Where does energy go when it's "Gone"? Promoting understanding of energy dissipation

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(Received 28 November 2018; accepted 19 May 2019)

The principle of energy conservation cannot be fully accepted or applied in most real-world contexts without an understanding and acceptance of the idea of dissipation: when the perceptible changes in the system have stopped, the energy that was present in the beginning is still present in the system and its environment, even if it is no longer detectable. This idea is challenging for learners of all ages and presents a serious obstacle to understanding. Results from Focus on Energy, an innovative elementary-school energy curriculum, show that fourth- and fifth-grade students can engage productively with the idea of dissipation, leading to a model of energy that includes dissipation. The curriculum does not explicitly include dissipation as a learning target, but it includes early and frequent exposure to dissipative phenomena, a meaningful conceptual framework, and appropriate representational tools. These resources offer opportunities to reason about dissipation and incorporate it into the students' developing energy model. In an open-response assessment, 23% of Focus on Energy students spontaneously included dissipation in their tracking of energy in a wind-up toy, compared to 3% for students who received standard energy instruction. Adult teachers experience similar difficulties with the concept of dissipation, and results from professional development workshops show that the same curricular approach is effective with these adult learners. We suggest that if young children and adult teachers can begin to reconcile energy conservation and energy dissipation, then similar instructional approaches could enable high school and college students to engage productively with dissipation ideas.
https://doi.org/10.1119/1.5110707

I. INTRODUCTION

"Energy is neither created nor destroyed" is the mantra of energy conservation. The elegant symmetry of that formulation, however, conceals a chasm in the comprehensibility of its two parts. In interviews and classroom observations with children as young as third and fourth grade, and in professional development activities for teachers, we have observed that even young children and adults with minimal physics background readily understand that energy cannot simply appear from nowhere. A stationary ball will not spontaneously start rolling; a car needs fuel. But it certainly appears that energy *can* simply *dis*appear—a rolling ball comes to a stop, hot coffee cools off, without any observable indicator that the energy has been transferred to another object.[1–3] In a fourth-grade classroom in our study, a student expressed this common idea poetically by saying the energy goes to "energy heaven": "Sometimes it might go in the air, sometimes it might go in the environment, but sometimes the energy just *dies*. Like some energy can't go anywhere, like it's not in this object, or this object, it's not anywhere around us, it's just POOF, gone."

The difficulty is not confined to children; in workshops for teachers, Tobin *et al*. and Daane *et al*. both reported that the participants had difficulty accepting and using the idea of energy dissipation.[4,5] At the same time, numerous assessments have shown that existing instructional approaches are largely ineffective in bringing students to the kind of integrated understanding of energy that is needed for the meaningful application of energy ideas.[6–9]

The "energy heaven" model is adequate for many practical purposes—selecting a car, insulating a house—and even in many public policy contexts. But from a scientific standpoint, conservation is the central idea about energy, and from the point of view of engineering design, the analysis of efficiency and management of "waste heat" certainly require an understanding that energy doesn't simply disappear. These crucial ideas simply cannot be accepted or believed without an understanding of dissipation.[2–4,10] Solomon cites a student who is explicit about this point: "Miss, I don't believe it [conservation]. You know when you have a battery and a lamp, and the battery has electrical energy, right? And it goes to heat and light in the lamp. Well, I mean, the heat evaporates and the light goes dim. So the energy has gone. It isn't there is it?"[11]

Many activities and demonstrations show the conversion of mechanical or electrical energy into detectable thermal energy, but many learners do not readily transfer that idea to contexts in which the dissipated energy is *not* readily detectable. In the K-8 teacher workshop described by Tobin *et al*., for example, participants burned a hole in paper by banging metal balls together,[4,12] measured the small temperature increase of the air in a closed foam box caused by running an electric fan, and used an infrared camera[13] to observe the heating of a piece of paper exposed to a laser pointer and of a board when a wooden block slid down it. The teachers were fascinated and apparently understood the energy transformations involved, but that understanding did not carry over to more typical dissipative scenarios in which the warming of the environment is undetectable. This difficulty may be related to the observation by Daane *et al*. that teachers expect perceptible energy (such as motion) to produce perceptible warmth—when that expectation is satisfied, energy dissipation is accepted, but when there is no perceptible warming, it is often rejected, or not even considered.[5]

II. THE FOCUS ON ENERGY APPROACH

We present here some results from Focus on Energy, a novel, experimental curriculum about energy for fourth and fifth grade students and teachers.[14–16] In this curriculum, students collectively develop a working model of energy through a carefully structured sequence of hands-on classroom activities and small- and large-group discussions.

For this grade level, dissipation and conservation are not explicit learning targets, and *at no point is energy conservation taught as a fundamental principle*. The curriculum focuses strongly on tracking energy flow in real (and therefore dissipative) phenomena that the students experience directly—such as two balls colliding; a cup of hot water cooling in a foam box; and a propeller turned variously by a rubber band, a hand-cranked electrical generator, a charged capacitor, and a solar cell. The "Energy Tracking Lens" (Table I) provides the students with a framework for thinking about energy flow in these or any other phenomena. It emphasizes the idea that "where does the energy come from" and "where does the energy go" are important and legitimate questions, thereby implicitly introducing the idea of energy conservation. Conservation is also implicit in a representational system they use for reasoning about and representing energy flow, as we describe below. As a result, the question of where the energy has gone when the phenomenon is "over" inescapably, and intentionally, arises early and often. The students are not given an answer, but are encouraged to explore a range of possibilities, as the following example illustrates.

The Focus on Energy curriculum aims to provide a solid foundation for understanding energy conservation (First Law), for which an understanding of dissipation is essential, and we have found it to be effective for both young children and adult learners. It does not attempt to raise the related issue of energy degradation (Second Law). With elementary school students the issue of the usability of different forms of energy typically has not arisen. Daane *et al*. have found, however, that adult teachers spontaneously raise such ideas in conjunction with the idea of dissipation.[17]

Table I. The energy tracking lens.

Part 1. Describe what you observe.
Part 2. Tell the energy story.
•What components are involved?
•Form(s) of energy?
•Increases and decreases in amounts of energy?
•Energy transfers?
•Change of energy from one form to another?
•Where does the energy come from and where does the energy go?
Use observations to support your energy story.

III. RESULTS

In this vignette, a group of fifth-grade students is discussing an activity, very early in the curriculum, in which a small fluffy pompom is launched into the air from a wooden springboard. The class has previously experimented with colliding balls, has begun to develop a working model of energy, and has been introduced to the Energy Tracking Lens and to representational tools for tracking energy. The main goal of this activity is to establish the idea of elastic energy associated with the bending of the springboard. But then the teacher raises another question. She sets up the situation after the pompom has landed and come to rest, and asks "Where's the energy now?" (All names are pseudonyms.)

(1) Katie: There's no energy now, because it's not moving. Because it was moving and it had motion energy.
(2) Teacher: There's no energy now. I agree with you. There's no energy now. But, energy always has to go somewhere. [Raises both hands in a "what's going on?" gesture]
(3) Ayanna: Maybe it goes to the ground?
(4) Teacher: Could it go into the ground?
(5) Katie: The air?
(6) Teacher: The air? Why don't you guys think about that. Because that might be something you want to add in your energy story. Where does the energy go when everything is still?
(7) […]
(8) Teacher: we saw the pompom move up, we saw the pompom come back down, that's motion. Then where did [the energy] go?
(9) Kevin: Maybe it dispersed into the air.
(10) Teacher: It could go into the air. I'm going to have you guys discuss that with each other. [Teacher leaves]

The teacher has raised a puzzle: it looks like the energy has disappeared, but the Energy Tracking Lens and the class's provisional energy model say that energy has to go *somewhere*. Rather than offering an answer or explanation, the teacher leaves the students to try to figure it out, and for six solid minutes, on their own, they take up the challenge. Figure 1 shows an image from their conversation.

(11) Ayanna: I think it goes into the air… it goes up (gestures up) then it drops back down [brings arm down].
(12) Katie: But when it drops down and it bounces a little bit maybe it like releases the energy…when it bounces…

Fig. 1. The fifth-grade students discussing where the energy goes. The springboard assembly is visible at the edge of the whiteboard that they have been using for the energy cube representation, and the student second from the left (Sasha) is holding the pompom.

(13) Ayanna: I think it does, like (she tosses the pompom into the air) right when it's about to fall because when you're flying, when you run out of energy you just drop back down.
(14) Katie: Right.
(15) [Overlapping voices]
(16) Katie: Maybe it goes into the air or something. But there's still a little bit of motion energy when it, like, bounces.
(17) Ayanna: Oh, yeah. Maybe half of it goes into the air and half of it goes…
(18) Katie: Well, nothing's different after the pompom falls so where could the energy go?
(19) Kevin: It disperses into the air,
(20) Sasha: Maybe
(21) Katie: The pompom continues to move after it's in the air so it still has motion energy after it's in the air, because it moved a bit.
(22) Kevin: the energy disperses into the air and slowly fades.
(23) Katie: But, but, it can't fade because it has motion and that is a type of energy
(24) Ayanna: maybe it's motion energy… or elastic energy… [smiles, sentence tapers off] [They launch the pompom again]
(25) Katie: it has a tiny bit of energy right before it hits the ground because it goes, like, bounces and then it stops.
(26) Kevin: I don't think it goes (indecipherable)
(27) Ayanna: When it bounces it has energy and when it goes up here [gestures upward], it loses energy. I think half of it, like, a little bit of it, and then a tiny bit of it stays. Cuz you need to have energy.
(28) Katie: Maybe some of it like goes into the air and some of it
(29) Kevin: goes into gravity
(30) Katie: Or goes into the ground. But what could take the energy? Well, I don't think air can actually…
(31) Ayanna: Hold energy.
(32) Katie: Well, I mean, it might be able to hold energy, but I'm not sure if it, like, takes the energy.
(33) Sasha: Wind, that's energy. […]
(34) […]
(35) Ayanna: Gravity is a type of energy.
(36) Katie: Gravity is like holding it down, so maybe it's, like, trying to…
(37) Ayanna: I think it stops when it bounces, then.
(38) Katie: Well, it bounces and then there's no more energy. But if there's no more energy in the pompom, then where does the energy go?
(39) Ayanna: It probably goes…
(40) Sasha: Maybe the energy, like, goes to the tips [Touching fluffy ends of pompom]
(41) Kevin: Oh, I have a theory.
(42) Ayanna: Into the ground.
(43) Kevin: It would go to the air but it would disperse everywhere.
(44) Ayanna: [Pointing to springboard] Wait, when this [springboard] touches it, it gives it [pompom] energy and it gives it energy. Guys, when it touches it gives it energy and then it takes up all the energy when it goes up, then when it comes back down it loses it.
(45) Katie: Well, so what if the energy, it goes, well it takes…
(46) Ayanna: It [pompom] probably gives it back [to the springboard].
(47) Katie: No, it can't give it back because it doesn't touch it [springboard] again
(48) Katie: Maybe, so when it goes down, yeah, it gives it to the ground and, like, but it's like, maybe it gives it to the ground but then the ground has potential energy.
(49) Kevin: Oh, yeah. That would be true. When something drops on the ground it would shake.
(50) Sasha: Maybe it gives it to the ground, but the ground doesn't have enough energy to move.
(51) Katie: But [the ground] doesn't have any… it can't move so…
(52) Sasha: Does it do this? Like does, could it go like this a little bit? [puts fingertips on whiteboard and wiggles them]
(53) Kevin: Yeah, probably yeah. If it was heavy.
(54) Katie: [lifts corner of whiteboard off the rug, drops the pompom onto the whiteboard, looks and feels to see if whiteboard moves] It [pompom] doesn't do anything even when you lift this [whiteboard] up.
(55) Sasha: I don't think there's enough energy in it.
(56) Katie: maybe there's not enough energy in the pompom to give to something else where you'll be able to see it.

In this exchange, we see the children trying out a variety of productive ideas. They consider the possibility that the energy goes into the air (ll. 19–23), but they're not sure whether air can "hold" or "take" energy. (ll. 30–32) They wonder if it goes back to the springboard, but reject that idea because the pompom doesn't hit the springboard (ll. 46–47). They suggest that the energy is transferred to the ground (ll. 48–50), and, realizing that the ground isn't going to move, devise and try an experiment of dropping the pompom onto the corner of their whiteboard to see if they can see or feel the whiteboard move or vibrate (ll. 52–54). Like the teachers described by Daane *et al.,* they seem to expect a perceptible indicator of the "lost" energy,[5] and are puzzled by their inability to find one. Kevin suggests, repeatedly, that the energy could spread out ("fade" or "disperse") so much as to be imperceptible (ll. 19, 22, and 43), but the other students do not pick up on that idea. They do, however, arrive at the important possibility that, because the pompom is so light and has so little energy, perhaps the motion of the ground is imperceptible (ll. 55 and 56).

These students do not arrive at an answer, let alone the scientifically canonical answer, to the question of where the energy goes "when everything is still." But they do consider several ideas that are essential to an understanding of dissipation: that the energy can go to more than one place; that it can spread out, disperse, or fade; and that it could be present but imperceptible. Equally significantly, moreover, these students take seriously the task of reasoning about where the energy has gone. Prompted by their teacher, they treat it as a legitimate question that could and perhaps should have an answer. In the process, they engage in the beginnings of multiple scientific practices, including asking questions, constructing explanations, arguing from evidence, and designing and carrying out an investigation.[18] Throughout the curriculum they have opportunities to engage fluently in multiple practices of science as they build and use their developing model of energy.[15]

They have not been taught—and in this curriculum are not taught—energy conservation as a principle, and they do not invoke it explicitly. Nevertheless, their discussion shows that their reasoning is at least tentatively using a conservation-based stance. The loss of energy from the pompom leads to the question of where there might have been an energy gain, and they find that idea sufficiently compelling and intriguing that they actively engage, over a period of several minutes, and without any additional prompting from their teacher, in a process of scientific inquiry to try to answer it.

Adult learners wrestle with many of the same issues, as described by Daane *et al.*[5] and by Seeley *et al.*[19] In the following exchange, from one of the Focus on Energy professional development workshops, two teachers, Ellen and Samantha, are discussing how to represent the same springboard/pompom scenario. They are using Energy Cubes—an abstract, semiquantitative representational scheme that is central to the curriculum and that the teachers and students learn to use fluently to reason about and communicate the flow of energy in any scenario. Units of energy are represented by small cubes similar to dice. Sides of the cubes are marked to represent different energy forms. The students or teachers draw circles to represent different objects, and it is their decision which objects to include—in particular, whether to include something like "air" or "environment" as part of the energy story. Energy flow is tracked by moving cubes between circles to represent energy transfer and flipping the cubes to represent energy transformation. Since the number of cubes is fixed, the idea of conservation is implicitly built into the representation.[15,19,20]

(1) Samantha:… We are noticing we have still some energy here (moving the 3 cubes from springboard circle and 2 cubes from pompom circle into a circle labeled "Abyss").
(2) Ellen: After that last instant when everything is at rest (moves the last cube from the pompom circle to the Abyss circle.)
(3) Samantha: And we turned them sideways (no label facing up) because we don't know exactly what kind of energy it is.
(4) Ellen: We observe no movement and there is nothing that is bent or stretched or deformed, so we have exhausted our list of energy indicators.

A similar idea is exhibited in Fig. 2, which shows two teachers' energy cube representation of energy flow in a rubber-band-driven propeller, visible at the top of the image. They have labeled the final destination of the energy as simply "out there," and, like Ellen and Samantha, have flipped the cubes to show a blank face, indicating that the form of the energy is unknown.

As with the fifth-grade students in the first example, the Energy Tracking Lens and the Energy Cubes representation have helped lead these teachers to take seriously the idea that even when all perceptible motion has stopped, the energy must be *somewhere* and in *some form*, even if, as their wry humor suggests, they don't know where or in what form.

This commitment, built into the Energy Tracking Lens, that energy cannot be lost in one place without being gained somewhere else, is also evident in some student responses to the "Cookie Energy" probe, which asks where the thermal energy of hot cookies goes when they cool off. This probe was administered as a formative assessment about 2/3 of the way through the curriculum—after a series of activities involving the transfer of thermal energy. The class's model of energy has become increasingly rich and detailed, and

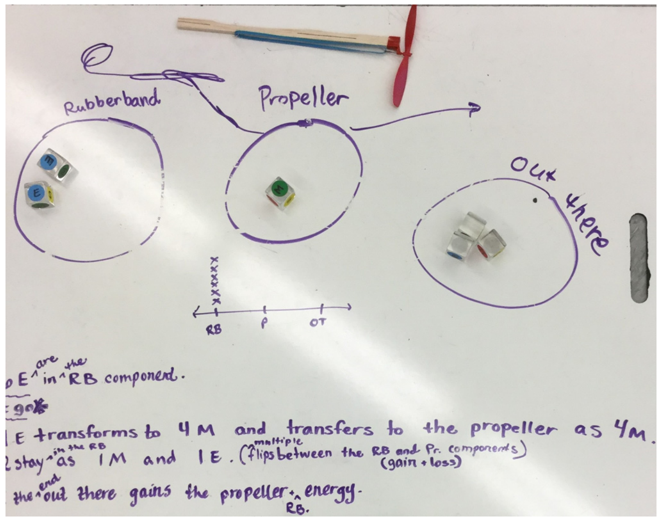
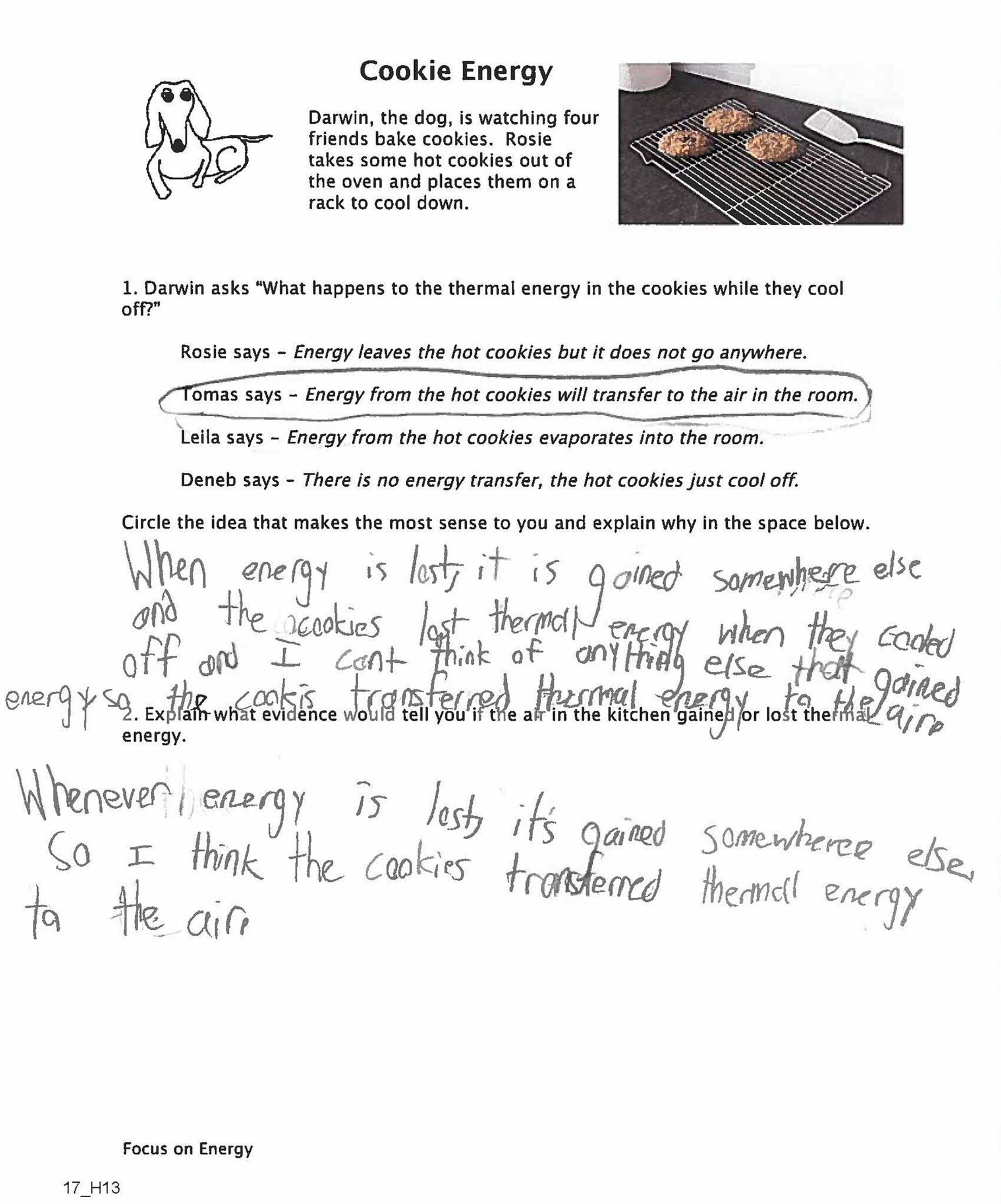


Fig. 2. Representation of energy flow for a rubber-band driven propeller, generated by teachers in a Focus on Energy workshop. In the end, the energy winds up "out there," with the cubes turned with a blank side up, indicating an unknown form of energy.

they have become more confident in reasoning with the idea that energy is never lost—although this has still not been presented to them as a fact or law.

Figure 3 shows the work of one student, who explicitly invoked the rule that "When energy is lost, it is gained somewhere else" to conclude that the cookies' thermal energy must have gone into the air. Others relied on the idea that the energy lost by the cookies has to go somewhere, with one student writing: "The energy from the cookies goes to the air—because, hey! Where else will it go!?" Among 130 papers from seven classes, 95% of students selected the correct choice, provided by Tomas, with about 40% offering either the "loss implies gain" or the "energy must go somewhere" argument. (Most of the remaining students didn't offer any meaningful explanation, usually just repeating their choice of answer.) At this point in the curriculum, many students are comfortable inferring that the energy must have gone somewhere, and concluding that it must have gone into the air, even in the absence of a perceptible change in air temperature.

Interestingly, when it is mechanical energy that is dissipated into the environment, students, and the elementary-school teachers in our workshops, often invoke the idea of dissipation—as in Kevin's suggestion that "the energy disperses into the air and slowly fades,"—but they rarely invoke the idea of thermal energy, which from a physicist's point of view is a key component of dissipation. They are more likely to describe it as "unknown," or as motion that has spread out so much that it is no longer detectable. The springboard/pompom and rubber-band propeller examples given above come from a point in the curriculum at which thermal energy had not yet been introduced. But even after completing the thermal energy unit, students who clearly indicate that mechanical energy is dissipated into the air still usually designate that energy as "motion" or "unknown." Several of the activities involve a propeller that produces an easily felt "wind" when it's spinning, and some students reason that far from the propeller, and even after it's stopped, that wind is still blowing, but is just too faint to detect. At this grade level, these students have not yet studied an atomic/molecular model of matter, so they



Cookie Energy

Darwin, the dog, is watching four friends bake cookies. Rosie takes some hot cookies out of the oven and places them on a rack to cool down.

1. Darwin asks "What happens to the thermal energy in the cookies while they cool off?"

Rosie says – *Energy leaves the hot cookies but it does not go anywhere.*

Tomas says – *Energy from the hot cookies will transfer to the air in the room.*

Leila says – *Energy from the hot cookies evaporates into the room.*

Deneb says – *There is no energy transfer, the hot cookies just cool off.*

Circle the idea that makes the most sense to you and explain why in the space below.

When energy is lost, it is gained somewhere else and the cookies lost thermal energy when they cooled off and I cant think of anything else that gained energy so the cookis transferred thermal energy to the air

2. Explain what evidence would tell you if the air in the kitchen gained or lost thermal energy.

Whenever energy is lost it's gained somewhere else, So I think the cookies transferred thermal energy to the air

Focus on Energy

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Fig. 3. One student's response to the "Cookie Energy" probe, invoking the idea of energy gains and losses.

are unlikely to associate thermal energy with random molecular motion. That may make it difficult to conceptualize how motion energy could eventually dissipate into thermal energy.

In contrast, Scherr *et al*. show a number of artifacts, and Daane *et al*. report conversations, from workshops with elementary and secondary-school teachers in which the teachers do explicitly identify the dissipated energy as thermal,[17,20] perhaps because at least some of the participants had stronger scientific backgrounds. In either case, though, the lack of a detailed conceptual model for where the energy goes, in what form, and how it gets there, is not a major obstacle to accepting the essential idea of energy dissipation—that the energy goes *somewhere*, in *some form*.

To assess their progress in reasoning about energy, a pre-post assessment was given to students before and at the end of the curriculum. The two assessments were identical: They were asked to describe the flow and changes of energy in the operation of a wind-up toy (Fig. 4) that moves, wobbles, and makes sounds and sparks.[21] Table II shows some results related to dissipation. Nothing in the assessment explicitly raises the question of what happens to the energy when the toy stops moving, and before instruction essentially no students address that issue in any way. After completion of the Focus on Energy curriculum, 23% of students spontaneously addressed the issue, typically by showing energy being transferred to "air" or "environment" at the end of the scenario. In contrast, only 3% of students in "control" classrooms

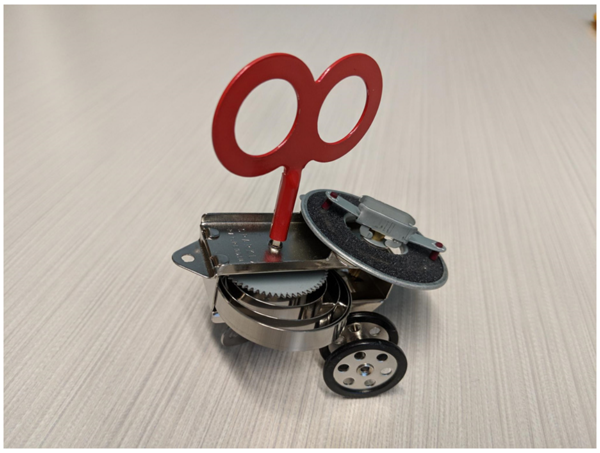

Fig. 4. "Sparklz" wind-up toy used in the assessment.

showed any indication that they thought about energy dissipation as part of the energy story. Control classrooms were in the same school districts as some of the Focus on Energy classrooms, but used standard curricula. Considering that dissipation was not an explicit learning objective of the Focus on Energy curriculum, and that nothing in the assessment asked about or drew attention to the issue, we find it remarkable that nearly a quarter of the Focus on Energy fourth and fifth grade students included it in their tracking of the energy flow for the toy.

Figure 5 shows two examples of work by fourth-grade students who made some reference to dissipation. The one on the left uses the Energy Cubes representation.

Table II also provides evidence for the effectiveness of the Focus on Energy approach for adult learners. It includes results for ten teachers who completed a week-long professional development workshop, in which they experienced the Focus on Energy curriculum as learners, in preparation for teaching it. On the same wind-up-toy assessment, prior to the workshop none of the teachers included dissipation, while at the conclusion of the workshop six of the ten (60%) spontaneously included dissipation in their answers. These results are representative of our general observation, consistent with others', that adult learners and young children frequently exhibit the same conceptual difficulties with energy in general, and dissipation in particular, and benefit from many of the same experiences and instructional approaches.[4,5,17,19]

IV. IMPLICATIONS FOR INSTRUCTION

The Focus on Energy approach reverses the sequence usually adopted in high school and introductory college physics courses. The conventional approach begins with, and typically spends most instructional time on, non-dissipative cases. Dissipation is usually introduced as an unwelcome complication that prevents mechanical energy from being completely constant. We have observed that college students often think that dissipative mechanisms such as friction play only a minor role in the energy story. For example, when a person lowers a heavy object at constant speed many learners recognize that some energy is transformed into thermal energy, but cannot believe that all of it could be.[19]

In contrast, Focus on Energy brings in dissipative phenomena from the very beginning, and the issue of where the energy goes when it's "gone" arises early and often, as a natural part of the overall framework for tracking the transfers and transformations of energy in the process under study. Results with both elementary-school children and adult learners suggest that this approach has promise for helping students overcome a major obstacle to fully accepting the principle of Conservation of Energy as a general physical law rather than as something that applies only in narrow and rather contrived or artificial situations. It could also help reconcile the energy conservation principle with the commonsense view of energy as a consumable commodity that can be "produced," "used," and "wasted," and can be "conserved" only with considerable effort and imperfectly.

By using versatile semiquantitative representations, such as Energy Cubes, this approach also shifts the focus from quantitative calculations in the very limited set of situations where they are possible, to the broader and more important idea of conservation in *all* phenomena. Even in something as simple as the springboard and pompom, it would be difficult to estimate how the energy is partitioned among the air, the ground, the springboard and the pompom—and it isn't important to the main point. In the Energy Cube representation, the precise division of the cubes among the various circles is deemphasized compared to the central requirement that all of the cubes that originally represented the elastic energy of the springboard wind up somewhere.

In common with many others, we note that understanding dissipation is critical to a working understanding of energy. Experience with adult teachers suggests that gaining that understanding is also considerably more difficult for many learners than most conventional teaching strategies acknowledge. Our evidence from the Focus on Energy curriculum, however, shows that students as young as fourth or fifth grade are capable of reasoning productively about dissipation, and of constructing a working model of energy that includes dissipation. Their reasoning is supported by multiple experiences with dissipative phenomena, combined with a consistent analytical framework (the Energy Tracking Lens) and versatile semiquantitative representational tools (Energy Cubes). We suggest that if this approach enables young children and adult teachers to begin to reconcile the superficially conflicting ideas of energy conservation and energy dissipation, then similar approaches are likely to be helpful in enabling high school and college students to

Table II. Percentage of students who, without prompting, included some aspect of dissipation in their analysis of energy flow in a wind-up toy, before and after instruction.

	Control students(standard curriculum)		Focus on energy students		Teachers	
	N	Included dissipation	N	Included dissipation	N	Included dissipation
Pre-instruction	133	0	240	0	10	0
Post-instruction	103	3%	239	23%	10	60%

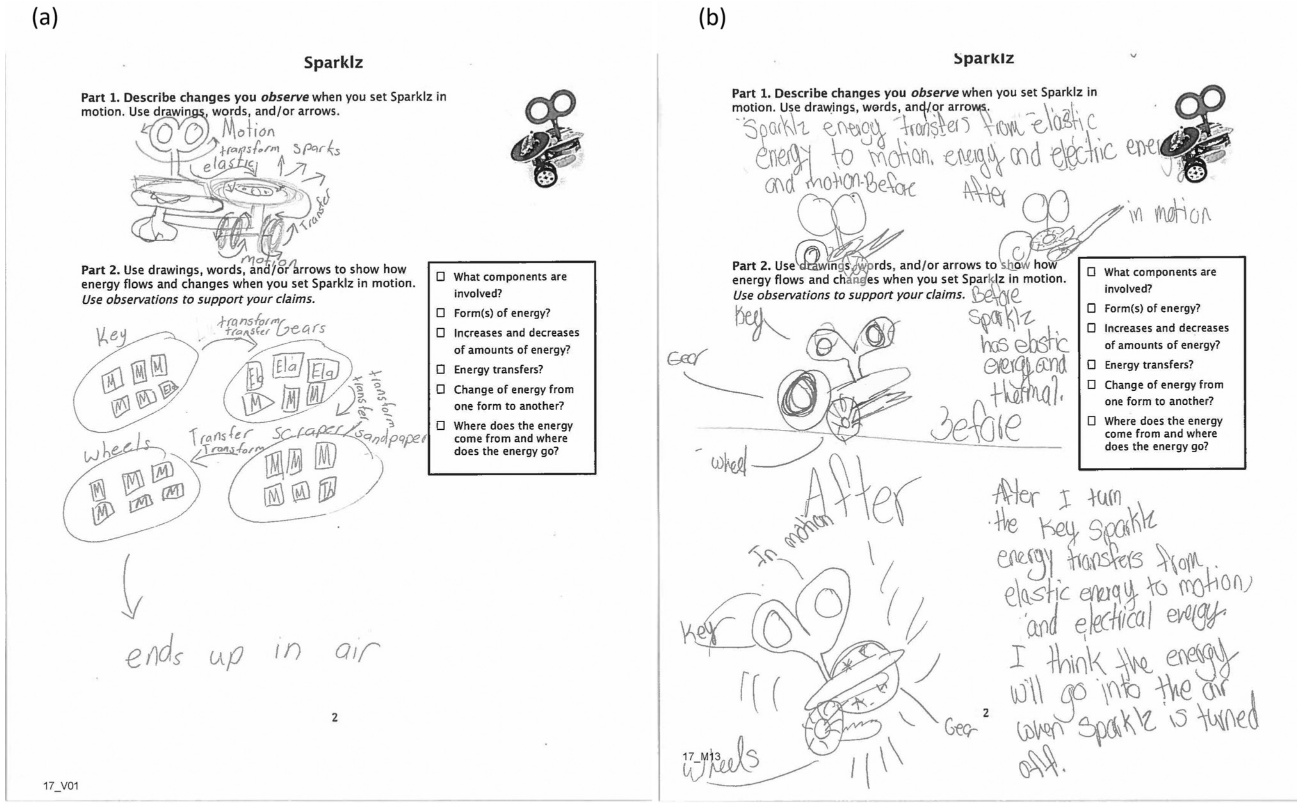

Fig. 5. Sample student assessments showing dissipation into the environment. The diagram in (a) is based on the "Energy Cubes" representation used in the Focus on Energy curriculum, with each square representing a unit of energy and the symbol representing the form (Refs. 15, 19, and 20).

engage productively with dissipation ideas early in their study of energy. We propose that analyzing real-world dissipative phenomena using aspects of the Energy Tracking Lens approach, including the use of semiquantitative representations, could be helpful in a range of high school and college-level classes, including introductory physics, physics for non-scientists, and topical courses treating energy as an environmental, social and policy issue.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation, Grant Nos. 1418052 and 1418211. The authors thank Rayleigh Parker for assistance in scoring the assessments.

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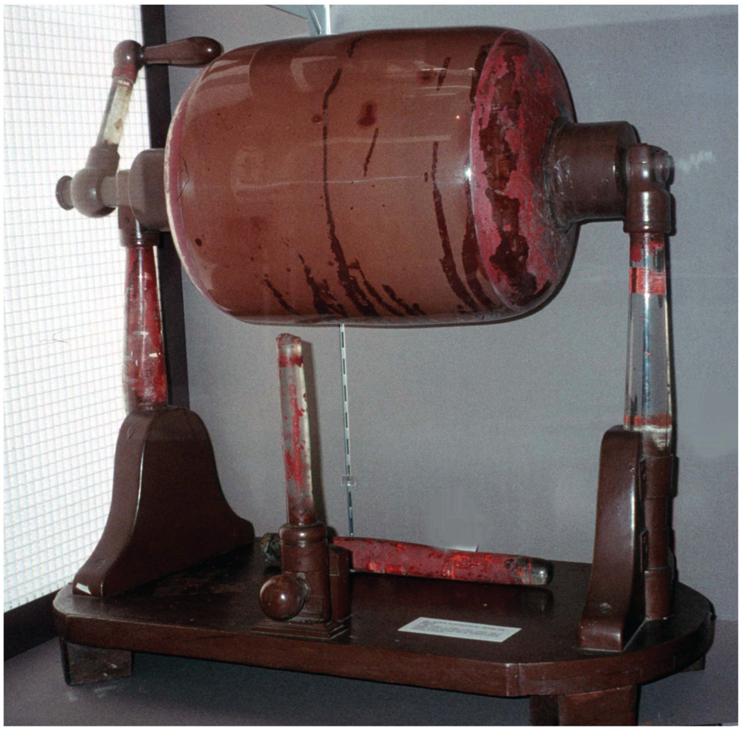

Cylinder Electrostatic Machine

There are three geometrical shapes possible for the production of electricity by rotating glass shapes against a “rubber”: the disk, the sphere and the cylinder. The cylinder type was developed by Edward Nairne (1726-1806). In this example at the Callan Museum at St. Patrick’s College in Maynooth, Ireland, the missing frictional rubber would be placed transversely on the upright glass insulator. This, and other apparatus from Maynooth, is described in Charles Mollan and John Upson, “The Scientific Apparatus of Nicholas Callan and other Historical Instruments” (Samton, Maynooth, 1994). The apparatus was photographed during two visits in 1998 and 1999. (Picture and text by Thomas B. Greenslade, Jr., Kenyon College)