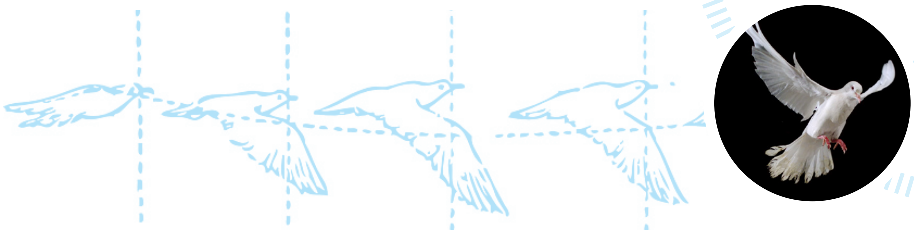
FEATURE // BY SALLY CRISSMAN, SARA LACY, ROGER TOBIN, AND NICK HADDAD

Getting a Grip on ENERGY



When you look at a bird in flight, a train in motion, an apple on a window sill, or a windmill, can you tell a story about energy? Where is the energy coming from? How is it changing? How do you know? Now imagine fourth graders looking for evidence of energy in these same scenarios.

What do they have to say? Some students say the bird has energy because it's a living thing, but the apple doesn't because it isn't attached to the tree. Some say, the train's wheels have energy, but the train car doesn't because it's "just going along for the ride." They have many ideas about energy, but are missing a framework to tie them together.

Current science and engineering standards call for students to start learning foundational energy ideas in elementary school.[1] Thanks to its conceptual importance in all fields of science and engineering, and its relevance to important social issues, energy is widely acknowledged as a vital topic for K-12 science education.[3,7] However, studies show that existing instructional approaches are largely ineffective in bringing students to the kind of integrated understanding of energy that they need to meaningfully use energy ideas.[3,5,8]

Teaching and learning foundational ideas about energy in elementary school present a significant set of challenges:

1. Energy is abstract. Like matter, energy assumes different forms, flows within and between systems, and is conserved. But unlike matter, energy is not a material substance. How can students who are only nine or ten years old reason about something we cannot see, or touch, or even measure directly?
2. Researchers have identified four key energy themes (forms and transformation, transfer, dissipation and degradation, and conservation) that cannot be learned sequentially or in isolation.[3,5,8,9] This requires an upper elementary energy curriculum that weaves together these conceptual themes and advances them in tandem.
3. Elementary teachers feel unprepared to teach about energy—they need a solid understanding of the science, classroom activities, and resources.

Getting a Grip on *ENERGY*

FOCUS ON ENERGY TO THE RESCUE

Addressing the challenges of the abstract nature of energy, the need for an innovative curriculum, and the need for teacher preparation, TERC's *Focus on Energy* project has developed a 13-session curriculum for grades 4 or 5, supported by teacher professional learning, web-based resources, and assessments.

The *Focus on Energy* curriculum is comprised of a sequence of increasingly complex phenomena investigations involving motion, elastic, thermal, and electrical energy. Each is framed by an investigation question, followed by firsthand explorations and activities, and the opportunity to make meaning. Students have multiple opportunities to apply and consolidate ideas about energy forms, transformations, transfer, and dissipation as they construct energy stories of ball collisions, elastic-band driven propellers, solar panels that can charge a capacitor, or temperature changes in the air of a "mini-room" warmed by a cup of hot water. Students using *Focus on Energy* go beyond simply identifying specific forms or transfers or transformations; they learn to track energy flow through each system. From the outset, students learn to use what we call the Energy Tracking Lens (ETL) and they use a set of representational tools to reason about energy flow and develop a model of energy.

Children investigate elastic energy.

The Energy Tracking Lens

PART 1. Describe what you observe.

PART 2. Tell the energy story.

- What components are involved?
- Form(s) of energy?
- Increases and decreases in amounts of energy?
- Energy transfers?
- Change of energy from one form to another?
- Where does the energy come from and where does the energy go?
- Use observations to support your energy story.

THE ENERGY TRACKING LENS (ETL)

The ETL provides a consistent framework and language that help students reason about energy flow in any phenomenon. The ETL begins with careful observation of an interesting phenomenon. Students describe what they observe, then use those observations as evidence of energy changes that they cannot see. Through a series of questions, students identify elements they'll need to tell the "energy story." Telling the energy story requires using the evidence they can see to infer or reason about the energy they can't observe directly. Implicit in the last question is the idea that energy is conserved—like matter, it cannot just appear or disappear, and whenever there is a decrease, there is an increase in some other forms or places. With the ETL, students begin to look at energy through the eyes of a scientist.

A MODEL OF ENERGY

Since energy is an inherently abstract concept that cannot be directly observed, the study of energy both demands and is an ideal context for modeling-based teaching and learning. The curriculum begins with an easy to observe motion phenomenon: a collision between a ball in motion and a stationary ball on a horizontal track. Students begin to generate a model in response to the question, "What can motion tell us about energy?" The class collectively adds to and revises the model throughout the unit uses it to construct sophisticated explanations of energy flow.

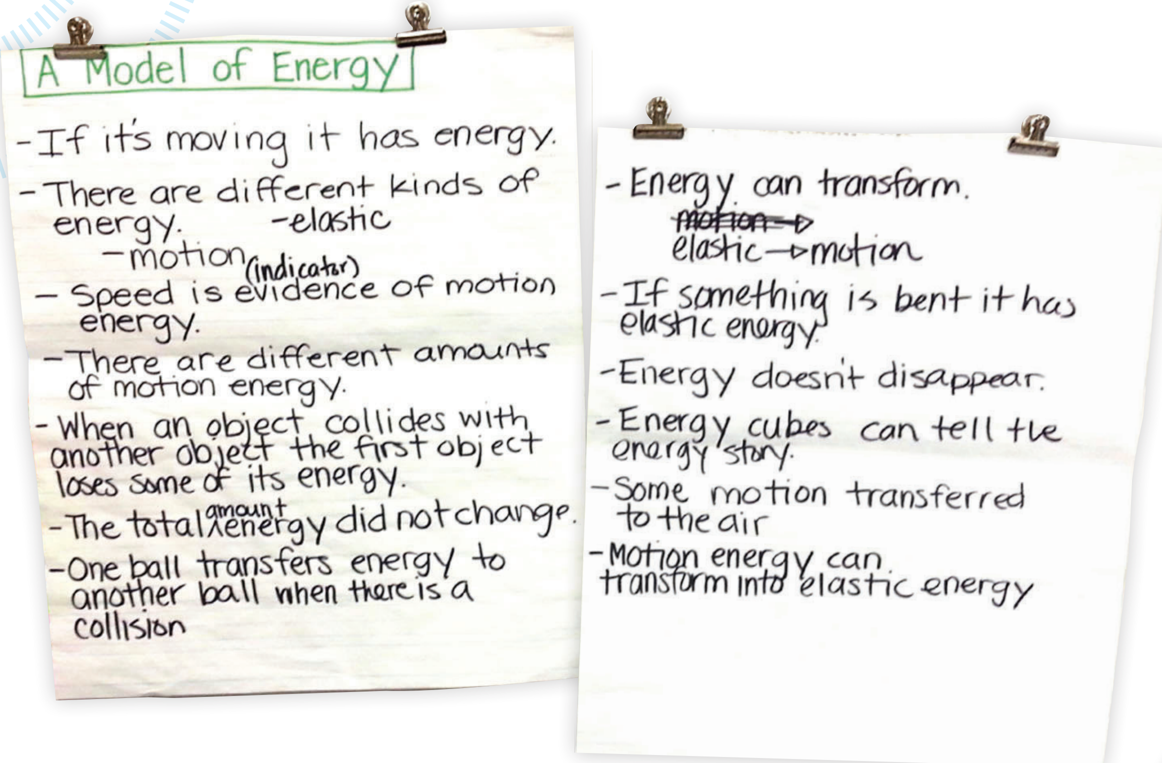


Figure 1: An emerging classroom model of energy

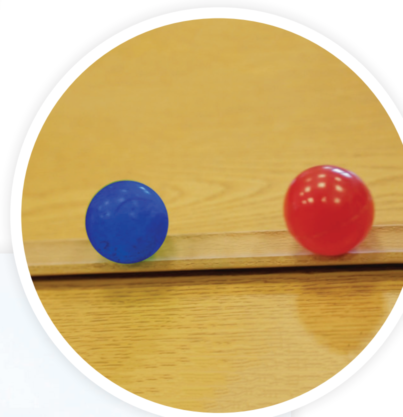
REPRESENTATIONAL SCHEMES

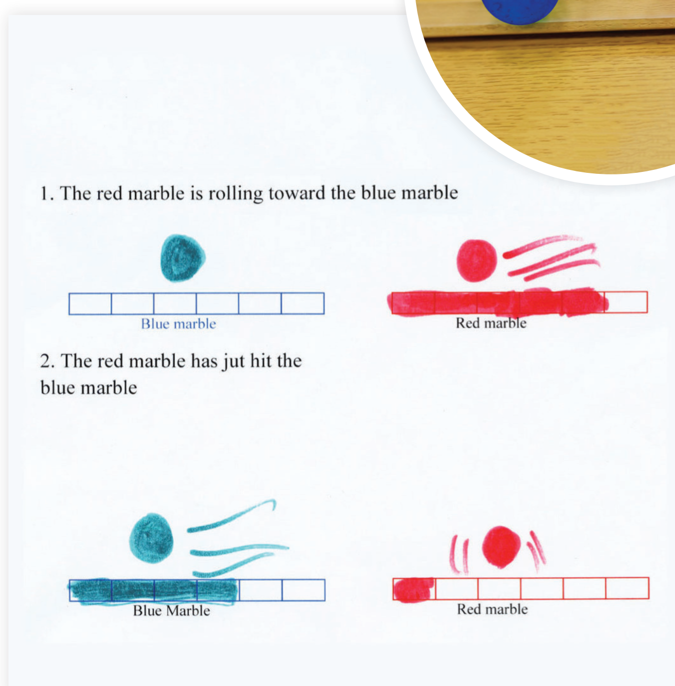
Representational schemes support model-based reasoning,[4,11] and the curriculum introduces representational tools that allow students to track energy flow in a flexible, context-independent way. Students use these representations to make the invisible visible, and to reason about the energy flow.

Energy Bars

Energy bars are introduced to show gains and losses during a collision and to convey the idea of energy as a quantity.[2,6] Students use the observable evidence of energy, in this case speed, to determine how many energy bars to color in. "The blue ball wasn't moving so I gave it zero energy bars but after it collided with the red ball, it moved pretty fast so I gave it four energy bars. I think it got its energy from the red ball. The blue ball started out with five bars and after the collision it hardly moved at all so I gave it one. It lost most of its motion energy."

Students use this single, versatile representation to show changes in motion energy, elastic energy, and thermal energy, 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 use energy bars to reason about energy gains and losses.

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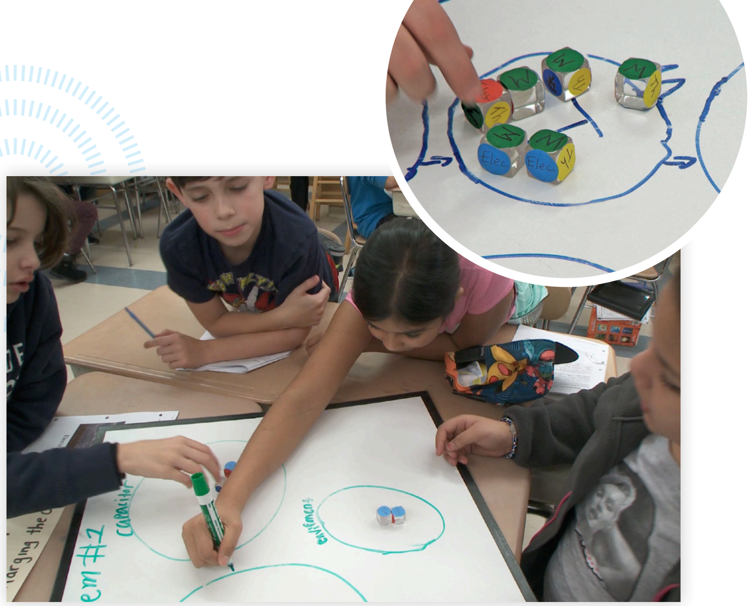

Students use energy cubes to reason about energy flow.

Energy Cubes

A key *Focus on Energy* representational tool is Energy Cubes.[10] Units of energy are represented by small cubes similar to dice. Cube sides are labeled to indicate different energy forms, such as M for motion or Th for thermal. Students draw circles on a whiteboard to represent what they consider the relevant components of a system. They have six energy cubes to distribute among the components, based on their reasoning from observations. The representation provides a context and tool for co-construction of meaning.

Groups of students negotiate which components to represent and how to tell the energy story. They move and flip the cubes to represent energy transfer and transformation while holding one another responsible for consistency both with their observations and their overarching model of energy.

Sketches, Diagrams and Drawings

As they create a drawing, or sketch of their ideas, students take another look at their thoughts about an energy story. As they share their ideas, they ask, "Am I accounting for everything? Does this still make sense to me?"

A FRAMEWORK FOR THE FUTURE

Teachers and their students are finding the *Focus on Energy* activities engaging and motivating and we have seen students learn to use the tools in a remarkably short period of time. Armed with an emerging model of energy, a set of representational tools, and a common language, students are poised to apply energy ideas in their future school work as well as in their everyday life. Energy is abstract, but the *Focus on Energy* Project is bringing a new level of reasoning about energy to elementary classrooms.

This work was supported by National Science Foundation Awards #1020013, #1020020, #1418052 and #1418211. The authors gratefully acknowledge the contributions of the Physics Education Research Group at Seattle Pacific University and of Marianne Wiser in developing the Energy Tracking Lens approach.

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