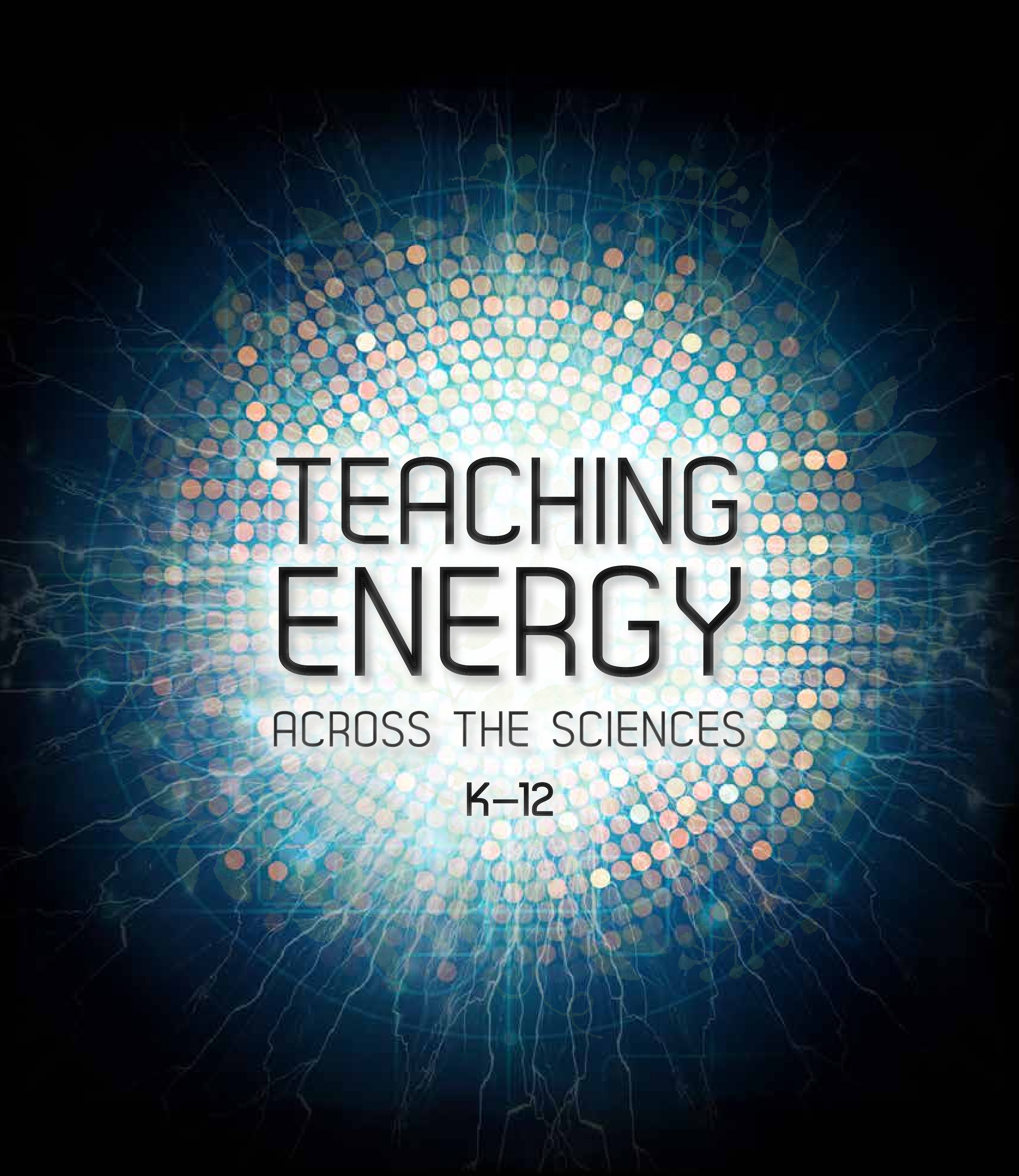

TEACHING ENERGY

ACROSS THE SCIENCES

K–12

Edited by
JEFFREY NORDINE

NSTApress
National Science Teachers Association

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The foundation for the ideas presented in this book comes from a series of two international summits on the teaching and learning of energy, which were held in 2012 and 2013 and funded by the National Science Foundation (grant NSF DUE-0928666).

The first of these summits sought to clarify what the research community has learned about energy as a crosscutting science concept and to identify trends, challenges, and future research needs in the field of energy education. Participants in this summit included science education researchers, scientists, and science teachers. This first summit resulted in the book *Teaching and Learning of Energy in K–12 Education* (Chen et al. 2014), which provides an overview of what the science education research community understands students ought to know about energy, challenges associated with the teaching and learning of energy, and promising approaches to energy instruction.

The second summit built on the first and was focused on the practice of teaching energy in grades K–12. The majority of participants in the first summit were scientists and science education researchers, with only a small group of teacher-participants; in contrast, the majority of participants in the second summit were teachers, with only a small group of scientists and science education researchers. For continuity, all of the teachers who attended the first summit also attended the second, and all of the scientists and science education researchers who attended the second summit also attended the first.

Researcher-participants in the first summit submitted papers based on their research and teacher-participants in the second summit submitted lesson plans from their teaching; these submissions formed the basis of discussion at both summits. The issues, ideas, and strategies related to the teaching and learning of energy that emerged from these summits form the foundation of this book.

The individuals in Table 1 participated in the first (research-focused) summit.

Table 1.

NAMES AND ORGANIZATIONS OR SCHOOLS OF INDIVIDUALS WHO PARTICIPATED IN THE RESEARCH-FOCUSED STUDY

Name	Organization or School
Charles (Andy) Anderson	Michigan State University
Nicole Becker	Michigan State University
Robert Chen	University of Massachusetts Boston
Costas Constantinou	University of Cyprus, Cyprus

Table 1 (*continued*)

Name	Organization or School
Melanie Cooper	Michigan State University
Jenny Dauer	Michigan State University
George DeBoer	Project 2061, American Association for the Advancement of Science
Reinders Duit	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Arthur Eisenkraft	University of Massachusetts Boston
Orna Fallik	Weizmann Institute of Science, Israel
David Fortus	Weizmann Institute of Science, Israel
Cari Herrmann-Abell	Project 2061, American Association for the Advancement of Science
Hui Jin	Ohio State University
Tom Kim	CREATE for STEM Institute, Michigan State University
Joseph Krajcik	CREATE for STEM Institute, Michigan State University
Sara Lacy	TERC, Massachusetts
Yaron Lehavi	David Yellin Academic College of Education, Weizmann Institute of Science, Israel
Xiufeng Liu	State University of New York at Buffalo
Ramon Lopez	University of Texas at Arlington
Alycia Meriweather	Detroit Public Schools
Robin Millar	University of York, England
Hannah Miller	Michigan State University
Kongju Mun	Michigan State University
Knut Neumann	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Jeffrey Nordine	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Ann Novak	Green Hills School, Michigan
Sebastian Opitz	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Nikos Papadouris	University of Cyprus, Cyprus
Mihwa Park	State University of New York at Buffalo
Pamela Pelletier	Boston Public Schools
Helen Quinn	Stanford University
Wei Rui	Beijing Normal University, China
Allison Scheff	University of Massachusetts Boston
Lane Seeley	Seattle Pacific University
Angelica Stacy	University of California, Berkeley
Roger Tobin	Tufts University
Sonia Underwood	Michigan State University
Margot Vigeant	Bucknell University
Lei Wang	Beijing Normal University, China

Table 1 (*continued*)

Name	Organization or School
Xin Wei	Ohio State University
Kristen Wendell	University of Massachusetts Boston
Holger Wendlandt	Käthe-Kollwitz-Schule, Germany

The individuals in Table 2 participated in the second (practice-focused) summit.

Table 2.

NAMES AND ORGANIZATIONS OR SCHOOLS OF INDIVIDUALS WHO PARTICIPATED IN THE PRACTICE-FOCUSED STUDY

Name	Organization or School
Brenda Breil	P. K. Yonge Developmental Research School, Florida
Amanda Chapman	North East Independent School District, Texas
Robert Chen	University of Massachusetts Boston
Michael Clinchot	Boston Public Schools
Arthur Eisenkraft	University of Massachusetts Boston
Orna Fallik	Central School District and Weizmann Institute of Science, Israel
Katie Fitch	Spring Branch Independent School District, Texas
David Fortus	Weizmann Institute of Science, Israel
Christine Gleason	Greenhills School, Michigan
Robyn Hannigan	University of Massachusetts Boston
Nick Kapura	Boston Public Schools
Joseph Krajcik	Michigan State University
Amy Lazarowicz	Detroit Public Schools
Yaron Lehavi	David Yellin Academic College of Education and Weizmann Institute of Science, Israel
Tatiana Lim-Breitbart	Aspire California College Preparatory Academy
Ramon Lopez	University of Texas at Arlington
Alycia Meriweather	Detroit Public Schools
Mike Metcalfe	Verulam School, England
Knut Neumann	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Jeffrey Nordine	Leibniz Institute for Science and Mathematics Education (IPN), Germany
Ann Novak	Greenhills School, Michigan
Michael Novak	Park View School – District 70, Illinois
Angela Palo	Boston Public Schools
Pamela Pelletier	Boston Public Schools

Table 2 (*continued*)

Name	Organization or School
Helen Quinn	Stanford University
Liz Ratashak	Vicksburg Warren School District, Mississippi
Joy Reynolds	Detroit Public Schools
Allison Scheff	University of Massachusetts Boston
Erica Smith	Cuba-Rushford Central School District, New York
Angelica Stacy	University of California, Berkeley
Gerd Stein	Alfred-Nobel-Schule Geesthacht, Germany
Rob Stevenson	University of Massachusetts Boston
Jennifer Stone	Boston Public Schools
Roberta Tanner	Thompson School District, Colorado
Margot Vigeant	Bucknell University
Wang Weizhen	Second High School, China
Holger Wendlandt	Käthe-Kollwitz-Schule, Germany
Huang Yanning	Capital Normal University, China

Reference

Chen, R. F., A. Eisenkraft, D. Fortus, J. S. Krajcik, K. Neumann, J. C. Nordine, and A. Scheff, eds. 2014. *Teaching and learning of energy in K–12 education.* New York: Springer.

FOREWORD

WHY IS THIS BOOK NEEDED?

HELEN QUINN

In the *Next Generation Science Standards (NGSS)*, there are seven so-called crosscutting concepts, which are advocated as one of the three dimensions of science learning (i.e., science and engineering practices, crosscutting concepts, and disciplinary core ideas). As listed in *A Framework for K–12 Science Education* (NRC 2012, p. 3), these seven concepts are as follows:

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

These concepts play a role across all disciplines of science and, yet, are rarely taught explicitly in traditional science curricula. The *NGSS* not only introduce these concepts explicitly, they encourage their use, along with the use of science practices, to build a connective tissue that relates different science concepts and builds student competence in applying them in unfamiliar problem contexts. I see the crosscutting concepts as providing a set of problem-solving perspectives. Each concept suggests ways of looking at a system and asking questions about it that are important to understanding the phenomena that occur (or do not occur) in that system.

This book is about a part of one of those seven crosscutting concepts, Energy and Matter: Flows, Cycles, and Conservation. The name is actually backward because what is important in understanding systems is the recognition that energy and matter are conserved and that their conservation has a major consequence. Understanding where energy and matter 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 4

TALKING ABOUT ENERGY

JEFFREY NORDINE

In science teaching, we are used to thinking about language in the context of helping students learn complex scientific terms that they do not use in their everyday lives. You or your colleagues may post science-specific terms like *covalent, scree,* or *hadron* around the classroom to help students learn such unfamiliar words. It can be a challenge to help students remember the meaning of esoteric science terms, but when teaching about energy we often have a different challenge—helping students recognize when to connect a specialized definition to widely used words. In energy instruction, everyday words like *conservation, work,* and *potential* take on special meanings that often do not align with how they are used in everyday conversation. Additionally, some energy terms commonly used by scientists, such as *flow* or *forms,* may imply to learners that energy has characteristics that it does not have. This chapter is dedicated to unpacking the language that scientists use to discuss energy and identifying guidelines for using energy-related words as students develop their understanding of energy over time.

Why Language Matters

Language affects how students participate in classroom science (Lemke 1990), but even more fundamentally, language mediates the very ways that we think. Lev Vygotsky (1978) wrote about the importance of language as a cultural tool that affects how humans engage in the construction of knowledge. This goes both for how we talk to one another and how we talk to ourselves. By mediating how we talk and think, language affects our understanding.

If you're a native English speaker, chances are that your inner narrative happens in English. Using English words to frame your thoughts means that if there is an English word for a concept, it is easier to think about—if there is not, it can be difficult to recognize that idea. If you have ever learned another language, you may have noticed times that a word in the new language captures a sentiment or an idea that is difficult to express in English. For example, Germans use the word *Treppenwitz* to describe a joke or comeback that you thought of just a little too late. In English, the word literally translates to "staircase wit," but the German word describes that experience of thinking of a great comeback or remark after the moment for it has passed—say, on the staircase on the way out the door.[1] Native English speakers are very familiar with this idea, but having a word for this experience unifies the feeling and makes it easier to think and talk about it.

Another situation that illustrates how language affects understanding is when we use the same word for multiple ideas; it may be difficult to distinguish between the meanings unless they are in context. Take, for example, the word *trim.* If you tell someone you are going to trim the tree, this can mean very different things depending on whether you are holding a pair of hedge clippers or a box of holiday decorations.

Scientists name ideas to make it easier to talk about them. Sometimes, this means inventing words like *chromatography* or *asthenosphere.* These words typically have little meaning in a nonscientific setting, but they are critical for helping scientists think and talk efficiently about the ideas the words represent. Sometimes, however, scientists borrow words that are already in common use and give them a second, scientific meaning that accompanies their everyday meaning. Robert Hooke borrowed the word *cell* to describe what he saw when he looked at plants under the microscope. This word was common before Hooke used it to describe the basic functional unit of living organisms, and it has retained several original meanings. In addition to its scientific meaning, *cell* can mean a small room for inmates, a small group of people, or a mobile phone. In general, however, these meanings are highly context dependent and don't interfere with one another; very few students have ever thought that organisms are made up of tiny phones.

Like *cell, energy* is also a borrowed term, but unlike *cell, energy* has meanings in different contexts that have substantial overlap. These overlapping meanings can contribute to students' confusion about energy as a scientific idea, and the reason why there is such overlap in meanings has to do with how its meanings have evolved over time.

A Brief History of the Word *Energy*

Do an internet search for the word *energy* and you will see plenty of articles that discuss energy as a scientific idea, pictures of technological devices, and news stories about the cost of a barrel of oil. In today's world, energy is a scientific and technological idea. But it hasn't always been like that.

It surprises many people that the word *energy* was actually used in everyday language long before it became a scientific term. Thomas Young, an English physicist, decided to borrow this word, which was already in common usage to describe strength and vitality, to refer to what we might now call mechanical energy (Coopersmith 2010). The word can be traced back to the ancient Greek term ευέργεια (transliterated as "energeia"), when it

1 German speakers may also know that, over time, this word has taken on another meaning that is closer to "irony" or "a silly joke or behavior."

was used to describe activity or vigor. The meaning of energy as a general sense of activity, strength, and vigor goes back thousands of years, but it wasn't until well into the 19th century that *energy* was used as a scientific term. Scientists appropriated this word and now unfairly criticize the public for using it in ways that are different from the precise scientific meaning. Nowadays, a student in science class may be corrected if he says something such as "drinking caffeine gives me energy"; his teacher may be quick to point out that caffeine contains no calories and could not possibly have given him energy. But the student *feels* more vital, more energetic after consuming caffeine, so is he wrong for using the everyday, historical meaning of the term?

In some ways, what happened to the term *energy* is similar to what has happened more recently to the word *spam* in the era of e-mail and social networking. Spam was originally a trademarked name for a canned meat product, but it has acquired a very specific new meaning in the computing era (i.e., to indiscriminately distribute an unsolicited message). Likewise, before social networking, a *tweet* used to mean only the sound that a bird makes and *friend* used to be exclusively a noun. Just as one could hardly fault your grandmother for thinking Spam is food or that a tweet is an avian noise, it is equally understandable that prior to instruction, a person might conceptualize the word *energy* as a type of human vigor or vitality, because that is what the word originally meant.

The problem with the historical meaning of the word *energy* is that it is actually quite close to its scientific meaning. Our feeling of human strength and vitality does depend on the scientific concept of energy—to run fast, jump high, or push hard, our bodies need to be able to convert chemical potential energy into other forms. But energy as a scientific idea is not exclusively a property of humans or living organisms, and students often enter science classrooms with the belief that energy only applies to living things. Holding the idea that energy is only related to living organisms can make it difficult to develop a more complete understanding of energy.

The statement "drinking caffeine gives me energy" is not a problem if we are only concerned with the historical meaning of the word *energy.* But if we are trying to teach students about energy as a scientific idea, this statement may convey the idea that caffeine carries energy, which it does not (caffeine cues a set of metabolic effects that facilitate the body's ability to convert chemical potential energy that it has already stored). If the student says instead that "drinking caffeine corresponds with my feeling energetic," then his teacher may not be so quick to correct him. Word choice and phrasing matter in science teaching, but they especially matter in energy teaching because there are so many common words associated with the energy concept that have meanings that are close to—yet distinct from—their everyday meanings.

Many different people talk about energy in lots of different ways. This is true across scientific and everyday contexts, and it is true across scientific disciplines. If we are to help students build an understanding of energy that connects to their intuitive ideas and is useful as a crosscutting concept, then we need to be careful about the language we use to talk about energy within disciplinary contexts. In the next sections, we discuss several key words in energy instruction that may promote student confusion and incorrect ideas about energy if we are not careful about how we use them.

Talking About the Five Big Ideas

Focusing on the Five Big Ideas in energy instruction (as described in Chapters 1 and 2) can help clarify the most important ideas about energy and how it is used across disciplines. These Five Big Ideas can simplify the energy concept for students by providing simple and consistent ways to talk about energy in a variety of contexts. However, the words we use to discuss these ideas carry connotations that may imply things about energy that are not true. Although there is no perfect solution to avoiding confusion, an important start is to clarify for ourselves what the terms related to the Big Five Ideas mean and to identify how they may potentially be misinterpreted. In this way, we can be more clear and consistent when talking about energy with students.

Energy Forms

Energy does not have a form. It is not a substance and does not have any material characteristics, thus, energy does not "take form." We cannot see it or touch it. In fact, we can never even measure energy directly! Every time we speculate on how much the energy of a system has changed, we do so by performing calculations based on observable characteristics of the system, such as speed, height, stretch, temperature, or mass.

We do not observe kinetic energy directly; instead, we observe speed relative to some reference frame. We calculate a value for kinetic energy using the mathematical formula

$$\textit{kinetic energy} = 1/2 \times (\textit{mass}) \times (\textit{velocity})^2$$

Likewise, we do not observe gravitational potential energy; instead, we observe the separation between objects and the Earth relative to some reference separation. For example, we can calculate a value for the potential energy between an airplane and the Earth using the mathematical formula

$$\textit{gravitational potential energy} = (\textit{mass of the airplane}) \times (\textit{acceleration of Earth's gravity}) \times (\textit{height of the airplane above the ground})$$

You may have seen or used formulas for calculating the energy of a stretched spring ($E = \frac{1}{2}kx^2$), the energy associated with a photon of light ($E = hf$), or the energy associated with mass ($E = mc^2$). Each of these formulas gives us a way of translating the measurements we make about systems into a numerical value for energy, and it is these numerical values that allow us to use the conservation of energy to set limits on the behavior of systems.

Over time, scientists have developed a shorthand for discussing each of these ways of calculating values for energy—forms. What we call forms of energy roughly corresponds with a different way of calculating numerical values for energy. When we use the formula $E = \frac{1}{2}kx^2$ to calculate energy, we call it elastic energy. When we use the formula $E = hf$, we call it light energy. The formula $E = mc^2$ helps us calculate what we call mass energy. When using the term *energy form,* a scientist is really letting you know what characteristics of a system are changing and what formulas are useful for quantifying energy changes associated with phenomena or processes.

Scientists may agree that energy forms are really just different ways of calculating energy, but young students have not yet learned this, and the term may imply that energy has a physical form. Some science educators have attempted to sidestep this issue by using other words, such as energy *type,* but this word may imply that there is more than one kind of energy, when, in fact, all energy is fundamentally the same thing. Whether we use *form, type, store,* or *manifestation,* there is no perfect word, but by far the most commonly used word—and what you will see in the *Next Generation Science Standards* (*NGSS*) performance expectations (NGSS Lead States 2013)—is *form.* Even though energy forms are not precisely defined (Quinn 2014), the term makes it easier to talk about the role of energy in phenomena using everyday language.

When using the term *energy form* in the classroom, we need to be aware that this term carries a connotation that energy is some material substance that can take on various physical characteristics. By doing activities and facilitating discussions that reinforce that all forms of energy can change into one another and, thus, are fundamentally the same thing, we help students understand that this term is just an expression for describing all of the ways that energy changes can be tracked by observing the measurable characteristics of a system.

Energy Transformation and Transfer

When watching a phenomenon or process unfold, we notice that any time one form of energy increases, at least one other form must simultaneously decrease. Because it seems that one form is becoming another, we call this process energy transformation. In the *NGSS,* you will see the terms *transformation* and *conversion* used to describe this process. Both of these terms, however, are distinct from the term *energy transfer.*

Transformation and conversion refer to energy changing from one form to another; energy transfer refers to energy crossing the boundary between systems or objects. For example, energy can be transferred from one marble to another when they collide. As a result of this collision, if the kinetic energy of one marble increases and the kinetic energy of the other decreases, then we refer to this process as an energy transfer because energy crossed the boundary between marbles. If you look closely, this transfer process involves a transformation, as the kinetic energy briefly became elastic potential energy when the marbles were in contact and were slightly deformed from their original shape. Transfer processes often involve energy transformations, but they don't have to. If we define our system as a region of space (e.g., the Earth and the region up to 100 km above it), then energy can enter or leave our system as matter enters or leaves. If an oxygen molecule in the upper atmosphere happens to move away from the Earth without striking another molecule, it will leave Earth and never return, taking its energy with it.

Although energy transfers nearly always involve transformations, these two terms mean different things. Energy transformations are processes that convert energy from one form to another, whereas energy transfers are processes that carry energy across system boundaries.

Just as we can identify a variety of energy forms (e.g., kinetic, thermal, elastic), we can likewise categorize a set of energy transfer processes. When energy is transferred via force, we call this work. Energy can also be transferred via sound or light waves (in which energy transfers between systems but matter does not), electricity (in which an electric field transfers energy by moving charged particles), or heat (in which energy transfers from a hot object to a colder one).

Energy Dissipation and Loss

As heat transfers energy from regions of high temperature to low temperature, particles that were moving fast tend to slow down and particles that were moving fast tend to speed up, until all particles are moving with about the same kinetic energy. In this way, thermal energy is evenly distributed throughout a system in a process called dissipation.

Dissipation can be a confusing word for students because it implies that energy vanishes—that it is, in fact, gone. If a small hot system interacts with a larger cool system, thermal energy will transfer via heat from the small system to the larger system until both come to the same temperature. If the large system is large enough, the thermal energy transferred to it from the smaller system will have virtually no effect on its temperature. If you poured a pot of boiling water into the ocean, there is no way you could measure an increase in the ocean's average temperature around the globe. There is a technically a change in the ocean temperature, but it is so slight that you could never measure it. Is the thermal energy from the boiling water gone? No! But it has dissipated over such a vast region of space that you could never hope to measure it or recollect and reconcentrate it. The thermal energy is effectively lost.

When scientists say that energy is lost, they mean that it has been transferred as thermal energy to such a large system that one cannot hope to recover it again. In this way, energy loss is actually very close to how we use the word *loss* in an everyday setting. If a ship is lost at sea, we accept that it is out there somewhere, but in an expanse so vast that hope of ever recovering it is all but gone. Similarly, energy still exists when it is lost, but hope of recovering it for useful purposes is gone.

Energy Conservation and Use

In everyday language, *conservation* is an environmental or ethical choice. Children encounter this term in a variety of settings, in the context of water, wildlife, energy, and even art conservation. As an environmental or cultural choice, the term *conservation* refers to keeping something in its original condition.

In science, the term *conservation of energy* is a fundamental statement about the nature of energy: that it is never created or destroyed. Yet, even though energy is never destroyed, it can be more or less accessible for doing things such as running machines. Its accessibility is based on a number of factors, such as how spread out it is within a system.

When we say that we use energy, this means that we transfer energy into a system or device (e.g., our car) in a form that is concentrated and readily available. In the device, the energy is transformed as the device operates. For example, we transfer energy to our cars via gasoline, which readily reacts with oxygen when it is heated and releases a lot of energy per kilogram burned, some of which can be harnessed and transformed into kinetic energy of the car. Gasoline is a very convenient way to power cars because it is so energy dense and its energy is so easily accessible. When we use the energy in gasoline to power our cars, its energy is not gone, but it is lost to the Earth's environment and outer space as thermal energy. The natural resources (such as crude oil) used to produce the gasoline, however, are gone. The oil molecules that stored so much chemical energy are broken apart and rearranged into lower potential energy configurations, and these molecules will not spontaneously reform. When we say that we should drive less to conserve energy, what we really mean is that we should conserve the energy resources that went into producing gasoline—that we should maintain these energy resources in their original condition.

It is worthwhile to discuss both *c*onservation of energy and conservation of energy resources in the science classroom, but we should clearly and consistently use the correct term for each.

Other Potentially Confusing Energy Terms

Outside of words related to the Five Big Ideas about energy, there are a variety of terms common in energy instruction that can promote incorrect ideas about energy and how it behaves.

Work

As we mentioned in Chapter 2, it is common to try to define energy as the ability to do work, even if one has not defined what work is. Students commonly accept this definition even without a formal scientific definition of *work,* because we all have an intuition of work as something that requires effort. But work is a precisely defined scientific quantity that describes how much energy is transferred between systems via force. It is possible to push on something and do no work on it; for example, a bookshelf exerts an upward force on a book, which counteracts the force of gravity, but this force doesn't transfer energy to the book and thus it does no work.

When we speak about work in science classes, it is important to remember that we are describing a *transfer process*—that is, we must specify an origin and a destination of this energy transfer. If we are describing the transfer of money between bank accounts, it is very important to specify the account from which the money should be transferred and the account to which the money should be transferred. If your bank sent you a confirmation that your account had a $1,000 transfer, you'd probably want more information! To or from my account? From where? To where? The same is true for work. We need to do much better in specifying which systems are involved, which one received the energy, and which one transferred it away.

In many physical science classes, we love to have a student volunteer stand in front of class holding a heavy book at rest and proudly declare that the student is doing no work since she is not moving the book. After all, work can be calculated by the formula *work* = *force* × *distance*,[2] and if she isn't moving the book, then work equals zero. This declaration surprises and amazes students, and it is also wrong—or at least imprecise. Considering work as a transfer process, the statement "she is doing no work" fails to identify an origin and destination system. A more complete statement is that "she is doing no work on the book," because it conveys the systems of interest in this statement. Even better, the statement "the force exerted by the student on the book is doing no work on the book" identifies the origin system, the target system, and the force in question.[3]

It is tempting to ignore that work is fundamentally a process by which a force acts to transfer energy between systems and, instead, simply have students calculate values for work, since the equation is so straightforward. But focusing on the equation, rather than having students use words to formulate a complete description of the energy transfers that occur when forces do work, ignores the core of what work is and why we care about it.

By talking consistently about work as a transfer process and specifying an origin system, a destination system, and the force of interest, students are in a better position to understand connections between energy transfer and force. Further, they are more likely to see that defining energy as the ability to do work is essentially saying that energy is the ability to transfer energy.

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2 Of course, this formula is a simplification of the more general formula for calculating work and is only applicable in certain situations. The full equation is more general, but this is the form most commonly presented at the middle school level.

3 Although this is a common demonstration that illustrates how the scientific meaning of work is different from our everyday use of the term, it is not technically accurate to say that the student is doing no work on the book in such a demonstration. There are many micromovements as the student is holding the book steady, and there is a transfer of energy to the book in these movements. Furthermore, for the student to keep her muscles contracted, chemical reactions must take place within her body that transform and transfer energy, making the student feel tired.

Potential Energy

Many students think that the term *potential energy* means that something has the potential to have energy. That is, students may think that potential energy is not really energy but rather some kind of dormant form of the real thing. In some sense, *potential energy* is an unfortunate term, and it caught on before scientists agreed that potential energy is every bit as real as kinetic energy (Hecht 2003). It's probably safe to say that if scientists had known then what we know now, potential energy would have a different name, like position energy or configuration energy, but it looks like we're stuck with the term *potential energy* for the foreseeable future.

The reason why position or configuration energy would be better names is that potential energy is associated with the arrangement of mutually interacting bodies. Gravitational potential energy is associated with how far apart an object is from Earth. The farther the object is from Earth, the more potential energy exists in the Earth-object configuration. The potential energy exists in this situation because all massive objects exert a force of gravity on each other. Earth pulls downward on a skydiver, and the skydiver pulls up on the Earth with an equal and opposite force of gravitational attraction. As a skydiver begins to fall, the potential energy of the skydiver-Earth system begins to be converted into kinetic energy of the objects in the system. Yes, *objects*! Earth moves, too, but while the force between Earth and the skydiver causes a noticeable change in speed for the 50 kg skydiver, this force is far too small to cause a measurable change in speed for the 5,970,000,000,000,000,000,000,000 kg Earth. So, although it seems like the only object in this system gaining kinetic energy is the skydiver, rest assured that Earth does, too. Just like we could never measure a change in the average global ocean temperature if someone poured a pot of boiling water into it, we will never notice a change in Earth's motion if someone jumps out of an airplane.

Like gravitationally attracting objects, magnets store potential energy due to their configuration. If you bring a north pole and a south pole of two small magnets close to each other, you will almost certainly notice that the magnets pull on each other. If you let them go, you will notice that both magnets start moving toward each other. They are converting potential energy associated with their configuration into kinetic energy as they move. If you instead use one really large magnet and a small one, you will notice that the small one moves more than the large one as they come together. As one magnet gets more and more massive compared with the other, this situation begins to more closely resemble the case of a skydiver falling toward Earth.

For both the magnets and the skydiver, the potential energy of the attracting objects increases as the objects are farther apart—the higher you drop an object above Earth, the faster they smack together. For mutually attracting objects, more distance between them corresponds to more potential energy. The opposite is true for mutually repelling objects, such as two magnetic north poles or two negatively charged objects. If things repel each other, then the potential energy associated with their arrangement increases as they get closer to each other. The closer they are in their initial arrangement, the more rapidly they will fly off from each other when released.

Whether related to attractive pulls or repulsive pushes, potential energy is fundamentally connected to force. There are many varieties of potential energy, and every type of potential energy is connected to a force. Gravitational energy, or gravitational potential energy, arises because of the force of gravity between objects. Chemical energy, or chemical potential energy, arises because of the electric force between charged atomic nuclei and electrons. Nuclear energy, or nuclear potential energy, arises because of the (very strong) forces holding an atomic nucleus together. Anytime the value of one of these potential energies increases, the interacting objects must have less kinetic energy (move slower); when the potential energy of a system decreases, its constituents move faster.

Potential energy is the counterbalance to kinetic energy, and it is every bit as real as kinetic energy. Further, potential energy is fundamentally associated with systems of objects and never a single object by itself. Our language in the classroom should reflect that potential energy is real and associated with systems. Phrases such as "a boulder on a cliff has a lot of potential energy" fail to convey that the potential energy is really stored in the boulder-Earth system; by focusing only on the boulder in this situation, our language fails to focus students on the key aspect of potential energy—its relationship to the configuration of a mutually interacting *system* of objects. Saying something such as "a boulder on a cliff is a high potential energy configuration of the boulder-Earth system" is a much better characterization of what we—somewhat unfortunately—call potential energy.

Energy in Chemical Bonds

It is very common in science classes to say that there is energy in chemical bonds, and that breaking these bonds releases energy. But this is exactly the opposite of what is true—energy is released when chemical bonds are *formed*!

Chemical bonds result from the electric force acting between positively charged atomic nuclei and negatively charged electrons, and this electric force gives rise to a potential energy associated with each possible arrangement of these charges. Just like boulders fall down cliffs rather than up them, charged particles also tend toward arrangements that have the least amount of potential energy. When atoms form bonds with each other, it is because the bonded arrangement is associated with a lower potential energy than the unbonded arrangement. When atoms are bonded, their potential energy is *lower* than it is when they are free. The term *bond energy* refers to the amount of energy input required to break a chemical bond such that the constituent atoms are free.

So, why is energy released when we burn something such as methane (in which four hydrogen atoms are bonded with one carbon atom)? This process happens in two steps.

First, we need an energy input (such as heat from a very hot object) to provide the atoms with sufficient energy that they escape their bonded state—this is like shaking a bucket of marbles vigorously enough so that some begin to escape the bucket. If we only excite them and do not provide them with other bonding options, they will reform the same bonds they had previous to heating and these bonds will have the same potential energy as they did before. The result will be no overall energy release. To get an energy release, the second thing we need is to provide the atoms with the opportunity to bond in a new arrangement that has a lower potential energy associated with it—this is the role oxygen plays in burning. When the carbon and hydrogen atoms in methane have the option to reform bonds with oxygen to form water (two hydrogen atoms and an oxygen atom) and carbon dioxide (two oxygen atoms and a carbon atom), they do so because these arrangements have a lower potential energy than the methane molecule did. Just like a boulder will fall until it reaches the lowest potential energy arrangement (lowest height above Earth) that it can, the free atoms will form bonds with the lowest potential energy arrangement possible. And just like the boulder-Earth system gains kinetic energy as the boulder falls to a lower potential energy arrangement, the newly formed molecules gain kinetic energy because the new arrangements have a lower potential energy.

Energy is released during the burning process not because the bonds of the burned substance release energy when they are broken, but because energy is released when the newly freed atoms reform chemical bonds with an even lower potential energy than they originally had. This decrease in potential energy must be accompanied by an increase in some other form of energy, such as the kinetic energy of the new molecules or the release of light.

Stored Energy

Often, scientists will say that molecules like methane (which is made of bonded hydrogen and carbon atoms) store energy. This is shorthand for saying that if we burn it (or use some other energy-releasing process), we can trigger a net release of energy when the atoms are broken apart and allowed to reform bonds with an even lower potential energy arrangement.

The term *store* can be interpreted as though energy were some material substance that is put into the atoms and kept there until we let it go again. Although this interpretation is not true, the idea of storing energy in chemical bonds is useful shorthand for scientists when talking about energy.

To form molecules that burn, such as methane (which is made of bonded carbon and hydrogen atoms) or glucose (which is made of bonded carbon, hydrogen, and oxygen molecules), we do indeed need an energy input. Although these molecules represent a lower potential energy arrangement than if the atoms were out there wandering free, the odds of finding free carbon, hydrogen, or oxygen atoms are extremely low. If these atoms are around one another, they will spontaneously bond in the lowest potential energy arrangement that they can, and water and carbon dioxide molecules are arrangements with a very low potential energy. Plants form glucose through photosynthesis (see Chapter 5), but the raw materials for glucose are not free carbon, hydrogen, and oxygen atoms; they are molecules of carbon dioxide and water! To form molecules of glucose (and oxygen molecules), which have a higher potential energy arrangement than the molecules of carbon dioxide and water, plants need to transfer energy to the molecules, and they get this energy from light. Photosynthesis is like pushing a boulder from the bottom to the top of a hill because it forms molecules with a higher potential energy arrangement than they were initially in; it requires an energy input to build the molecules, just like it does to get the boulder up the hill. In some sense, this is like keeping money in a bank account—it is simply there until you need it later. By forming glucose, plants have constructed a molecule with a high potential energy arrangement that can later react with oxygen to release energy again. This process functions a lot like our everyday process of storage, so scientists will often simply say that some molecules, such as the ones built in photosynthesis, store energy, without describing the whole energy process.

More broadly than chemical energy, it is common to refer to any form of potential energy as stored energy. You might hear people talk about the energy stored in a stretched bow and arrow or in a battery; both of these are cases in which a device maintains a high potential energy arrangement that can be used to release energy by allowing a transition to a lower potential energy arrangement. In general, this term refers to any time energy exists in a form where it is localized and easily accessible later. Energy can even be stored as the kinetic energy of a spinning flywheel or the thermal energy of hot water. Note that we say thermal energy can be thought of as stored; we did not use the word *heat.* This is because *heat* has its own very specific scientific meaning.

Heat

Like energy, the word *heat* was widely used in everyday language before it became a precisely defined scientific term. Children hear the word *heat* very early in their lives, and the everyday meaning of the word can be quite different from its precise scientific meaning. Students may hear that heat rises when discussing hot air balloons, they may be asked to turn the heat up on a cold day, or they may make a rash choice in the heat of the moment. In everyday language, *heat* can mean a variety of things, but the term is very precisely defined in science.

As a scientific term, *heat* describes the transfer process by which energy moves between regions of different temperature. Heat is related to temperature, but these are distinct scientific concepts. Temperature is a measure of the average kinetic energy associated with the random movements of particles in an object. The higher the temperature of an object, the faster its particles vibrate or move. The energy form associated with this random motion of particles is called thermal energy (not heat energy). All objects have thermal energy because all molecules are in motion, and the faster the particles in a system are moving, the more thermal energy it has. Thermal energy is essentially a measure of the total energy in an object or system arising from its random particle motion. Thus, a system can have more thermal energy by having either faster-moving particles or more particles. So, temperature measures the average kinetic energy of particles, thermal energy measures the total energy of a system arising from random particle movements, and heat occurs when these moving or vibrating particles transfer energy to their surroundings.

To keep the conceptual boundaries between heat and thermal energy clear, a good rule of thumb is to use the word *heat* only as a verb. Saying "heat the water" implies that you transfer energy into the water to increase its temperature. On the other hand, the phrase "hot water has a lot of heat" blurs the line between heat and thermal energy. When systems are heated and their temperature increases, this change in energy is an indication that the thermal energy of the system has increased as well.

There are three mechanisms by which energy can transfer to or from systems via heat: conduction (in which fast-moving particles collide with slower-moving particles to transfer energy), convection (in which fast-moving particles move from one region to another), and radiation (in which vibrating particles emit energy as electromagnetic waves). In each of these processes, energy moves from place to place. Scientists originally thought of heat transfer as involving a very special fluid called caloric, but we now understand that there is no such fluid being transferred. Yet, the word *flow* has remained part of the scientific vocabulary for energy.

Energy Flow

When energy transfers between systems and spreads out within the largest region it can, it acts a lot like a fluid. Scientists use the term *energy flow* to describe energy transfer between systems because there are parallels between the transfer of energy and fluid or air flow. If you used a funnel to pour 2 liters of water into a 2-liter bottle, you'd be pretty surprised if the bottle only filled up halfway—that is, you'd be surprised that during this transfer of water, the amount that left your cup was not the amount that entered the bottle. If you noticed this was, in fact, the case, you'd start to look for leaks rather than think that the water just spontaneously disappeared in the process of being transferred. Fluid flow is a useful analogy for energy transfers between systems because most of us have developed an intuition that fluid that flows from someplace must end up someplace else, and because we understand that fluids tend to spread out to fill as much of their container as they can. Energy flow, however, is different from fluid flow because energy is not a material substance—its flows are typically tracked as changes in energy forms across systems.

Although using the term *flow* to describe energy transfers isn't perfect, it does have the major benefit of helping students use their intuition about fluids to bolster their sense that energy missing from one place must show up someplace else. That is, energy is conserved.

Building Energy Language Over Time

We learn science words just like we learn every other word: with time and practice in a variety of contexts. Furthermore, we learn words when we need them and distinguish among multiple meanings of the same word when it is time to do so. We would not expect kindergarteners to describe their relationships with classmates as amicable because this word implies a rather adultlike understanding of interpersonal relationships. Likewise, we would expect kindergarteners to think that a cookie is a delicious treat; we would not expect them to realize that a cookie is also a packet of data sent by an internet server to be stored by a user's web browser.

As they learn the energy concept, students begin to use new words and distinguish between everyday and scientific meanings of familiar words. In this process, new words should be introduced when they are necessary and the multiple meanings of words should be distinguished only when there is a reason to do so. Students will have heard and used words such as *energy, heat,* and *work* in their everyday lives before they encounter them in a scientific setting; using the nonscientific meaning of these words is okay until it is not. Investigations of phenomena should precede the introduction of new terms and meanings, and these new language tools should be introduced when they are useful for clarifying concepts.

This does not mean that teachers are off the hook for using appropriate energy language throughout. Nobody defines the word *chair* for us when we are young, but as we hear adults use the term in a conceptually consistent way, we develop an understanding of the term and an ability to use it in consistent ways that mirror how the adults use it. If we are sloppy with energy language in the science classroom, this can make it difficult for students to discern the conceptual delineations of a term. For example, we needn't define the term *heat* for young students or insist that they use its scientific meaning, but by using the word in ways that are consistent with heat as a process (rather than, say, a property of an object), students are in a much better position to use the word appropriately themselves later on.

Just as we should use scientific terms correctly even though we may not expect our students to do so, we need to be careful using language shortcuts before they have been earned by students in our classes. For example, using the term *energy flow* too soon may promote the idea that energy is some sort of physical fluid.

So, what do we say and when do we say it? The *NGSS* are a good guide.

Talking About Energy in Elementary School

The fourth-grade performance expectations for energy in the *NGSS* emphasize energy transfer and conversion (i.e., transformation). By design, the performance expectations focus on energy transfer processes that are easy for students to observe. These transfer processes include heat, sound, light, and electricity; students should not be expected to precisely define these terms, but they should be able to use them in the context of discussing the role of energy transfers in natural phenomena and designed devices.

The major emphasis at the elementary level is on building students' intuition for the role of energy in driving processes. There is no attempt at this level to define *energy*—only to associate the term with things such as motion, sound, light, heat, and electricity. Rather than distinguishing among energy forms at this level, the emphasis is on seeing how energy transfers and motion are really manifestations of the same thing. Thus, at the elementary school level, language should reflect unifying energy-related phenomena under the same conceptual umbrella, by recognizing that something called energy can be transferred between objects and systems in a variety of processes.

Terms such as *potential energy, kinetic energy, conservation,* and *work* are inappropriate and unnecessary for energy instruction at the elementary level. On the other hand, introducing and consistently using terms such as *energy transfer* and *energy conversion/transformation* are critical to helping students understand that energy is associated with certain observable characteristics of systems and that energy can transfer from place to place in a variety of ways. It's too early at this age to use shortcut words such as *flow;* students should instead practice using the language of transfer and conversion.

Talking About Energy in Middle School

The middle school performance expectations for energy in the *NGSS* focus on helping students develop a more sophisticated understanding of energy transfer and transformations. By advocating the introduction of ideas such as potential energy in middle school, the *NGSS* help students build toward a deeper understanding of energy as a conserved quantity (though this idea is not yet introduced).

In middle school, students should begin to use language that reflects a more nuanced understanding of energy. While elementary students focus on relating easily observable phenomena (i.e., sound, light, heat, electricity, and motion) around the unifying idea of energy, middle school students are developing an ability to think about energy in a more abstract manner. Rather than focusing on the overt phenomena, middle school students begin to understand that their observations are merely *indicators* of different forms of the same underlying quantity called energy.

To reflect a more sophisticated understanding of the difference between their observations and the unobservable, unified quantity called energy, students should begin to use terms describing various forms of energy, such as *kinetic energy, thermal energy,* and *gravitational energy,* and to describe how each is related to what they observe. For example, while elementary students should associate the idea of energy with motion, middle school students should begin to call this energy kinetic energy. Calling the energy of motion kinetic energy corresponds with an increased emphasis on uncovering its precise relationship with mass and speed. That is, the term is not simply introduced because it is the next more sophisticated word, but because the term has a precise scientific meaning that students in elementary school are not yet ready to describe.

Just as introduction of the term *kinetic energy* at middle school corresponds with an increased need and ability to specifically describe it, students at the middle school level will begin to use other terms that reflect concepts that are not introduced in elementary school. For example, they should begin to use the term *potential energy* to describe the energy associated with objects that interact at a distance and should be careful to associate this term with systems of objects rather than individual objects.

As students analyze phenomena from an energy perspective, they should describe changes using terms such as *energy transformation* (between energy forms) and *energy transfer* (between systems) and connect these processes to the evidence that they are occurring. By consistently using the language of transformation and transfer, students gain practice identifying various forms of energy and connecting observations to changes in energy within and between systems. For example, students in middle school become ready to identify heat as an energy transfer process rather than an energy form, but initially using a term such as *thermal energy transfer* to describe heat exchange processes can help students recognize that the process of heating and cooling requires the transfer of energy between systems at different temperatures.

As students at the middle school level expand their energy vocabulary, the emphasis should be on introducing words that help them understand and explain the processes of energy transformation and transfer. As their familiarity with the ideas of transfer and transformation grows, students begin to earn linguistic shortcuts such as *flow,* but such terms should only be introduced after students have had sufficient practice identifying and describing phenomena using the language of transformation and transfer. By regularly using language focused on energy forms, transformations, and transfers, students are in a better position to use these terms consistently throughout the course of the year as they study phenomena from the physical, life, and Earth sciences and to use language shortcuts in appropriate ways.

Talking About Energy in High School

The high school performance expectations for energy in the *NGSS* focus on helping students understand and use energy as a quantitatively conserved quantity. Students begin to calculate energy changes within systems and transfers between them. As students begin to transition into discipline-specific science courses in high school, it becomes even more important for teachers to be aware of how discipline-specific energy language can make it more difficult for students to see connections among the role of energy in phenomena across disciplines.

Different science disciplines talk about energy in different ways. Terms such as *energy flow* and *energy use* are more commonly used in a life science context than in a physics context, whereas terms such as *conservation* are more commonly used in a physics context. The simple fact is that certain dimensions of energy are less critical in some contexts than others, but if we hope to help students connect ideas across disciplines, it is important to use terminology that puts students in a strong position to see the overlap in energy ideas across disciplines. Energy terminology may vary among disciplinary contexts, but the rules of energy remain the same.

In physical science classes, students commonly calculate energy transfer into and out of systems via processes such as work and heat. Earth science classes commonly identify sources of energy that drive cycles. Life science classes often discuss energy flows. In the context of energy, words such as *work, heat, source, drive,* and *flow* all involve energy transfer, but without making this connection explicit, such disparate terminology can contribute to student confusion and difficulty connecting ideas across disciplines. Thus, it is especially important for disciplinary high school teachers to define such discipline-specific terms in terms of the Five Big Ideas that make energy crosscutting.

By connecting discipline-specific terms to energy forms, transformations, transfers, conservation, and dissipation, teachers put students in a better position to connect ideas and use what they learn in one discipline to inform their learning in another. If, for example, Earth science students connect the idea of source to the idea of transfer between systems, then they may be more likely to go beyond identifying the Sun as the source of energy for the water cycle and realize that any transfer into a system must equal the energy change in the system plus the energy transferred from it. Such a realization might spur questions about how the balance of different states of water on Earth affects global warming. Likewise, using the language of flow in a physics class exploring the "work-in, work-out" balance in simple machines may help students connect their exploration of simple machines to more meaningful and complex systems, such as living organisms, that they encounter in other disciplinary contexts.

Summary

Language is a critical tool in science for formulating and communicating ideas. To describe the behavior of energy, scientists have borrowed many words from everyday contexts. The overlap of some energy-related words in scientific and everyday contexts can be both a blessing and a curse—it can help connect energy learning with students' intuitive ideas, but it can also confuse the precise scientific meaning of energy terms. When teaching and learning about energy, it is especially important to use language carefully.

To use language carefully in energy instruction, consider which terms are important to define in scientific contexts, which ones can be used colloquially (but consistently) without stressing the scientific meaning, and which ones should be avoided entirely as students are building their understanding within each grade band. The *NGSS* are very intentional about how they include energy-related terms across the science disciplines and during grades K–12, and they serve as a good guide for when and how to use particular terms related to energy.

By identifying energy as a crosscutting concept, *A Framework for K–12 Science Education* (NRC 2012) and the *NGSS* call on teachers to help students understand how a consistent set of energy ideas is applicable across disciplines. To do this, students need language that is unified around a small set of core ideas about energy. The Five Big Ideas about energy help do this, but even these Five Big Ideas use terms that have different meanings in scientific and everyday contexts. Thus, the call to build a consistent set of energy ideas that are crosscutting also involves a call for all of us to be more careful with our language as we help students build and discuss their ideas about energy over time.

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TEACHING ENERGY

ACROSS THE SCIENCES

K–12

Students may have an idea of what energy means but still lack a full understanding of how it is a part of their everyday lives. As editor Jeffrey Nordine explains, many essential social and personal decisions require an understanding of energy as a concept and in practice. By starting with an explanation of why energy is important and what students should know, then moving on to how energy should be taught in several disciplines, *Teaching Energy Across the Sciences, K–12* can clarify—rather than complicate—how both your students and you regard instruction about energy.

This valuable resource provides you with the strategies and tools you need to help students understand the crosscutting nature of the concept—an understanding that's crucial to developing a clear lens on how energy works in many contexts, both inside and outside the classroom.

Whether or not you have a strong science background, you'll welcome this book's accessibility. In addition to the foreword by Helen Quinn, the book's three main sections cover these important topics:

1. Understanding why energy is such an important concept, what students need to know about it, and how to address the concept with the *Next Generation Science Standards* in mind
2. Using five central ideas about energy to teach the subject consistently across the life, physical, and Earth and space sciences, as well as in all grades
3. Providing the professional development and systemic support that teachers need to adopt this book's approaches

"The *NGSS* firmly assert that we can no longer accept teaching energy in a way that does not show students how energy ideas are connected," Nordine writes. Simply and clearly, this book shows you how to make those vital connections.

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