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Teaching Teachers About Energy: Lessons from an Inquiry-Based Workshop for K-8 Teachers

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Abstract:

We report results and impressions from a three-day inquiry-based workshop for K-8 teachers, aimed at improving their understanding of energy from a science and engineering perspective. Results suggest that the teachers made significant gains in understanding and appreciation of important energy concepts, but their comprehension of some key ideas remained incomplete. The dissipation of energy into thermal energy of the environment proved to be a particularly difficult idea, and one that represents a serious obstacle to understanding the principle of the conservation of energy.

Keywords: Energy; teacher training; elementary school; conservation of energy; thermodynamics

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Introduction

Energy is one of science's core ideas. From a physicist's perspective, it is "perhaps the concept most central to all of science." (Hewitt 2009) It is a concept that citizens must understand in order to make informed decisions about important social issues including climate change and energy production, use, and conservation. (Mohan et al. 2009). Like other core ideas, it "helps learners make sense of an enormous amount of observations in the natural world." (Slater and Slater 2009)

Teaching and learning about energy in high school are notoriously difficult, and multiple studies indicate that prevailing approaches are usually unsuccessful. In spite of substantial efforts to teach accepted scientific ideas about energy in secondary school, for example, very few students fully understand or correctly use these ideas (Brook & Driver 1984; Brook and Wells 1988; Solomon 1985; Trumper 1993; Jin and Anderson 2007). Liu and McKeough (2005) report that fewer than 25% of high-school students in advanced physics classes correctly answered either of two questions related to the conservation of energy on the Trends in International Mathematics and Science Study (TIMSS).

Perhaps even more than is the case with most scientific concepts, students' intuitive ideas about energy and ways of using the term are very different from scientists'. (Watts 1983) Energy itself is an inherently abstract concept, not directly measurable or observable, but rather inferred or calculated from other measurable quantities, such as temperature, velocity or position. In common language it is often not clearly distinguished from force, momentum, movement and power (Watts and Gilbert 1983; Solomon 1985; Kruger et al. 1992). At the heart of physicists' understanding of energy is its status as a conserved quantity. As Richard Feynman et al. (1963) describes it,

> There is a fact, or if you wish, a law governing all natural phenomena that are known to date. There is no known exception to this law; it is exact as far as we know. The law is called the conservation of energy. It states that there is a certain quantity, which we call energy that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens.

Colloquial references to "producing," "consuming," "wasting," and "conserving" energy, however, appear to flatly contradict the scientific principle of energy conservation. So does everyday experience: When a ball stops bouncing or a flashlight "dies," to all appearances the energy has simply disappeared or been "used up." (Solomon, 1985) Thus it is hardly surprising that while it is relatively easy to train students to recite the principle of energy conservation, there is little connection between a correct recitation and the ability to use the principle appropriately (Brook and Wells 1988; Solomon 1985; Liu and McKeough, 2005).

The K-8 physical science content standards (NRC 1996) identify energy as an overarching content theme for physical science. However, existing standards for elementary science do not describe how to lay sound foundations for understanding energy, but suggest that elementary teachers help children progress in their understanding of energy by "build[ing] on their intuitive notions." (NRC 1996) Yet, as argued above, in many contexts intuitive and everyday notions of energy appear to contradict scientific ideas of energy, and in particular the central principle of conservation of energy. It is no surprise, then, that not only many primary school teachers, but even high school science teachers' understanding of energy as a scientific concept is limited (Kruger 1990; Kruger et al. 1992; Trumper, 1997a,b). If we wish children to arrive in middle and high school with the conceptual foundation they need, it would surely help for their teachers to have a more solid grasp of the key concepts.

The Workshop

We describe a case study of an effort to improve elementary and middle school (Grades K-8) teachers' understanding of energy through an intensive three-day inquiry-based workshop. Our experience suggests that a small-scale intervention can achieve significant improvement in teachers' comprehension of energy concepts and appreciation of their broad applicability. At the same time, the inherent subtlety of energy ideas limited the gains that could be achieved by this brief intervention, even in a nearly ideal situation.

The workshop participants were twenty experienced in-service teachers, from kindergarten to eighth grade, from various school districts in eastern Massachusetts. The overwhelming majority (85%) taught in high-need schools. Eight (40%) taught in grades K-4, twelve (60%) in grades 5-8. Participating teachers were compensated with a cash stipend and given a budget with which to order science education materials for their classrooms. They also received professional development points.

The workshop was designed over a period of several months by a team comprising physicists, engineers, education researchers, and curriculum developers. A central goal was to focus on a few key concepts, "big ideas," and thought-provoking questions identified by the scientists as central to the understanding and application of energy ideas across a wide range of fields. Key learning objectives for the workshop included an improved understanding of:

1) The nature of energy

- Energy comes in many forms, but is a single entity;
- Two fundamental types of energy are energy of motion (kinetic) and energy of position or configuration (potential). Other apparent forms of energy (chemical, thermal, electrical) are manifestations of these two types at a microscopic level;[1]
- When energy is transferred or transformed, the systems involved must change in some way;
- Energy is not matter. Energy may be transferred between systems with no flow of matter between them;
- Why energy concepts are important, and how they can be used to understand issues of engineering, technology and society;

2) Conservation of energy (First Law of Thermodynamics)

- Energy is *conserved* – in any process energy may be transferred from one system to another or transformed from one form to another (or both), but the total amount of energy does not change. When it appears that energy is lost, it has usually been transferred to the environment, often in the form of thermal energy;

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[1] The question of how to fit radiant ("light") energy into this framework was not explicitly included, but it did come up in discussions.

3) Conversion of thermal to mechanical/electrical energy (Second Law of Thermodynamics)

- It is possible to convert ordered forms of energy completely into thermal energy. Thermal energy can also be converted (partially) into ordered energy. Such processes require a temperature difference between two systems.

While all of these ideas are crucial to a deep understanding of energy and an ability to apply energy ideas in real-world contexts, in retrospect this set of goals was probably too ambitious for a three-day workshop.

Each day of the workshop centered on a set of engaging hands-on open-ended activities and discussion questions carefully selected to address a subset of the learning objectives. The day's activity was preceded by assigned readings chosen to prepare for and supplement the activities. During the morning the teachers, in small groups and assisted by members of the design team, carried out hands-on investigations linked to the day's topic. Following the investigation, one or more of the scientists or engineers led an all-group discussion in which the data and results were reported and discussed. The afternoons focused on the application of the day's ideas in the teachers' classrooms, followed by the introduction of the next day's topic.

A challenge in developing effective science training for elementary school teachers is that they often have limited formal background in science and mathematics. (On the other hand, it can be an advantage that they know what they don't know and are open to learning.) Few have degrees in science, and many have taken few or no science or math courses in college or since. As teachers they do not specialize in science, and indeed it is often a relatively small and underemphasized part of their curriculum. (Again, this can also be an advantage, as they may have more leeway in what and how they teach than in higher-stakes subjects such as reading and math.) Moreover the science they teach is often extremely broad. Some middle school teachers have deeper background and experience in science, but it is still typically less extensive than that of high school science teachers (whose science backgrounds are also often limited).

While the formal science backgrounds of the participants in our workshop was indeed limited, they had all completed a sequence of three online courses through the Fulcrum Institute for Leadership in Science Education at Tufts University, (Tufts University 2011) centering on such ideas as the particulate nature of matter, heat and heat transfer, and dynamic equilibrium, and they were known to the workshop organizers and in many cases to each other. We could therefore assume a body of shared experiences with inquiry-based science learning and group discussion that we could build on, a certain level of mutual trust and respect, and a baseline level of exposure to, if not necessarily mastery of those topics. Nevertheless we could not assume familiarity with fundamental physics concepts such as force and work, let alone energy and power. Mathematical representations, such as the formula relating kinetic energy to mass and speed, while familiar and helpful to some participants, would be obscure and intimidating to others and so could be introduced only sparingly and with considerable scaffolding.

For these reasons we chose thermal phenomena as the entry point, rather than following the approach of traditional physics classes, where work and the kinetic and potential energy of macroscopic systems are usually introduced first. Thermal phenomena also afford the advantages that temperature changes are familiar, can often be directly sensed, and are measurable with familiar and comprehensible instruments. Moreover, all forms of energy can be readily converted into thermal energy, allowing us to highlight the unity of different forms of energy rather than their diversity. In addition, the online coursework previously completed by the teachers included significant exposure to thermal phenomena, including measurements, analysis of thermal transport mechanisms, and computer representations of thermal phenomena at a microscopic level.

A second challenge was the tension between presenting energy as the term and idea are understood by scientists, for whom Conservation of Energy is a fundamental and universal law, and providing a context for understanding "energy" as the term is used in engineering, economics and public policy, where conserving energy is a goal to be achieved. While we wanted the teachers to leave with an improved scientific understanding of energy, we also felt it was important for them to return to their classrooms with an improved ability to make connections to energy-related questions and issues that are likely to arise in everyday contexts – to understand, for example, why perpetual motion machines are impossible, why it is so challenging to make electric cars with long range and high performance, and why such a car isn't necessarily a "zero-emission" vehicle.

The activities for Day One centered on heating water – by burning a hazelnut, burning a commercial jellied-alcohol fuel, and running electrical current from a battery through a resistor. In each case the teachers were asked to measure the temperature increase of the water and the change in mass of the energy source, and estimate a stored energy density for each one. In the case of the battery the temperature increase was too small to be measured, and the intent was to derive an upper limit on the energy density.[2] Discussion questions focused attention on the fact that diverse phenomena could lead to the same result (an increase in water temperature); that the process could be, but did not have to be, associated with a measurable loss of mass by the energy source; that energy could be transferred into the water even though matter was not; and that some systems and processes are more effective sources of energy than others, in the sense that a greater or lesser amount of energy could be extracted from a given amount of mass. An implicit message throughout the day was that the questions "Where did the energy come from?" and "Where did the energy go?" are always appropriate and often important. The reading was a journal article on the introduction of energy ideas in kindergarten, focusing on the idea that energy storage is associated with changes in physical configuration or conformation (Van Hook and Huziak-Clark 2008).

On the second day the emphasis shifted to engineering and practical applications of energy concepts, and to traditional definitions and descriptions of macroscopic kinetic and potential energy. The teachers used video cameras to record and then qualitatively analyze a variety of devices or situations involving kinetic and potential energy, including a swinging pendulum, a ball rolling down a ramp, a catapult, and a person bouncing an a trampoline. Quantitative expressions for kinetic energy and gravitational potential energy were introduced but were not extensively used. Discussions centered on the idea that energy can change

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[2] The focus on the idea of energy density was motivated in part by its importance to practical applications (e.g. electric cars) but also as an effort to generalize the concept of intensive quantities that had been introduced, in the context of mass density, in their online courses. Despite their prior experience with mass density, the more abstract one of energy density proved challenging and may have been a distraction.

forms or be transferred between objects, but that the total quantity of energy does not change. There was also discussion of the many different units used for energy in different contexts, and a brief introduction to the distinction between energy and power. The reading was an excerpt from Richard Feynman's *Lectures on Physics* in which he presents energy as an accounting scheme with conservation as its central theme (Feynman et al. 1963).

During the first two days the participants saw many examples of the conversion of various forms of energy into thermal energy, either deliberately, in the heating of water, or as a result of dissipation, for example through friction. The activities of the third day centered on the inverse process, the conversion of thermal energy into other forms. The participants observed or experimented with a variety of heat engines, including "angel chimes," in which rising hot air from candles drives a windmill; a simple Stirling engine that turns a propeller when placed either on top of a mug of hot water or on ice (American Stirling Company 2011); a thermoelectric generator (Sci-Supply 2011); and a heat engine based on nitinol "memory" wire (Images Scientific Instruments 2011). In each case the device could be, and was, operated either from a source of "heat" (temperature above ambient) or from "cold" (temperature below ambient); showing that what is always needed is a temperature difference. The fact that the conversion from thermal to other forms of energy cannot be complete (Second Law of Thermodynamics) was mentioned, but not strongly emphasized, and no attempt was made to introduce ideas of entropy, simply because of lack of time. The reading was the chapter on Thermodynamics from Hewitt's book, *Conceptual Physics* (Hewitt 2009). Day Three concluded with a written assessment and evaluation and with a final all-group discussion.

The course designers considered this set of topics to be ambitious and challenging for a three-day workshop, and indeed it was probably too ambitious, as we discuss below. Nevertheless many ideas of great importance were either omitted or given minimal attention. The issue of light as a carrier of energy, for example, came up repeatedly in group discussions, and the participants were perplexed as to how light can carry energy through empty space if energy isn't matter. The distinction between energy and power was touched on in our discussion of units on Day Two, but was not explored sufficiently to clarify the difference. The apparent conflict between the Principle of Conservation of Energy as a matter of physical law and the exhortation to conserve energy as a matter of public policy was also touched on, but not explored in detail. As noted, the unavoidable inefficiency of heat engines as a consequence of entropy and the Second Law of Thermodynamics was not discussed except in the Hewitt reading. We could not describe in any detail how chemical energy is stored or released, or why burning a hazelnut releases so much more energy per unit of mass than discharging a battery. The microscopic description of thermal energy was somewhat familiar to these teachers from their prior coursework, but nevertheless would have benefited from greater exploration. Little attention was paid to the conversion of mechanical work into thermal energy, and almost none to biological applications of energy ideas. On the more applied side, many of the teachers were very curious to know more about both fossil fuels and alternative energy sources such as photovoltaic, wind, biomass and geothermal. Many of these topics came up in the group discussions and led to animated and interesting conversations among the participants, with the scientists as discussion leaders.

Given such a rich and daunting list of topics, all of them of great scientific or practical importance, conceptually challenging and highly interconnected, any choice we made would contain an element of arbitrariness. We would argue that the topics and activities we chose represented a good balance among the competing priorities, and kept the focus throughout on ideas that are central to the understanding and application of energy concepts in any context. At the same time, we recognize that other sets of choices could be at least equally valid.

Assessment

Assessment of the workshop's effectiveness was carried out in three ways: (1) a formal written pre/post assessment, (2) daily informal written evaluations by the participants, and (3) the course designers' informal impressions based on discussion comments, one-on-one conversations, and the content of the written assessments, and in a follow-up meeting with some participants six months after the workshop.

1) Formal Pre/Post Assessment

The pre-assessment was administered at the very beginning of the workshop, after the first reading but before any of the hands-on activities or discussions. Each group of 5-6 participants was asked to choose one of a number of toys, including a gun that shot toy darts, a toy pinball machine, a robot pencil sharpener (turning the pencil to sharpen it wound up the robot, which then walked around the table), and various others. After examining and playing with the toy, each individual participant was asked to write down answers to four questions, the first three of which related to the toy:

1. *List the forms of energy storage and energy transformation that you think are involved while the device is operating. What do you think is the original source of energy for the device? What do you think happens to the energy when the device stops?*

This first question was intended to get at ideas of energy storage, transformation and conservation. Ideally, we looked for an answer that not only discussed the overt forms of energy manifest in the toy itself, but also traced the energy back to the muscles of the person who set it in operation, the food that person ate, and even the sun as the origin of the chemical energy in the food. A complete answer would also include the eventual dissipation of the energy into thermal energy of both the device and the environment.

2. *Describe an instance that you think represents energy of motion of the system. Describe an instance that you think represents energy of position or configuration of the system.*

Here we are focusing on the ideas of kinetic and potential energy in their various manifestations, but the emphasis, both in the framing of the question and in our evaluation of the teachers' answers, was not on the terms but rather on the physical distinction between energy associated with motion and energy associated with "lift, squeeze, stretch and twist." (Van Hook and Huziak-Clark 2008).

3. *Describe changes that occur as the device operates. For each change, what physical systems are involved, and how do you think energy is transferred or transformed?*

This question focuses attention on the idea that transfer or transformation of energy is associated with physical changes in the system or systems involved – the spring of the dart gun changes its shape from a compressed to a relaxed form, reducing its energy of configuration (potential). That energy is transferred to the dart, which changes its state of motion, increasing its energy of motion (kinetic).

4. *For conventional cars, the energy source is a chemical fuel – gasoline. For electric cars the energy source is a battery. What do you think the difference between these two forms of energy has to do with the*

> *difficulties of making an electric car that performs as well as a gasoline car?*

This question was designed to see whether the teachers could extrapolate their knowledge and experience from the workshop to a real-world situation. In particular, we hoped that their activities heating water on Day One would reveal the very low energy density of batteries compared to combustible fuels such as hazelnuts and jellied alcohol, and that they would recognize that discrepancy as a challenge for the design of electric cars.

The questions were intended to be ones that could be understood and perhaps answered even by someone who had not had formal instruction in scientific energy terminology and concepts, yet that probed some of the “big questions” that the workshop hoped to address. None of the toys were used in any of the workshop activities, and none of the questions were explicitly addressed in this form during the workshop. Answering the questions therefore required far more than rote learning; the teachers had to apply energy concepts appropriately in a real-world context with minimal explicit prompting or guidance.

At the end of the workshop, after completing the final activities and discussion, the teachers were asked to answer exactly the same set of questions, about the same toy. Completed pre- and post-assessments were collected from 19 of the 20 participants.

To evaluate the assessments, three of the physicists on the design team, all with expertise in the subject and extensive experience in teaching it, developed a scoring rubric for each question. The teachers’ responses were transcribed and coded anonymously so that the graders could not identify responses with individuals or know which were pre- and which were post-workshop. Each of the three physicists graded all of the papers independently, and their scores were averaged. The results are summarized in Table 1.

Inter-rater agreement was evaluated using the $r_{WG(J)}$ index, which compares the average inter-rater variance among the scores given for each individual item to the variance expected for an assumed random distribution of scores. The average standard deviation among the three raters was 0.95. The index values assuming uniform and normal null distributions were 0.99 and 0.94, respectively, indicating very strong agreement among the scorers. (LeBreton and Senter 2008).

Table 1. Average pre- and post-workshop scores for the four individual assessment questions, and for the total of the four. Uncertainties represent one standard deviation of the mean. *p* values are for a two-tailed *T*-test. Gains were observed on all questions. The gains on Questions 1 and 2 are of marginal statistical significance ($p \geq 0.1$), but the gains on Questions 3 and 4 and overall are highly significant ($p < 0.01$).

	Question 1 **Storage, transformation, conservation**	**Question 2** **Kinetic and potential energy**	**Question 3** **Physical changes**	**Question 4** **Energy density**	**Total**
Points	5	5	5	5	20
Pre	2.8 ± 0.25	3.4 ± 0.33	2.5 ± 0.26	2.2 ± 0.24	10.9 ± 0.85
Post	3.3 ± 0.23	4.1 ± 0.25	3.8 ± 0.24	3.5 ± 0.26	14.7 ± 0.66
p	0.12	0.10	0.0005	0.007	0.001
g	0.24 ± 0.27	0.43 ± 0.65	0.53 ± 0.22	0.45 ± 0.24	0.42 ± 0.22

Figures 1-3 compare the average pre- and post-workshop scores for the 19 participants for which both were available, and the results are given in tabular form in Table 1. Figure 1 shows the results for the four individual assessment questions. Figure 2 shows the overall change, averaging over all four questions, expressed as a percentage of the maximum possible score. Gains are seen on all questions, with those on Question 3 and 4 of high statistical significance ($p < 0.01$). Before the workshop the participants' average score was 54.3%. Following the workshop the score had increased to 73.4%. This gain is also highly significant ($p = 0.001$).

A better way to characterize the improvement is with the "*g*" value, defined as the ratio of the actual improvement in score to the maximum possible:

$$g = \frac{\left(S_{post} - S_{pre}\right)}{\left(S_{\max} - S_{pre}\right)} \ .$$

Regardless of the subject's initial level of understanding, a *g* value of zero represents no gain of understanding – at least as measured by these questions – and a *g* value of one represents the maximum possible gain. Figure 3 shows the average *g* value for the workshop participants on the four questions and overall. The values range from 24% on Question 1 to 53% on Question 3, with an overall gain of 42%.

The participants had relatively little difficulty in identifying and distinguishing kinetic energy (energy of motion) and potential energy (energy of position or configuration), as shown in the results for Question 2. This was the question with the highest average scores both pre- and post-workshop. Their answers to both Question 1 and Question 2 also showed a good grasp of the conversion between potential and kinetic energy.

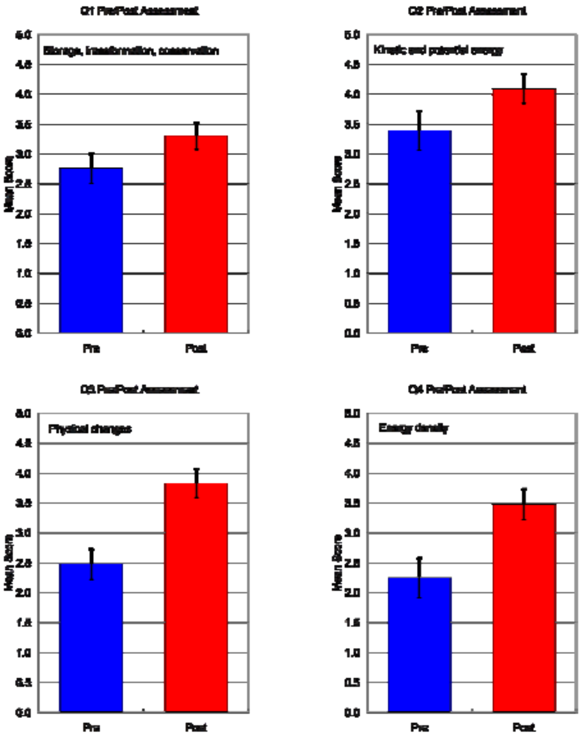

Fig. 1 Average pre- and post scores on the four assessment questions. The maximum score on each question was 5. Gains were seen on every question, with those on Questions 3 and 4 having high significance. Error bars represent one standard deviation of the mean.

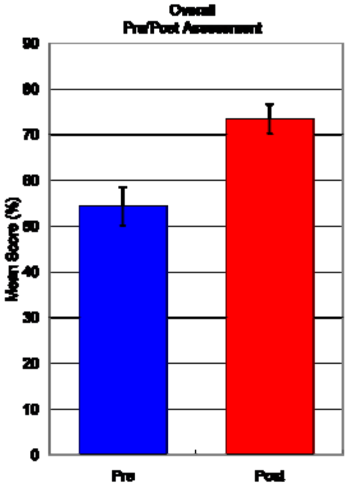

Fig. 2 Average overall pre- and post- assessment scores. The average score increased from 54% to 73%, corresponding to 42% of the maximum possible improvement. Error bars represent one standard deviation of the mean.

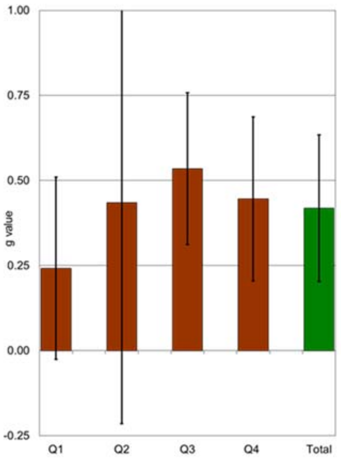

Fig. 3 "g" values (average actual gain/maximum possible average gain) for the four individual assessment questions and overall. Error bars represent one standard deviation.

Some answers, however, showed confusion about the scientific use of the word "potential." One teacher wrote, for example, "The energy within the toy becomes potential again until someone else pulls the string," and several others said that when the toy stopped the energy was transformed once again into potential energy. We speculate that these comments are less a confusion about the physics – the teachers certainly don't think that the toy can just start moving again on its own – than about the terminology. Another teacher reported students saying that a soccer ball resting on the ground has potential energy, because it would move if you kicked it. There seems to be a fairly common (and understandable) interpretation of the term "potential energy" to refer to the ability of a system to be given energy by an external source – in informal interviews with some of the authors (S.C. and S.L.) elementary-school children have reported being taught that moving things have kinetic energy and things that aren't moving have potential energy.

Questions 3 and 4, dealing with connecting energy flow with corresponding physical changes and with energy density, respectively, were characterized by low pre-workshop scores with large and highly statistically significant gains. These are ideas that are typically not emphasized in elementary discussions of energy.

The weakest area was in the teachers' ability to trace the energy flow beyond the toy in either direction. On Question 1, roughly half the teachers (8 of 19 pre, 10 of 19 post-) identified the energy for the toy as having come from the person, and only 3 (both pre- and post-) traced it further back, to food or the sun. Before the workshop only 3 teachers wrote that the energy of the toy is dissipated to the environment as heat; that number more than doubled after the workshop, but still only 7 – fewer than half – demonstrated a grasp of that crucial idea.

It is possible, of course, that the fault lies with the phrasing or context of the question rather than with the teachers' understanding. But studies of children's conceptions also suggest that appropriately applying the conservation principle, particularly when the energy of a system is dissipated as low-grade thermal energy, is much more challenging than identifying different (visible or tangible) forms of energy and transformations between those forms (Duit 1981; Solomon 1985; Brook and Wells 2008). It seems entirely plausible, therefore, that the teachers' responses reflect the same difficulty, and that more careful and consistent attention to issues of energy dissipation during the workshop might have been desirable.

2) Participants' Evaluations

The daily written evaluations demonstrated the teachers' passion for new knowledge. They were given time to reflect on what they had learned each day, and many of them wrote about their plans to incorporate energy concepts back in their own classrooms and throughout the science curriculum. The selected quotes below answer the prompt:

The most important idea that I will take away is…

- *I want to probe my students to further understand where energy goes, and what types of energy exist.*
- *To make connections for students about energy when teaching the digestive system and look at different forms taught in other grade levels.*
- *My mind re-opened to the concept of energy through the hands-on activities and informative discussions. And while I'm still frustrated because I don't have answers, I do have insight.*
- *I loved the hands-on engineering activity – adding technology would certainly "hook" the students!*
- *I now have an overarching set of questions about energy that I will thread throughout the curriculum throughout the year.*
- *"Energy" can be viewed as an overarching concept that I can keep revisiting during the school year, and connecting as we move through each curricular area.*

The teachers' comments were overwhelmingly positive and enthusiastic. They clearly felt they learned a great deal and came away with ideas for incorporating energy concepts in their own lessons. Comments like those above indicate that many of them developed an appreciation for energy as an idea that can be used to think about a wide range of phenomena and technologies. At the same time, there was acute awareness that their understanding was still incomplete and unsteady. Arguably such an awareness can be productive, but it can and did also lead to some frustration.

3) Informal Impressions

From their written responses as well as from their questions and discussion contributions, it was clear to the design team that the teachers felt they learned a great deal from the workshop and greatly appreciated the opportunity to participate. They grew noticeably in their ability to identify different forms of energy and the transformations among them, and to appreciate the unity of apparently disparate forms of energy. They developed an improved understanding of kinetic and potential energy on both a macroscopic and microscopic scale, and they recognized that flows and transformations of energy are accompanied by changes in the physical state of the system. They understood that it is possible to extract useful work from thermal energy, but that a temperature difference is required.

At the same time, many of them did not seem to fully understand the dissipation of organized energy into thermal energy in the environment, or that thermal energy is not fully available for use. The idea of energy density was not clear to most of them, and there were other areas where their understanding was not precise or fully coherent. Given the well-established difficulty of these concepts, the limited formal science background of many of the participants, and the brevity of the workshop, it is not surprising that we were only partially successful in conveying these challenging ideas.

A subset of the workshop participants came together about six months later (February, 2011) for further discussion of energy concepts. Prior to that meeting, each teacher carried out a structured interview with one of her students, discussing energy issues in relation to a wind-up toy and a flashlight, and they shared their observations at the meeting. One very clear message was that the idea of energy dissipation is extremely difficult and is a major obstacle to fully developing an understanding and belief that energy is conserved. Virtually all the students, and many of the teachers, found it very difficult to believe that when the toy stops moving (for example) the energy hasn't simply vanished or been used up (reasonably enough, since it's clear that *something* has been irreversibly lost). Overcoming this conceptual obstacle poses a major challenge to teaching a scientific conception of energy at all levels.

Conclusions and Observations

Our experience shows, most importantly, that it is possible to make measurable progress in expanding and improving the understanding of energy concepts by elementary and middle-school teachers with a very limited and focused intervention. Some aspects of our workshop that we suspect were important for achieving this partial success include:

- Close collaboration among scientists, educators and curriculum developers to identify key ideas and develop appropriate and engaging activities and topics;
- Highly motivated teacher participants with strong desire both to improve both their own content knowledge and their effectiveness in the classroom ;
- A carefully designed combination of hands-on activities, guiding questions, and facilitated discussion to bring out the key questions and ideas.

At the same time, energy is a difficult and slippery concept, and there are formidable barriers to achieving a level of comprehension sufficient to use it effectively in scientific, technological and policy contexts. Thus the improved understanding that the teachers took away from the workshop was incomplete, fragmentary and probably fragile. The dissipation of perceptible or tangible forms of energy into diffuse and usually imperceptible thermal energy in the environment is one of the most difficult conceptual hurdles. Yet it must be overcome, and reconciled with the common-sense observation that the energy has been "used up," if the principle of conservation of energy is to be absorbed at any level beyond rote memory (Solomon 1985; Brook and Wells 1988). As Duit (1981) observes, "Learning the energy concept in physics always means learning the principle of conservation of energy." While some teachers did make that leap, our workshop was not nearly as effective as we hoped in convincingly conveying the idea of dissipation. A more focused and extensive effort directed specifically at that idea is probably needed, perhaps involving some combination of hands-on experiments and computer-based simulations.

Acknowledgments

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