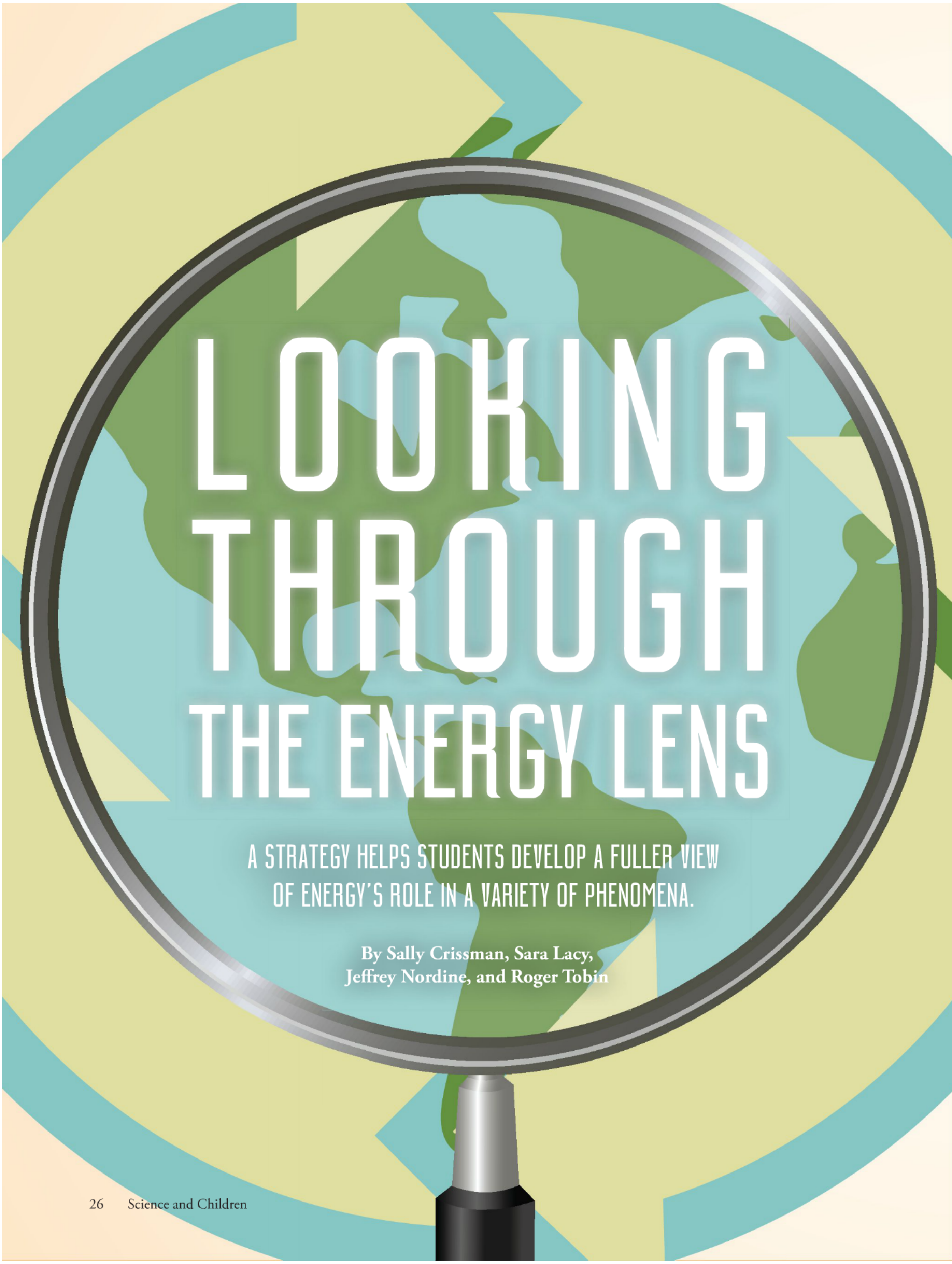

LOOKING THROUGH THE ENERGY LENS

A STRATEGY HELPS STUDENTS DEVELOP A FULLER VIEW OF ENERGY'S ROLE IN A VARIETY OF PHENOMENA.

By Sally Crissman, Sara Lacy, Jeffrey Nordine, and Roger Tobin

Energy is perhaps the quintessential Crosscutting Concept because we use it in every branch of science and because it plays a central role in everyday life as well. Scientists and engineers can identify the forms and flows of energy in any natural phenomenon or human-designed device to set limits on its behavior; non-scientists commonly decide what to eat based on how many calories (a measure of energy) foods contain. Even very young children build intuitive ideas about energy that help them understand why playing makes them tired or why they should close the door if the air conditioner is running.

Like matter, energy assumes different forms, flows within and between systems, and is conserved—in a closed system the total amount does not change. But energy is not a material substance. We cannot see it or touch it or even measure it directly. For these and other reasons, energy can be challenging to teach and learn. In this article, we present a strategy for helping children to identify the role energy plays in a variety of phenomena. We call this way of looking at phenomena the "Energy Lens" (Lacy et al. 2014).

The Energy Lens and the *NGSS*

Energy occupies a special place within the *NGSS* as a Disciplinary Core Idea in physical science (4-PS3 Energy), a Crosscutting Concept (Energy and Matter), and a component of Disciplinary Core Ideas in life science (LS1.C: Organization for Matter and Energy Flow in Organisms, LS2.B: Cycles of Matter and Energy Transfer in Ecosystems) and Earth science (ESS3.A: Natural Resources). The Energy Lens provides a consistent framework and language to help students develop a fuller picture of the energy concept and how it is useful across all fields of science and engineering. Using the Energy Lens entails asking a series of questions:

- What is the system of interest?
- What observable changes are taking place?
- Where in the system are energy changes occurring?
- Where does the energy come from?
- Where does the energy go?

Implicit in the last two questions is the idea that energy is conserved—like matter, it cannot just appear or disappear but can only flow. This conservation principle is by far the most important aspect of energy, but at the elementary level conservation ideas should remain implicit rather than explicit (NGSS Lead States 2013). While students can often recite that "energy is never created or destroyed," actually accepting and being able to use that idea is difficult, even for much older students (Liu and McKeough 2005; Neumann et al. 2013). Therefore, the *NGSS* stress that students should gradually build an increasingly sophisticated evidence base for identifying the role of energy in familiar phenomena. By focusing on interesting and familiar phenomena, students can more readily connect their intuitive ideas to the ones they learn in the classroom.

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The *NGSS* recommend that fourth-grade students focus on identifying forms of energy and finding evidence of energy transfers and transformations in phenomena and devices like colliding marbles, solar heaters, or electric cars (4-PS3-1, 4-PS3-2, 4-PS3-3, 4-PS3-4). By focusing on transfers and flows in a range of phenomena, students can build a foundation to extend those ideas in later grades to more complex contexts, including Earth and life sciences and engineering, and to learn the challenging but crucial principle of conservation of energy. Because changes in energy are not directly observable or measurable, students need carefully designed activities and guidance to track its transfer and conversions.

How Can We Help Students Understand Energy as a Crosscutting Concept?

In teaching interviews with pairs of children and in the classroom, we have explored hands-on, guided investigations in grades 3–5 that begin with easy-to-observe phenomena and simple representations and progress to increasingly complex scenarios. In each activity, children identify a system (or phenomenon) of interest and link observable physical changes to corresponding changes in energy. Children learn to look for *indicators or observable evidence* of energy, for example, motion, light, temperature changes, and sound (Nordine, Krajcik, and Fortus 2011). They develop and use representations that help them to think about energy as a quantity that can be greater or less, not just present or absent. They observe that increases in energy indicators of one object are associated with decreases in energy indicators of another. They learn to ask, "Where does the energy come from?" and "Where does the energy go?" and to use representations that show energy gains associated with energy losses. Using the same questions and representations in diverse contexts promotes an evolving model of energy that enables students to integrate a progressively larger network of ideas and address increasingly complicated situations. Children begin to move conceptually from "giving energy" and "losing energy" to "transferring energy" (e.g., the stored energy of a battery is transferred to energy of motion of a propeller, heating of a resistor, or light from a bulb).

Introducing the Energy Lens in the Elementary Classroom

The *NGSS* state that by the end of fourth grade, students should be able to "Ask questions and predict outcomes about the changes in energy that occur when objects collide" (Performance Expectation 4-PS3-3; NGSS Lead States 2013, p. 35). We use collisions between marbles to introduce the language and questions of the Energy Lens to students. In the next several sections, we use examples from teaching interviews and classrooms to illustrate how teachers could introduce the Energy Lens questions in this context.

What Is the System of Interest?

The teacher gathers students around a 36" horizontal board with two marbles resting in a shallow groove (Figure 1).

Teacher: *We're going to be thinking about energy today. We call the parts we'll be observing—the track and the marbles—"the system."*

The teacher gives the red marble a push and students watch it roll toward a stationary blue marble. The marbles collide, setting the blue marble in motion and bringing the red marble to a stop.

What Observable Changes Are Taking Place?

The teacher prompts students to notice how indicators for energy (motion in this case) are changing.

Teacher: *Let's look at the collision again. Would someone describe changes you observe? Use the terms "no motion," "more motion," and "less motion."*

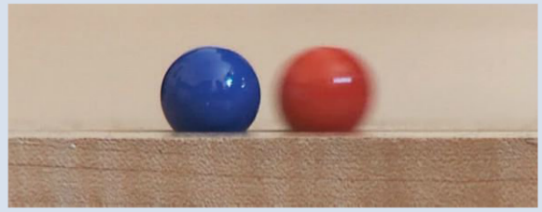
Students agree that initially the blue marble has "no motion" and the red one has "more motion," and that after the collision they are reversed.

Where in the System Are Energy Changes Occurring?

When we asked students about the energy of a marble that is motionless on a flat surface, we found that students often did not have a ready response. However, given time to think and talk, most students reason that a stationary marble has no energy. When we asked students to describe the marble collision in terms of energy changes, we found that they readily associate motion with energy.

FIGURE 1.

Marbles colliding.



Student 1: *It [the red marble] has more energy when you push it. It gets more energy when you push it harder.*

Student 2: *So, first of all, the blue marble is just sitting there. It's not moving so it has no energy. And the red marble—it's moving so it has energy—hits the blue marble, so then the blue one gets energy. The red marble slows down and stops so it doesn't have energy.*

Student 3: *The marble loses energy as it rolls, as it gets slower and slower.*

Even scientists cannot directly measure energy; there's no instrument that can measure the energy of an object in the way a scale measures mass or a thermometer measures temperature. Instead, energy is calculated from things that can be measured, like speed and temperature. We don't expect children in elementary school to do those calculations, and in fact the *NGSS* specifically rules them out in the early grades. But the idea that energy is transferred from one thing to another requires some idea that amounts of energy can be smaller or larger, and the students need some way to compare the energy of one object with the energy of another, or the energy an object has now with the energy it had before. Encourage your young students to devise their own pictorial and simple graphical representations of relative amounts of energy, building on their intuitive ideas. In the process, they will be engaging in the scientific practice of creating and using scientific models and representations that "enable them to elaborate on their own ideas or findings and present them to others" (NRC 2012, p. 58). To assess students' ideas about different amounts of energy, we asked them to show "a lot," "a little," and "no" energy of a soccer ball (see Figure 2).

FIGURE 2.

Visual representation of a soccer ball's energy.

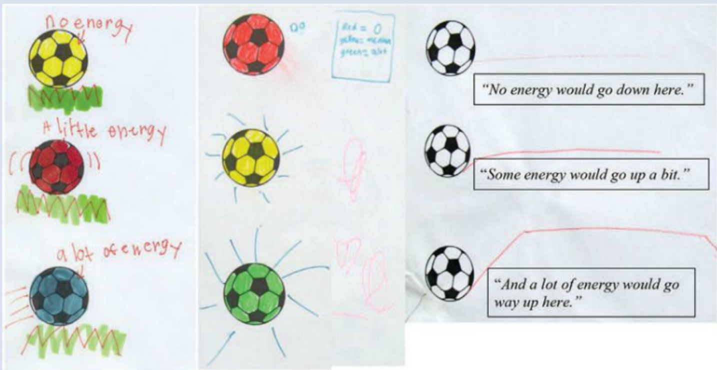
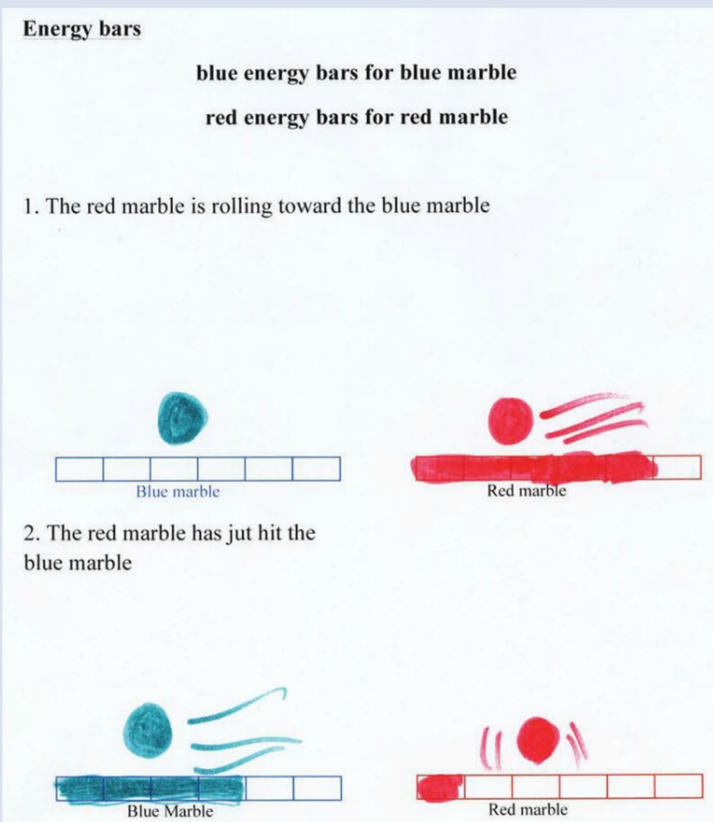


FIGURE 3.

Showing energy transfer with energy bars.



Transfer: Where Does the Energy Come From? Where Did the Energy Go?

A major goal of energy instruction in the elementary grades is the idea of energy flow: Energy can be transferred from one object to another and/or transformed from one form to another. Students must first be led to notice that in any process, a gain of energy in one place is accompanied by a loss in energy somewhere else. Once students learned to use invented representations to show that the amount of energy can vary, we asked them to use "energy bars." This single, versatile representation can be used to show changes in motion, stored energy, heat, light, or sound, reinforcing the idea that all forms of energy are the same stuff, and that the same tools and ideas can be used to analyze energy across a wide range of phenomena.

Students were asked to indicate the number of "bars" of energy of the red marble and of the blue marble just before and just after the marble collision (see Figure 3). The before and after representations indicate that the energy lost by the red marble (four "bars") corresponds to the energy gained by the blue marble.

Next, they described observable changes using the language of energy gains and losses. The teacher helps students recognize that the blue marble gains energy while the red marble loses energy.

Teacher: *Someone said that when it began to move, the blue marble must have gained energy. Where did the energy come from?*

Student: *Maybe if the red marble was rolling and it hit the blue marble, because then it made the blue marble roll and get energy.*

Teacher: *The red marble stopped after it collided with the blue marble. Where did the energy of the red marble go?*

Student 1: *I'd say the red marble lost its energy to the blue marble.*

Student 2: *The energy of the red marble went to the blue marble but not all of it because the red marble moved a little more before it stopped.*

In one class, a student felt the track vibrate as the marble rolled and speculated that some of the red marble's energy was transferred to the board's motion. Another student said she could hear the marbles roll so maybe some energy went to sound.

To emphasize that the blue marble's energy must have come from the red marble, the teacher places the red marble next to the blue marble, neither moving.

Students agree that neither marble has energy.

Student: *[The red marble] doesn't have energy yet. So it has to gain energy from something to be able to give it.*

The teacher introduces the word *transfer*:

Teacher: *There's a word—transfer—that describes the energy of an object like the red marble being passed along to another object, the blue marble.*

This idea may lead to the following question: "The blue marble slowed down and stopped. Where did that energy go?" Ultimately the energy winds up as thermal energy—the energy of random motion of the molecules that make up the ball, the track, the air, even the walls of the room. After the marble stops, the temperatures of all those things are slightly higher than before, although the change is usually much too small to detect. Simply *telling* this to students is unlikely to be productive or persuasive until they have more experience tracing energy flows in complex situations, and some familiarity with the particulate nature of matter. At this early stage it's important to acknowledge that it's a good question and encourage students to think about possible answers and how they might begin to investigate them, but the full answer requires ideas of energy dissipation and degradation that will be addressed in later grades.

The quotes above suggest that children can accept the idea of energy transfer as scientists understand the term, but we found that the idea of energy transfer can also be challenging. Some children don't necessarily believe that one object gives some of *its* energy to the other in the transfer process. As one child said of a collision between a bowling ball and pins, "I don't think the ball is giving energy to the pin, I think it's just like making it be forced to fall down."

Students need support and experience using the Energy Lens with many different phenomena to see that the energy giver hands over some of *its* energy to the energy receiver. In our work we continued to build on the Energy Lens questions and the energy bars representation in phenomena involving rubber bands, batteries, propellers, lightbulbs, and heat. The use of consistent terms and representations helps children see energy not just as an isolated topic, but as a concept that cuts across many phenomena.

PHOTOS COURTESY OF THE AUTHORS

A student places a room-temperature copper cube in warm water and uses energy bars to show the loss of energy by the water and gain of energy by the copper cube.

Conclusion

The *NGSS* emphasize that energy is useful as a crosscutting concept because tracking its transformations and transfers can help to make sense of phenomena from every scientific discipline and in everyday life. The Energy Lens gives students a set of tools that can be consistently applied in many situations. It can be introduced in a physical science context (as the *NGSS* recommends) and form the foundation for a deep understanding of how energy flows, cycles, and conservation affect our world. ■

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

4-PS3 Energy *www.nextgenscience.org/4ps3-energy*	
Performance Expectation *The materials/lessons/activities outlined in this article are just one step toward reaching the Performance Expectations listed below. Additional supporting materials/lessons/activities will be required.*	**Connections to Classroom Activity**
4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object. 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat and electric current. 4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.	• Students learn to use the Energy Lens in the context of marble collisions on a flat track. They use change of motion as an indicator of change of energy as they track energy gains, losses, and transfers in marble collisions. • Students learn to look for observable evidence, or indicators, of energy changes; for example, changes in speed, light, temperature, and sound. • Students explain diverse phenomena in terms of energy gains and losses and test the idea that an object has to have energy to give energy.
Science and Engineering Practices	
Constructing Explanations and Designing Solutions Developing and Using Models	• Students create representations to show that a ball can have different amounts of energy. They use "energy bars" to account for energy gains and losses and transfers.
Disciplinary Core Ideas	
PS3.A Definitions of Energy • The faster a given object is moving, the more energy it possesses. PS3.B: Conservation of Energy and Energy Transfer • Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion.	• The faster an object moves, the more energy it has. • Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another.
Crosscutting Concepts	
Energy and Matter: Flows, Cycles, and Conservation	Students use the Energy Lens as a tool to track energy flows in simple physical systems.