TEACHING ENERGY

ACROSS THE SCIENCES

K–12

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EDUCATION

CONTENTS

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come from and where they go—their flows and cycles into, out of, and within a system—provides critical information that helps us understand the functioning of that system more broadly. That functioning is constrained, or limited, by the availability of these two related but distinguishable resources. Energy and matter are linked as a single crosscutting concept because they share the feature of conservation, which can be applied across systems in similar ways; however, there are significant differences in the concepts of energy and matter and the issues related to teaching these concepts.

Thus, it makes sense to devote a book solely to energy and the ways in which its use as a crosscutting concept supports and illuminates science learning across all science disciplines. There is a need for such a book because the ways we have traditionally taught about energy have not stressed the value of looking at energy flows as a tool to understand aspects of a system's behavior, nor have they allowed students a sufficiently deep and broad view of energy to be able to see the connections across disciplines in the application of energy concepts. Yes, ideas about energy are taught in the physical sciences and the term *energy* is used across the science curriculum, but we have not done enough to help students connect energy ideas across disciplines. As the K–12 science curriculum has traditionally been taught, a student would have a great deal of difficulty making any connection between, for example, the way the term is used in a biology class and what they learn about energy in physics class.

This book arose from a set of workshops around the teaching of energy. The authors' conclusions and ideas were developed in the context of those workshops: They seek to address why and how we must approach teaching about energy differently to enable students to use this concept as a tool to address and understand new problems and contexts. I believe that teachers will find these perspectives very useful as they work to help their students understand the crosscutting nature and significance of energy and apply the idea of its conservation to reason about a wide range of systems.

Reference

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

CHAPTER 1

WHY IS ENERGY IMPORTANT?

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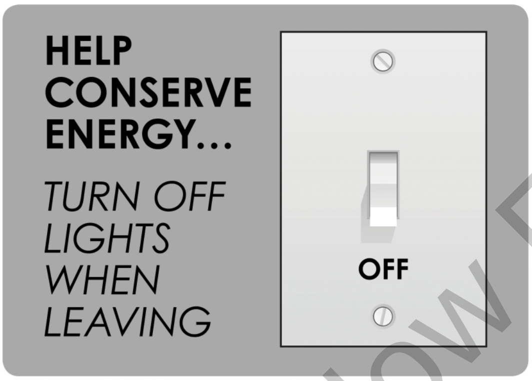
Conservation of energy is one of the most simply stated principles in all of science—that is, initial energy equals final energy for any isolated system. Yet, some scientists devote their entire career to understanding how energy behaves, and students often have a great deal of difficulty in understanding energy principles and applying them to make sense of everyday systems. Why is this?

Although the simplicity of the energy conservation principle makes it so critically important in science, its application in complex real-world systems can be very difficult indeed. Most real-world systems are not isolated; they allow energy to transfer into and out of them. If a swinging pendulum acted like many science classrooms assume, then it would swing back and forth forever. But this is not the way the world works. Pendulums slow down and eventually stop, clocks need to be wound, and batteries eventually need to be recharged or replaced. Thus, while it is easy to state the conservation principle for any isolated system, it is difficult to find a system that we can reasonably think of as isolated and actually calculate a numerical value of the energy within that system so that it is possible to track changes in energy that occur.

In schools, teachers commonly ask students to use the energy conservation principle to solve problems involving prediction of the behavior of real systems, such as pendulums and model roller coasters. It doesn't take long for students to notice that their answers are always wrong. The more interesting the system (e.g., more complex machines and faster-moving objects), the more their predictions tend to differ from results. Before long, conservation of energy can begin to look like abstract scientific dogma that is really useful only for solving problems from a textbook. One problem with the typical approach to energy instruction in schools is that it often fails to show students how the principle is useful outside of the classroom setting.

Further complicating the issue is the fact that energy ideas pervade our everyday lives and have many nonscientific meanings. Most students show up to school already having a set of intuitive ideas about energy. Prekindergarten students have likely been told by their parents, "Whoa, you have a lot of energy today!" Older students have likely noticed commercials on television that tout an oil company's role in energy production. Virtually all children have been asked to turn off the lights to conserve energy (see Figure 1.1).

Figure 1.1. A sign found next to many light switches



Students' experiences with hearing and using the term *energy* to describe everyday events give them a very intuitive sense of what energy is and how it behaves. Yet, these intuitive feelings are often at odds with school science instruction. After years of seeing batteries die or being asked to turn off the lights to save energy, their science teacher suddenly tells them that energy is *never* used up and that energy is *always* conserved, no matter what they do! When classroom instruction seems to conflict with—rather than clarify—their intuitive ideas about energy, students struggle to develop a strong and self-consistent understanding of the energy concept that is useful for interpreting phenomena and events across in-school and out-of-school contexts (Driver et al. 1994). However, intentionally designed instruction can help ensure that students develop a set of connected ideas that are applicable in a wide range of contexts.

Why Is Energy Learning So Important in Today's World?

The energy concept is fundamentally scientific in nature, but it has tremendous personal and social consequence. Even without explicitly thinking about energy as a concept, people make energy-related decisions every day. For example, as people make dietary decisions, a key consideration is that they ingest an appropriate number of calories each day to carry on life processes without exceeding this amount. Said another way, we need to be sure that the energy inputs (calories we eat) and outputs (calories we "burn") for our human body system are in balance. It requires very little scientific or mathematical sophistication to engage in the process of counting calories. An individual needs only to track the number of calories that he or she ingests and to approximate the daily calories burned through

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his or her activities—a process that has been made exceptionally simple by a variety of smartphone applications. If people ingest more calories than they burn, they will almost certainly gain weight over time. If they ingest fewer than they burn, they will almost certainly lose weight over time.[1] Most people can use calorie tracking to explain changes in their weight, but few deeply understand the complex chemical processes of metabolism that link the energy associated with the arrangement of atoms in our food to the change in mass that manifests in our bodies as a result of a calorie imbalance. The beauty of the energy concept is that a person can use it to predict and explain complex phenomena without needing to understand the full details of the human body system.

The human body houses some of the most complex systems in the known universe, and it is remarkable that a few simple ideas about energy can help us predict and explain how it will respond to changes. Most modern technological systems and devices are also enormously complex, and people make decisions every day that affect how they will function. Whether considering how to lower monthly electric bills, extend the battery life on a cell phone, or improve the fuel efficiency of a vehicle, people can make energy-related decisions without a full understanding of the mechanical or electrical processes that are going on. However, not all energy-related decisions are equally easy to make. For example, most people know that using an air conditioner to make a house very cold on a hot day will lead to higher electric bills, but it is typically less clear what settings have the biggest effect on the length of time that a cell phone battery will last. Lowering energy bills and extending cell phone battery life may feel like fundamentally personal decisions, but in today's interconnected world, these choices affect broader systems. The cumulative effects of people's everyday energy-related decisions have significant consequences for how societies function and the natural environment.

Although many people make energy-related decisions without a sophisticated scientific conception of energy, a deep understanding of energy can help us know the right questions to ask as we make energy-related decisions or evaluate energy-related claims. For example, too many people are fooled by nutrition charlatans who claim that they have a strategy to "Eat all you want and still lose weight!" Similarly, too few people think to ask how the electricity for a zero-emissions electric car was generated in the first place; if it was generated at a coal-fired power plant, it just means that the emissions happened at the power plant instead of the car. Many important personal and social decisions we have to make in the world today are related to energy. If people hold a deep understanding of energy, they are less susceptible to being fooled by energy-related claims that are too good to be true. It turns out, though, that far too many students leave school without understanding some of the most important ideas about energy and how it affects their lives (Liu and McKeough 2005; Neumann et al. 2013).

1 Scientists have learned an incredible amount about weight management in recent years and have found that weight gain or loss can vary widely in individuals based on factors such as genetics, type of food, sleep patterns, and environment.

What Makes Learning About Energy Particularly Challenging?

Even as early as prekindergarten, students have developed a set of intuitive ideas about how the world works. Virtually all students have heard and used the term *energy* in a variety of ways to describe a wide range of everyday events well before they learn about energy in school. It is perhaps no surprise, then, that even very young students enter school with a set of intuitive ideas about energy and that these ideas often contradict one another.

Among the most common alternative conceptions that students form about energy is that it is primarily associated only with living things (Solomon 1983; Watts 1983). At the same time, students may hold a range of other ideas about energy, such as that it is associated only with obvious activity (e.g., movement or burning), that it is fundamentally connected to technical devices, or that it is a substance that flows from one place to another (e.g., around an electric circuit) (Domenéch et al. 2007; Driver et al. 1994; Solomon 1983; Trumper 1998). Though it may not seem logical that a student could think of energy as primarily associated with living things and simultaneously hold the belief that it is primarily connected to technical devices, students commonly fail to notice disharmony among their ideas because they are so strongly connected to the contexts in which they use them. That is, student ideas tend to be situated within particular contexts (Lave and Wenger 1992), and certain ideas are more strongly cued by some events than others (diSessa 1993). The notion of situated cognition helps explain why students can simultaneously hold contradictory ideas about energy, but it provides little insight about why energy itself is a difficult concept to learn.

Although we experience some notion of energy every day, the concept can be very difficult to define. Many textbooks offer definitions such as "energy is the ability to do work" or "energy is the capacity to cause a change," but these definitions are often circular (in the first example, "work" is an energy transfer process measured in the same units as energy) or so broad that their utility must be questioned (in the second example, simply associating energy with change does little to nail down what it is as a scientific idea). Energy is a fundamentally abstract concept that eludes a clean definition. In his famous lectures on physics, Richard Feynman (a Nobel Laureate in physics) said,

> *It is important to realize that in physics today, we have no knowledge of what energy is. We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. However, there are formulas for calculating some numerical quantity, and when we add it all together it gives "28"—always the same number. It is an abstract thing in that it does not tell us the mechanism or the reasons for the various formulas. (Feynman, Leighton, and Sands 1989, p. 4-2)*

