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Lift, Squeeze, Stretch, and Twist: Research-Based Inquiry Physics Experiences (RIPE) of Energy for Kindergartners

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Abstract

This study examines changes in kindergarten students' understanding of energy after participating in a series of lessons developed using an inquiry-based early childhood science teaching model: Research-based Inquiry Physics Experiences (RIPE). The lessons addressed where objects get their energy and what they use their energy to do, and how energy can be "stored" in ordinary objects such as toys. Many of the students moved from associating energy solely with living things to recognizing energy in mechanical processes and articulating how energy can be transferred (stored) by lifting objects or squeezing/stretching/twisting elastic objects.

Introduction

Energy is an important concept that spans all areas of science, but it is also a very difficult concept that even scientists struggle to define, and such definitions (e.g., a bookkeeping device [Feynman, 1995]) are far too abstract to be meaningful to early childhood students. In addition, there are many different important aspects of energy to be grasped (Duit, 1984): the various forms of energy, the transfer of energy between objects (both work and heat), the transformation of energy from one form to another, the conservation of energy, and the degradation of energy over time (the 2nd law of thermodynamics). Unfortunately, both preservice and inservice elementary teachers often have a poor understanding of these ideas about energy (Kruger, 1990; Trumper, 1997; Trumper, Raviolo, & Shnersch, 2000). Thus, it is no surprise that junior high and high school students also have many misconceptions about energy (Driver & Warrington, 1985; Goldring & Osborne, 1994).

Watts (1983) examined 14- to 18-year-old students' ideas about energy and identified several alternative frameworks that students use to understand energy, including human-centered, depository (a source of force), ingredient, obvious activity (motion), product (waste), functional, and flow model (fluid). Other researchers have shown that students' notions about energy are vague and not consistent, and thus, students move among frameworks rather than consistently using a single framework (Gair & Stancliffe, 1988; Lijnse, 1990; Solomon, 1983b). Driver, Squires, Rushworth and Wood-Robinson (1994) suggest a developmental sequence for students' ideas about energy: energeticness of oneself and all living things, spontaneous action and energeticness of nonliving things, stored energy (elastic and gravitational potential energy), energy conservation, and energy degradation. A similar sequence is proposed by Solomon (1982), in which students begin with a notion of liveliness and motion, develop a notion of stored energy, start using quantitative ideas about energy (through work), come to energy conservation, and finally recognize the second law of thermodynamics. Solomon (1985) and other researchers (Duit, 1984; Liu & McKeough, 2005) later argued that an understanding of energy degradation should precede that of energy conservation since students very rarely encounter energy conservation without energy degradation. In addition, it appears that students do not begin to grasp the conservation of energy idea until approximately age 15 (Duit, 1981; Shultz & Coddington, 1981).

An additional complication to teaching energy stems from students holding separate "life-world" and "theoretical" views about energy, where the former is how the concept is usually discussed in our daily lives, and the latter is an abstract idea taught in science class (Lijnse, 1990; Solomon, 1983a). These life-world views "arise from a context which is inappropriate for school science, but which is valid and valuable in their everyday world" (Trumper, 1990, p. 211). The life-world view is more persistent than the theoretical, and students face difficulties understanding energy when they fail to realize the difference between these two worldviews (Solomon, 1993), or revert to the life-world view when faced with a situation requiring the theoretical perspective. The most successful students recognize the difference and are able to apply the appropriate worldview based on the context; that is, they learn to move between these two worldviews "with fluency and discrimination" (Solomon, 1983a, p. 58). Thus, Lijnse (1990) suggests the first step in teaching students about energy is

> starting from the point of thinking and talking about energy at the life-world level in life-world situations. A first selection should then be made, in the sense that pupils' attention is drawn to situations and aspects that are relevant to deal with in the context of physics lessons. In this way the physical life-world is selected from the life-world as a whole. (p. 580)

Similarly, Trumper (1990) suggests that teaching about energy should

> extend pupils' understanding of energy from its human-centred beginnings to a more general notion gradually approaching what is taught at school. . . . This strategy should be presented as early as possible in primary or junior high schools, so that the scientific domain of knowledge concerning the energy concept could be reinforced step by step. (p. 211)

While much research has been conducted on the ideas and misconceptions about physics concepts, such as energy by middle grade and secondary students (Brook & Driver, 1986; Brook & Wells, 1988; Driver, Guesne, & Tiberghien, 1985; Solomon, 1983a, 1983b, 1985; Watts, 1983), little has been reported about the misconceptions and concept development of young children. However, standards documents generally recommend some basic teaching of energy concepts in the early grades. For example, the *National Science Education Standards* (*NSES*) state that, "[K-4 students] cannot understand a complex concept such as energy. Nonetheless, they have intuitive notions of energy—for example, energy is needed to get things done; humans get energy from food. Teachers can build on the intuitive notions of students without requiring them to memorize technical definitions" (National Research Council [NRC], 1996, p. 126). Along these lines, Project 2061 suggests that "[b]y the end of second grade, students should be familiar with a variety of ways of making things go and should consider ‘What makes it go?’ to be an interesting question to ask” (American Association for the Advancement of Science [AAAS], 1993, p. 83). The Academic Science Content standards for the state in which our study took place, Ohio, expect that students will have explored how energy makes things work and have learned how energy can be obtained from many sources in many ways by the end of the first grade (Ohio Department of Education, 2002).

In this study, we examine how kindergarten students’ conceptions of energy changed due to a series of inquiry-based lessons. In developing this study, we followed recommendations in the literature, starting from personal experiences and having students begin young with simple real-life experiences with energy (Lijnse, 1990; Trumper, 1990). In previous studies (Van Hook, Huziak, & Nowak, 2005; Van Hook & Huziak-Clark, 2007b), kindergarten students were able to develop a basic conception of physics concepts (e.g., air and magnetism) when taught with inquiry-based lessons that combine hands-on activities with class discussion, a simple conceptual model, succinct phrases (cognitive hooks) that capture key concepts, and reinforcement through multisensory activities. These elements of RIPE aid student learning when dealing with abstract concepts and new scientific vocabulary. This study of the early childhood RIPE model examines the effect of a set of lessons that provided kindergarten students with a range of experiences to help them begin to develop an understanding of energy.

We used the conceptual hook “lift, squeeze, stretch, and twist” in this study to describe how one can store gravitational potential energy[1] (lift) or elastic potential energy (squeeze, stretch, and twist) in an object. Technical terms, such as *potential energy* or *kinetic energy*, were not used in the lessons since our goal was to give the students a vocabulary that would be meaningful to them, not an abstract scientific vocabulary. To begin students’ development of their ideas of energy, we selected just a few specific aspects of energy that we felt were within reach of kindergarten students and which could be applicable to the students’ lives—for example, where the students themselves get their energy and how they use it, and where everyday objects (e.g., a flashlight, a mechanical toy) get their energy and how they use it.

Several forms of energy were discussed in the lessons (e.g., gravitational potential energy, energy in food and gasoline, and electricity), but elastic potential energy was the primary focus of the lessons. We felt that this form of energy would be the most concrete for students. For example, it is used in many toys so it connects to the students’ lives, it can be demonstrated with many objects at hand (e.g., rubber band, paperclip), and it is possible to see what is happening to the object (e.g., see the spring compressed or the rubber band stretched). In addition, we were partially inspired by a criticism physicist Richard Feynman made about how a textbook explained energy (Feynman & Leighton, 1985, pp. 297-298). The textbook showed a variety of situations (e.g., a wind-up toy, a boy on a bike) and for each situation, the textbook stated only that “energy makes things go” without any description of the physical mechanisms involved. Feynman objected that,

> For everything [the textbook explained], “Energy makes it go.” Now that doesn’t mean anything. There’s no knowledge coming in. The child doesn’t learn anything; it’s just a word. . . . What they should have done is to look at the wind-up toy, see that there are springs inside, learn about springs, learn about wheels, and never mind “energy.” (pp. 297-298)

With Feynman’s insight in mind, we focused on elastic objects and were careful to focus on the physical mechanisms involved in storing or releasing energy.

Research Study Methodology

The following questions were used to guide the lesson development and the research interview protocols:

1. To what extent were students better able to identify where objects (including people) get their energy?
2. To what extent were students better able to distinguish between where objects get their energy and how they use their energy?
3. To what extent did the students adopt and then use this cognitive hook of storing energy in an object through "lift, squeeze, stretch, and twist"?

The focus of this study was two kindergarten classrooms in a rural Midwestern college town. The classroom teachers both had at least 20 years of teaching experience and well-established classroom management and routines. The kindergarten had a half-day program, so class sizes were small, approximately 16 students. Several students stayed for both the morning and the afternoon classes for extra enrichment. There were 49 students participating in this study, split almost evenly between females and males. This school building contains approximately 20% minority students and 25% economically disadvantaged students.

As part of this study, a scientist from the university (hereafter referred to as "the scientist") visited each of the four classes once or twice a week to present a science lesson (described in the next section). The scientist had visited the classroom for several years due to an interest in science education. Three additional researchers conducted audiotaped pre- and post-lesson interviews using a semi-structured interview protocol. Before the lessons, 20 students, selected at random, were interviewed individually to ascertain what their prior knowledge about energy was. Several weeks after the lessons, 45 students were interviewed with an expanded interview protocol (see Appendix A). Once this data was collected, the audiotapes were transcribed and analyzed from the grounded theory perspective (Erickson, 1986). From iterative readings of the responses of the students, initial codes for the general underlying pattern were developed, and the codes were subsumed under broad categories. These categories were used in further iterations of data readings by each of the researchers. Once all parties agreed to the codes, assertions were formulated and analyzed. For example, one specific theme that was common from all of the students was the use of the phrase "lift, squeeze, stretch, and twist" when describing how to store energy in a toy. This became a code through which we analyzed student responses to better understand how and why the students were using this phrase similarly and differently. A similar process was used for all of our agreed-upon codes.

Students' Initial Ideas About Energy

The literature on young children's understanding of energy is rare and vague. The AAAS (1993) in their *Benchmarks for Scientific Literacy* suggests that students' ideas about energy differ from their scientific definitions: "Students believe energy is associated only with humans or movement, is a fuel-like quantity which is used up, or is something that makes things happen and is expended in the process" (p. 338). Working with kindergarten students, we found this to be true in the pre-interviews to an extent. Slightly more than half of the students were unable to find words to define energy and commented that they did not know. However, less than half of the students were able to identify energy as something that had to do with the human body—that is, making the body strong, helping the body to move, or that it came from food.

According to Black and Solomon (as cited in AAAS, 1993), "upper elementary-school students tend to associate energy only with living things, in particular with growing, fitness, exercise, and food" (p. 338). These same concepts were clear themes in the kindergarteners' answers to the previous question and others that were asked of the students. To gain a clearer picture of what the students really understood about energy, a series of questions about energy was asked. Over half of the students responded like Carrie with a series of "I don't know"s. As this was before the lessons, these types of responses are typical for many very young children. The students who did provide answers associated their energy with motion or movement, such as running or playing. Christopher uses several of these motion examples to answer the questions. The ability to state where this energy came from was less common—for example, from food or other substances, as was mentioned by Jason when he referred to cereal and even the fruit he eats at soccer games. Note that many of the responses are simple and typically one-word responses. These responses are pre-interviews, and none of the students have had formal lessons on the topic of energy, so they may not possess the vocabulary to communicate their understanding.

Instructor (I): What is energy?
Student (S): I don't know.
I: What is energy used for?
S: Don't know.
I: Where do you get your energy?
S: Don't know.
I: What are some things that you need energy to do?
S: I don't know. (Carrie)

I: What is energy?
S: Walking.
I: What is energy used for?
S: Play.
I: Where do you get your energy?
S: You don't.
I: What are some things that you need energy to do?
S: Play. (Christopher)

I: What is energy?
S: I don't know.
I: What is energy used for?
S: Running, skipping, and jumping.
I: Where do you get your energy?
S: From some cereal; fruit.
I: What are some things you do that you need energy for?
S: To eat fruit; soccer games. (Jason)

When students were asked if they could think of other things that needed energy, they typically referred to people or, in a few instances, pets at home or all living things such as described by Black and Solomon (as cited in AAAS, 1993). This "human-centered" energy framework (Watts, 1983) is associated with the most basic level of the developmental sequences discussed earlier in this report. Only two students listed inanimate objects, such as cars, as things needing energy.

When students were shown several different toys and a flashlight and asked if the objects had energy or how the object got its energy, most of the students were unable to articulate correct answers. This is to be expected based on the students limited prior experience and knowledge of how things work. Some students did not associate energy with nonliving things. For example, when asked if a particular toy had energy, Britney responded, "No. Because it's a toy." About one-fourth of the students were able to cite batteries as the source of energy to make the flashlight work, while several others referred to the on/off switch as the energy source for the flashlight.

Summary of Lessons

Five half-hour-long lessons addressing the physics of energy were developed and taught by the scientist to students in four kindergarten classes. This was the sixth year that the scientist had taught lessons at this school, and most of the lessons used in this study had been taught and continually improved over several years. The lessons included kinesthetic activities (e.g., pretending to be compressed springs), hands-on activities (e.g., examining a toy to see the spring inside it, making "paperclip hoppers"), class discussion, demonstrations, and songs about energy. The lessons were structured around the 5E model: Engage, Explore, Explain, Extend, and Evaluate (Bybee, 1997).

In the first lesson, the students explore energy by examining a flashlight and several toys (e.g., wind-up, pull-back, and pop-up toys) to figure out where they get their energy and what they use their energy to do. The key idea in this lesson, emphasized in the class discussion and explanation, was to distinguish between where something gets its energy and how it uses its energy (e.g., food and running for a person). This concept was then extended by discussing where a car, a plant, people, and a television get their energy. The lesson ended with a song about where things get their energy—a song that was used to start most of the rest of the lessons.

In the second lesson, additional toys and objects (e.g., pop-up toys, rubber bands, an airplane with a rubber-band-driven propeller, etc.) were used to show how one can store elastic potential energy in a flexible object by compressing, stretching, or twisting it. The key phrase, "squeeze, stretch, and twist," was introduced and emphasized throughout the lesson, with corresponding hand motions. The third lesson looked at how the concepts of "squeeze, stretch, and twist" explained how many toys work. For example, several toys were disassembled and shown to have springs or rubber bands inside that were squeezed, stretched, or twisted to give the toy energy. The fourth lesson introduced another way to give energy to an object—lifting it (i.e., gravitational potential energy). To aid in making the connection between both elastic and gravitational potential energy more concrete, one activity consisted of showing how the energy stored in a pop-up toy or a lifted object could be used to light a small light bulb. In addition, a second energy song about the concepts "lift," "squeeze," "stretch," and "twist" was introduced to reinforce this key idea from the lessons. In the final lesson, the students examined more objects (e.g., slap bracelets, clip board, clothespin) that illustrate elastic potential energy, and they made paperclip hoppers consisting of a bent paperclip with a paper covering for safety, which they were allowed to decorate. (For more details of the lessons, see Van Hook and Huziak-Clark, 2007a.)

Students' Ideas About Energy After the Lessons

After participating in the lessons described earlier, the students were asked about their ideas about energy. Several main themes emerged from the data. First, students generally understood the difference between where they get their energy from and how they use their energy. Second, students were able to understand and cite examples of other living things (other than humans) and inanimate objects that use energy. Third, they were able to use specific examples of nonliving objects and determine where their energy is from and how they use their energy. Fourth, students were able to explain the different ways that they can put energy in an object such as lifting it or squeezing/stretching/twisting it. Fifth, students recognized springs and other elastic objects as mechanisms in devices they use.

Students Ideas about Energy—Its Sources and Its Uses

Prior to the lessons, less than half of the students were able to state where their energy came from and how they used that energy. Most students were able to do so after the lessons. The following examples document this ability:

I: What is energy?
S: It's stuff that when you eat you get energy.
I: What is it used for?
S: To give you energy.
I: Where do you get your energy?
S: From food.
I: What are some things you do for which you need energy?
S: Run and get exercise. (Selena)

I: What is energy?
S: Something that helps someone or something do something.
I: What is energy used for?
S: Moving yourselves. I don't know what else.
I: Where do you get your energy?
S: Food. Water.
I: What are some things you do for which you need energy?
S: Move around. Do stuff; chores. (Ashley)

The students now have a better understanding of where they get their energy and how they use their energy. Also, note that while the definitions of energy are not exactly scientific, the students are referencing the gaining or using of energy in their definitions, and Ashley's definition hints of an "ability to do work" definition used in many textbooks. In the pre-interviews, most students did not even attempt an explanation. In the post-interviews, most of the students were citing both the sources of energy and the action associated with the output of the energy source. Most students began to combine the requirements for energy sources in order to be able to do something or go somewhere.

Students' Ability to Cite Inanimate Objects

One of the main ideas from the literature (e.g., Driver et al., 1994) is that young children attribute energy only to living organisms. That is, an object needs to be able to grow or move to be considered to have energy. This held true for most of these students during the pre-lesson interviews. In the post-interviews, however, almost half of the students were able to name other nonliving examples of objects that needed energy that were never discussed during class lessons. The following examples show the students use of inanimate objects to show their understanding of energy, how an object gets its energy, and how it uses its energy:

I: Can you think of something that needs energy?
S: Toys. Yourself needs energy—like doing push-ups. I can do 70-hundred.
I: Where does that energy come from?
S: Food, winding, and batteries.
I: Could you tell me how some other object gets and uses its energy?
S: Like a videotape, like an audio-recorder tape, like a TV gets one from electricity. (Travis)

I: Can you think of something that needs energy?
S: Airplanes.
I: Where does that energy come from?
S: Gas. (Lorne)

In addition to inanimate objects, the students were also able to apply their energy knowledge to other living things not mentioned in class. For example, the following student was able to talk about a bunny and another was able to cite a bird:

I: Can you think of something that needs energy?
S: A bunny.
I: Where does that energy come from?
S: Carrots. (Jackie)

I: Can you think of something that needs energy?
S: Animals.
I: Where does that energy come from?
S: Worms and stuff for birds. (Eve)

Students' Ability to Differentiate Sources and Uses of Energy (Flashlights)

The unit engagement consisted of having the class figure out why a flashlight was not working. Student ideas included "no batteries," "dead batteries," and "it only works in the dark." This activity led to a discussion of why a flashlight needs batteries—that is, what it gets from the batteries. A key point in this discussion was to distinguish between where the flashlight gets its energy (batteries) and how it uses that energy (to make light). In the remaining lessons, the flashlight was given as one of the two examples of this distinction (the other was the children themselves).

In the post-interviews, the students were asked several questions about flashlights; in addition, the flashlight example sometimes appeared in students' responses to more general questions (e.g., "Can you think of something that needs energy?"). Most students were able to correctly state how the flashlight got its energy and what it used its energy to do. The following quotations highlight typical kindergarten responses:

I: Where does this flashlight get its energy?
S: From batteries.
I: What does it use its energy to do?
S: Make light. (Richard)

I: Here, take this flashlight. Tell me about how this flashlight uses energy.
S: [flips the switch to turn it on]
I: Okay, you flipped the switch and what happens?
S: It turned on.
I: Where does this flashlight get its energy?
S: From batteries.
I: What does it use its energy to do?
S: Light up. (David)

However, a few students still had difficulty distinguishing between something required for the flashlight to work and the source of its energy. For example this student was clear on what the flashlight used its energy to do, but included both the light bulb and batteries for the flashlight's source of energy:

I: Does the flashlight have energy?
S: Yes.
I: Where does this flashlight get its energy?
S: Light bulb and battery.
I: What does it use its energy to do?
S: Light [while turning it on and off]. (Michael)

Students' Use of "Lift," "Squeeze," "Stretch," and "Twist" Concepts

The lessons employed the phrase "lift, squeeze, stretch, and twist" as a cognitive hook for remembering different ways the students could give energy to objects (usually toys). A song with hand motions employing the phrase—for example, "Lift, squeeze, stretch, and twist!/Wind those springs with a twist of your wrist"—was used throughout the lessons (Van Hook & Huziak-Clark, 2007a). The students used the vocabulary from this phrase throughout their discussions in the lessons and during the post-interviews:

I: What is energy?
S: Energy is you can squeeze, you can stretch, you can pull, you can twist, you can lift. (Bob)

I: What are some things you do for which you need energy?
S: Lift, squeeze, stretch, and twist.
I: Can you think of something that needs energy?
S: Like a ball that you can lift and bounce.
I: Where does that energy come from?
S: By you pulling it up and letting it drop. (Kyle)

The students were asked about storing energy in several objects (e.g., a spring, a rubber band, a paperclip hopper, and a plastic ruler). The following examples illustrate how the students apply this vocabulary to articulating how to transfer energy to these objects:

I: [Shows spring to student] Do you know what this is?
S: A spring.
I: What are some ways that you can give it energy?
S: By twisting it; squeezing it.
I: [Shows rubber band to student] What are some ways that you can give this energy?
S: Stretching it, twisting it, flexing it—make it shoot.
I: [Shows paperclip hopper] Do you remember this toy?
S: You push it down to make it jump. I've seen it before. I got one but it broke.
I: Can you show me how to give it energy?
S: Like that. [Pushes down on toy]
I: Can you tell me in words what you did to give this energy?
S: Pushing my finger down on it.
I: [Shows plastic ruler] Can you give something like this energy?
S: Yes.
I: How?
S: Bend it, stretch it, and flex it. (Jason)

I: [Shows a spring] What are some ways that you can give it energy?
S: Push it down, squeeze it, and it pops up. You put your finger on the end and it pops.
I: [Shows a rubber band] What are some ways that you can give this energy?
S: Stretch it; pull it. (Katherine)

I: [Shows paperclip hopper] Can you show me how to give it energy?
S: [flipping noise]
I: Can you tell me in words what you did to give this energy?
S: Squeeze; bend.
I: [Shows plastic ruler] Can you give something like this energy?
S: Bend it; squeeze it. (Robert)

The students are consistently using the vocabulary from the cognitive hook to explain a variety of situations. They even employ new words to convey the same ideas ("bend," "flex," and "pull"), showing that they are not just parroting words from the lessons without understanding their meaning. This ability to explain using their own words is important to document that students are doing more than just memorizing new words.

In the interviews, students were asked to discuss how they can give energy to two different toys: (1) a plastic bunny that hops when a student presses down on it and then lets go (this was also used in the lessons), and (2) a wind-up robot toy with an obvious key, as well as visible gears and a coil spring wrapped around the gears. In the pre-interviews, most students were able to figure out how to put energy into the robot by winding it up, but fewer students were able to figure out how to put energy into the plastic bunny. In the post-interviews, all students were able to put energy into both. In addition, students better articulated what they were doing, employing the "twisting" language from the cognitive hook:

I: Does this one [the robot] have energy?
S: Yes. Because you twist it up.
I: You twist the handle?
S: Yea. It'll go—there it goes! (Selena)

Some students still had difficulty consistently distinguishing between how the toys got their energy and what they used their energy to do. For example, this student is confused about the first toy discussed (she associated hopping with getting energy not using energy), but she is correct about the second toy:

I: Does this have energy?
S: Yes. It gets its energy from hopping. [Student is making the toy hop.]
I: What just happened?
S: It hopped. I pushed it.
I: You pushed on its ears and it hopped. Where is energy stored in that toy?
S: From hopping.
I: It's stored from hopping? Tell me about this toy [robot]. Does this have energy?
S: [Winds up the robot] Yes. It gets its energy from twisting that. (Melissa)

Students' Recognition of Springs as Mechanism in Objects

As the lessons progressed, the students were better able to identify objects that use elastic potential energy. For example, at the beginning of the lessons, many of the students believed that the mechanical toys used in the first lesson got their energy from batteries. After a couple of lessons, however, most of the students predicted that new objects introduced in the lessons probably had springs or spring-like objects in them. For example, a clipboard used in one lesson was an unexpectedly engaging example of elastic energy to the students. The following representative segments of post-interviews illustrate how the students recognize springs or spring-like behavior in objects, none of which has the spring visible (the Pez® dispenser was used in the third lesson, while the toy airplane was not used in the lessons):

I: [Shows Pez® dispenser] Tell me about this toy. Can you give it energy?
S: Yea.
I: Can you tell me how you give it energy?
S: Stretching it.
I: What inside this toy stores the energy?
S: Spring.
I: Good job! [Shows toy airplane] What do you think is in here to store energy?
S: A spring. (Greg)

I: [Shows a Pez® dispenser] Tell me about this toy. Can you give it energy?
S: You stretch it, turn it, turn the head. You can leave it like that.
I: What inside this toy stores the energy?
S: It stores candy right here.
I: What stores the energy inside there? What holds the energy in there?
S: I think it must [be] the springs in there. Stretch it and it squooshes.
I: [Shows toy airplane] What do you think is in here to store energy?
S: Squish the spring and it makes it go up. (Sascha)

The students have begun to recognize the important role that elastic objects play in the physical mechanisms of many devices in their lives. Note how the students use terms such as *stretch* and *squeeze* (or *squish*) in their discussions of energy in these objects.

Conclusions

The concrete experiences combined with class discussions and multiple reinforcements provided by the lessons helped the students gain a greater understanding of energy. In particular, having several experiences with nonliving objects in the lessons helped these students recognize that energy is a concept that extends beyond living systems—that energy relates to a Pez® dispenser as well as to them. In addition, the students were better able to distinguish between where an object gets its energy and how it uses its energy. The students were also given a cognitive phrase (with hand motions) to use to remember how they can give energy to many kinds of objects, and the students were beginning to use these ideas. Within the developmental sequences of Driver et al. (1994) and Solomon (1982), most of the students started at the lowest "energeticness of oneself" level, moved through the level of also associating energy with the action of nonliving things, and finally to recognizing how energy can be stored by lifting, squeezing, stretching, or twisting the objects. These gains are important to recognize in young children. While the learning can be considered basic, it is important that educators remember the potential that students have—even at very young ages—for learning and that we should not assume that energy of any nature should be avoided. Rather, we concentrate on what can be obtained and build from these scaffolds as a child grows.

Implications for Teaching, Learning, and Future Research

Each of these conclusions leads to some important implications for teaching and learning science in the early grades. First, kindergarten students are capable of developing a basic understanding of energy if they are provided with hands-on experiences that relate to their own lives. In particular, they can make critical distinctions about energy (e.g., source of energy and use of energy), and thus employ higher-order skills in Bloom's taxonomy. They can learn to apply energy to nonliving things, to recognize that energy is stored in nonliving things, and to articulate a mechanism for how energy is stored in the object (e.g., spring compressed).

Second, these conclusions suggest that the RIPE early childhood instructional model (developed by the authors) can be effective in teaching physics concepts to early childhood students. The RIPE model includes inquiry-based activities; learning cycle approach to instruction; multisensory activities such as kinesthetic movements, songs, and key concepts; and cognitive hooks to help students remember and apply knowledge. Key to this model is identifying a small set of core concepts and focusing intensely on them rather than trying to address many concepts in a unit. In addition, the concept is phrased in a manner that is as simple and concrete as possible and that is continually reinforced through brief phrases expressing interactions (not simply vocabulary words) that help students articulate scientific notions about a wide variety of experiences. These cognitive hooks, such as "lift," "squeeze," "stretch," and "twist," capture key scientific principles and yet are meaningful to students. The 5E model provides a powerful overall structure to the lessons, engaging students, allowing them to explore the concept, explaining the scientific concept, extending and reinforcing the concept, and evaluating the students' understanding throughout. In the RIPE model, it is critical that the explanation of the scientific concept develops from a class discussion of the students' ideas and observations, and does not devolve into a lecture about the concept by the teacher. Finally, several multisensory activities are incorporated in the lessons—for example, kinesthetic activities, songs, jokes, drawing, and writing. It is clear that given the right opportunities, even kindergartners can begin to develop scientific ideas. This instructional model suggests ways for early childhood teachers to provide these opportunities to their students. Future research includes helping K-3 teachers learn how to use the RIPE model to design and teach physical science units effectively for student understanding.

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Endnote

1 Strictly speaking, gravitational potential energy is not a property of an object (e.g., a book) but rather of a system (e.g., the book-earth system). This distinction was intentionally not addressed since it is not an age-appropriate concept for kindergarten students.

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Appendix A. Energy Interview Protocol

1. What is energy?

2. Where do you get your energy?

3. What are some things you do for which you need energy?

4. A) Can you think of something that needs energy?
   B) Where does that energy come from?

5. Hand the student a spring. What are some ways that you can give it energy?

6. Hand the student a rubber band. What are some ways that you can give this energy?

7. Show a paperclip hopper. Do you remember this toy? Can you show me how to give it energy? Can you tell me in words what you did to give this energy?

8. Hand the student a plastic ruler. Can you give something like this energy? If so, how?

9. Show a Pez® dispenser. Tell me about this toy. Can you give it energy? What inside this toy stores the energy?

10. Show a toy airplane (one that is powered by pushing down on it). What do you think is in here to store energy? What do you think we have to do to it to give it energy?

11. Can you tell me about how any of your toys at home get energy? What do they use that energy to do?

12. A) Show a frog toy. Does this have energy?
    B) How can you give energy to this toy?
    C) [If they answer A or B]: How or where is energy stored in this toy?

13. A) Show a wind-up toy (not wound up). Does this have energy?
    B) How can you give energy to this toy?
    C) [If they answer A or B]: How or where is energy stored in this toy?

14. A) Does light have energy?
    B) (If answers yes): How do you know?
    C) (If answers yes to A): What is something that uses the energy in light?

15. A) Show the student a flashlight. Tell me about how this flashlight uses energy.
    B) Where does this flashlight get its energy?
    C) What does it use its energy to do?

Questions 5-11 were used only in the post-lesson interviews.

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