Disciplinary Core Ideas	
PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer • When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5) ETS1.A: Defining and Delimiting an Engineering Problem • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (MS-EST-1)	Students create an initial Rube Goldberg machine diagram and revise it to explain the types of motion energies present and energy conversions that occur during the machine's operation. Students collaborate to develop possible solutions when challenges arise. Students modify their designs, test them, and then modify them again.
Crosscutting Concept	
Systems and System Models	Students create diagrams of their Rube Goldberg machines that illustrate their understanding of relationships between components of the system.