Criteria for Creating and Categorizing Forms of Energy

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Abstract. Traditional instruction on energy often presents forms of energy as a seemingly arbitrary list to be memorized, with little discussion of the meaning or purpose of these forms. Learners often struggle to make sense of these forms, and neither physicists nor physics educators are explicit about the criteria used to create these lists. This article presents our understanding of the meaning and purpose of forms, based on (1) our understanding of how physicists have used forms and (2) our observations of how elementary teachers create new forms and categorize existing forms in order to understand real-world problems. We propose that explicitly articulating the criteria used to identify forms of energy can empower teachers and students and help them to understand both the concept of energy and the nature of science.

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INTRODUCTION

National[1] and state[2] standards often present lists of energy forms (e.g. kinetic, potential, thermal, etc.) that students should know, but often do not offer guidance on how students should use such lists or what they should make of them. Elementary teachers grappling with these standards in professional development courses on energy have expressed dissatisfaction with both their own understanding of energy forms and with what they are expected to teach their students. These teachers challenged the authors of this article, who were instructors and researchers in their professional development courses, to offer a more satisfying explanation of forms of energy. We present a step towards such an explanation, which we have developed through engagement with their questions.

Attempts in the science education literature to address the inadequacies of the standard treatment of forms of energy have sometimes led to the abandonment of the concept partially or entirely. Various authors have suggested that forms should be interpreted merely as "carriers" of energy[3] or as vestiges of a "transitional language" on the road to a more complete thermodynamic description of energy[4], or that forms might disappear entirely if energy is interpreted in terms of cause and effect[5]. In this article, we take a different approach. Rather than abandoning forms of energy as a concept, we attempt to develop an operational definition based on epistemological utility using (1) the criteria used by physicists to create and categorize forms and (2) our observations of elementary teachers' struggles to make sense of form.

INSTRUCTIONAL CONTEXT

The Energy Project at Seattle Pacific University includes a professional development program for K-12 teachers on the learning of energy. This article is based on our experience in two concurrent one-week Energy Project courses for elementary teachers in June 2011: a first-year course for teachers new to the Energy Project, and a second-year course for teachers who had completed the first-year course in a previous summer.

The Energy Project professional development program, which is based on the Algebra Project[6] and Rogerian Discourse Analysis[7], has two main goals: (1) to help teachers learn about energy, and (2) to empower teachers to view themselves and their students as intelligent agents who can figure things out. To achieve the first goal, Energy Project instruction is inquiry-based with respect to content: participants construct their own understanding about energy by asking questions.

To achieve the second goal, Energy Project instruction is also inquiry-based with respect to method: participants construct their own understanding about what it means to learn by developing their own standards of evidence and explanation. Participants are encouraged to ask and answer their own questions about energy using many different methods, including engaging in small group and whole class discussion, calling on the expertise of the instructors (and researcher-videographers who are participant-observers in the classroom), searching for answers on the internet, and using a technique called Energy Theater[8] to represent energy transfers and transformations in real-world scenarios with their own bodies.

Just as instructors do not necessarily step in to correct content errors when learners are in the process of constructing physics knowledge, Energy Project instructors do not correct participants' reliance on prior knowledge and external sources of authority when learners are in the process of constructing their sense of what it means to understand a concept deeply. Instead, instructors help learners recognize that deep understanding requires using evidence and theory in explanations as well as reconciling results with authoritative sources.

DISSATISFACTION WITH FORMS

Elementary teachers in our courses routinely express dissatisfaction with their own understanding of forms of energy and with what they are expected to teach their students. In the summer of 2011, teachers discussed lists of forms promoted by textbooks, curricula, districts, and national and state standards. For example, the *Benchmarks for Science Literacy*[1] lists motion energy, thermal energy, gravitational energy, elastic energy, chemical energy, electrical energy, and light energy. Another list promoted in a particular school district has the acronym SCREAM, for sound, chemical, radiant, electrical, atomic, and motion energy. Teachers wanted to know which list was correct, which forms they should be teaching their students, and where other forms they had heard about fit into these lists. For example, one teacher wanted to know where solar energy fits into SCREAM: Is it light and heat energy, which she had been told belong under "radiant"? Is solar energy something other than light and heat together? She also wondered about other forms of energy that didn't seem to be on the list, such as gravitational energy; was it within one of the listed categories? If not, what was this a list of?

Another discussion of forms focused on which names their students should use. Is mechanical energy a real form of energy? If not, do students need to be discouraged from using this phrase? Does curriculum that uses this phrase need to be "fixed up"?

CRITERIA FOR CREATING AND CATEGORIZING ENERGY FORMS

We propose the following definition for forms of energy: *Energy forms are categories of mechanism by which energy acts and/or evidence for the presence of energy*. We propose the following criteria for creating and categorizing forms:

1. There should be enough forms to account for all the energy in the scenario being analyzed.
2. The forms should be divided into enough categories to distinguish all the features of interest in the scenario.

One consequence of the above criteria is that there can never be a single list of forms that applies for all time and in all situations. By asking students to work with predefined lists such as SCREAM, we are discouraging engagement in the actual function of form for physicists, as categories that are created in the moment to solve specific problems.

CRITERIA IN PHYSICIST AND TEACHER DISCOURSE

In this section we present evidence for our two criteria in the discourse of physicists and in the discourse of elementary teachers in our professional development course.

Accounting For All the Energy

Historically and in current practice, physicists create new forms of energy whenever known forms do not add up in a way that satisfies the principle of conservation of energy. Two famous examples of this are the postulation of a new form of energy called "mass energy" when both mass and energy conservation appeared to be violated in nuclear reactions, and the postulation of the neutrino based on missing energy in particle interactions. More mundane examples include postulating that "thermal energy" is created when an object slows down due to friction even when we don't detect changes in temperature, and postulating that an inert object raised in the air has "potential energy" to explain the source of the kinetic energy it gains when dropped.

During our professional development courses, teachers frequently postulated new forms of energy in order to satisfy conservation of energy. Teachers were asked to explain the evidence for each form of energy they used, and these discussions of evidence were often very rich, including many questions about whether the principle of conservation of energy itself could constitute evidence. The first scenario analyzed by teachers in the first-year course was a basketball rolling along the ground and coming to a stop. Because the representation they used (Energy Theater) required each person who had represented kinetic energy at the beginning to become some other form of energy (either in the ball or somewhere else), teachers had to grapple with where the energy went and what form it took. They postulated that it went into thermal energy, but struggled with this because they could not detect the thermal energy (no temperature change was observable). A minority of teachers in each of two independent groups wanted to introduce sound energy as well. Some teachers argued that you could not hear the basketball rolling, but then recognized that you could not feel a temperature change either, so there was no evidentiary basis to prefer one form over the other. Teachers then wondered whether there were other forms of energy that they could not detect.

Though these questions were at times vexing for teachers, they demonstrated teachers' facility in applying the criterion that there should be enough forms to account for all the energy in the scenario being analyzed.

Distinguishing the Features of Interest

Physicists frequently and unconsciously switch between models with finer and coarser distinctions of forms of energy, subdividing forms when we need more forms to explain something and lumping forms together when the finer distinctions aren't useful. For example, in some situations we talk only about kinetic energy, and in other situations we divide kinetic energy into vibrational, rotational, and translational kinetic energy. When attempting synthesis, physicists may say that kinetic and potential are the only two forms of energy in the world, but when solving real problems, we typically use more than these two.

Teachers in our professional development courses discussed how to subdivide forms when analyzing energy scenarios. One question that arose repeatedly was whether various forms that involve a specific type of motion are the same or different from "motion energy" (their term for kinetic energy). For example, is sound energy, which involves the vibration of air molecules, the same as motion energy? Teachers brought up several criteria for why these two forms of energy might or might not be the same. First, most teachers knew that sound is normally accompanied by the motion of molecules, but did not initially know whether sound itself was actually something other than the motion of molecules. To answer this question, one teacher proposed doing an experiment of making a sound in a vacuum and seeing whether you could hear anything. She said this experiment would resolve the issue of whether sound energy and motion energy are the same or different, because if we can hear sound without air, then sound is distinct from the motion of molecules. A YouTube video of a bell in a bell jar demonstrated to the teachers' satisfaction that sound cannot exist without air. (In other contexts, teachers were quite comfortable expressing when they were dissatisfied with an explanation or demonstration.) However, this did not resolve the question of whether sound and motion were distinct forms of energy, which teachers continued to debate for several days. Criteria teachers considered for resolving the question included that sound involves vibrational motion rather than translational motion, that sound is a wave, that sound and motion are detected using very different techniques (an ear or microphone versus watching something move), that we care about sound for different reasons than we care about motion, and that sound energy appears in the state standards for elementary science instruction.

Another debate over subdividing categories arose in the context of doing Energy Theater for a germinating seed. In order to represent plant growth, they needed to determine what form of energy is associated with growth. In one small group, most of the teachers quickly decided that growth energy was the same as motion energy. One teacher was not satisfied with this categorization, and the group argued at length about whether or not growth should be a separate form of energy. The main concern of the dissenting teacher was that growth involves expansion rather than translation. Other concerns that were raised and addressed in the discussion included that plant growth happened on a much slower time scale and smaller distance scale than the motion we are used to thinking about, that it is biological, and that it is more powerful than we might imagine it to be (e.g. some plants can break through chain link fences).

Teachers applied the second criterion by asking and successfully answering many questions that were relevant to distinguishing the features of interest of these forms of energy. In spite of this, many of them were unsatisfied with their inability to resolve the debates about whether sound energy and growth energy were the same as motion energy. Teachers enjoyed the freedom to explore ideas in the context of a professional development course, but expressed frustration that in their own teaching, they needed to make sure that their students understood a specific list of forms. Therefore, they wanted clarity about which forms were accepted by the scientific community, and sought answers from instructors. Teachers were surprised to learn that physicists have neither an agreed-upon list of forms nor well-articulated criteria for creating and categorizing forms of energy.

We suggest that some of the frustration teachers experienced in debates about the legitimacy of forms could be alleviated by framing the activity more explicitly in terms of identifying features of interest rather than in terms of identifying the right forms.

CONCEPTUALIZING NEW FORMS

In one of the professional development courses, the instructor shared video of secondary teachers inventing a new form of energy called "phase energy,"[9] which is the kind of energy that a gas has more of than a liquid at boiling point. One teacher, Marjorie, expressed skepticism about making up a name:

Marjorie: Phase energy. I know, we don't have any, we don't have understanding or, we'll make something up. We'll call it phase energy.

Instructor: Mmhmm. Is that okay? Is that what you're asking?

Marjorie: Yeah. I mean is it okay? Well, yeah, it.. you know, it accomplished I guess what they set out to accomplish, but is it real?

Other teachers responded by discussing the ways in which they understood scientists to name physics quantities:

Brian: Isn't it all arbitrary anyway? ... I mean, you know, thermal energy – that's an idea. Like you could have called it pancake energy if you wanted to.

Anthony: So, in essence, it's kind of like what the experts which basically are the people that first like kinda first decided to think about it and create the benchmark or create the idea. It'd be the same thing if we called it Blue Bland. Once everybody agrees to that it's Blue Bland, as long as it conveys the understanding of what's happening to the best of our understanding, then basically it was okay. Is that kind of the... the thing?

While these responses suggest that the speakers understand the provisional nature of science, they do not suggest an understanding of the criteria scientists use to create new forms of energy. Empowering teachers to engage in this activity themselves seems to require either an explicit understanding of the criteria, or engagement in a real problem that is sufficiently complex as to require new forms of energy. For example, two days later, in the process of producing an Energy Theater storyboard to explain how an elevator works, Marjorie and her partner made up a new energy form that they called "potential rotational energy".

IMPLICATIONS FOR INSTRUCTION

We propose that explicitly articulating criteria for creating and categorizing energy forms can help both teachers and learners understand the meaning and purpose of forms of energy. It can aid their understanding of the content included in national and state standards by giving them a framework in which to place the many forms of energy that they learn about. It can aid their understanding of the nature of science by sharing that science content is defined by usefulness in particular situations, not by arbitrary lists. We expect these criteria, developed in direct response to needs expressed both implicitly and explicitly by teachers in our professional development program, to inform future instruction on energy.

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