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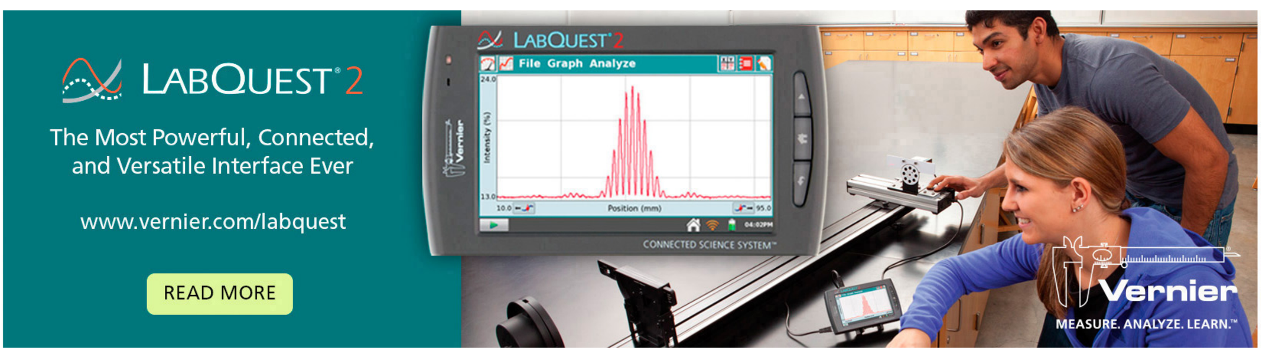

Energy Theater

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Energy Theater is a dynamic, full-body activity that engages all students in representing the flow of energy in various phenomena, such as a light bulb burning steadily or a refrigerator cooling food.[1,2] In Energy Theater, each participant acts as a unit of energy that has one form at a time. Regions on the floor correspond to objects in a physical scenario, and participants move from one region to another to demonstrate the flow of energy among objects. (See Figs. 1, 3, and 4.) The goal of Energy Theater is for students to track energy transfers and transformations in real-world energy scenarios while employing the principle of energy conservation and disambiguating matter and energy. Unlike most representations of energy, which are static before-and-after accounting schemes for energy changes, Energy Theater is a dynamic representation that provides a natural stepping stone toward the more advanced ideas of energy density, energy current, and a continuity equation relating them. The fact that conservation of energy is embedded in the representation encourages students to "find the energy" in situations where it may be imperceptible. The rules of Energy Theater are listed in Fig. 2.

Learning goals

The Next Generation Science Standards include the following major learning goals for secondary students studying energy[3]:

1. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
2. Changes of energy in a system can be described in terms of energy flows into, out of, and within that system.
3. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
4. Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.

These standards are supported by Energy Theater through its design and application in the classroom. Energy Theater emphasizes energy conservation (goal 1 above) by treating energy as concrete units (people) that neither appear nor disappear during any process. Changes of energy are represented by people who move into, out of, and within the system of objects in the scenario (goal 2). Each person (unit of energy) has a form associated with an observable indicator, such as a hand sign (goal 3). Finally, Energy Theater supports theorizing mechanisms for energy transfers and transformations (goal 4): since Energy Theater represents energy transfers and transformations as visible events, learners are called upon to account for their representation of these events in terms of causal mechanisms. Other representations, such as bar charts, pie charts, and Sankey diagrams, support fewer of these learning goals.[4]

Fig. 1. In this enactment of Energy Theater, high school AP/IB Biology students represent the energy involved when a rabbit hears an apple fall to the ground. Each student is a unit of energy; loops of rope on the floor represent the rabbit, the apple, and the Sun.

Energy Theater Rules

1) Each person is a unit of energy in the scenario.
2) Regions on the floor correspond to objects in the scenario.
3) Each person has one form of energy at a time.
4) Each person indicates his or her form of energy in some way, often with a hand sign (such as a letter) or an iconic movement (such as fanning).
5) People move from one region to another as energy is transferred, and change hand sign as energy changes form.
6) The number of people in a region or making a hand sign corresponds to the quantity of energy in an object or of a particular form, respectively.

Fig. 2. Rules of Energy Theater.[1,2]

Energy Theater supports the "Energy and Matter" Crosscutting Concept in the Next Generation Science Standards in that it can model many physical situations across multiple science disciplines (e.g., roller coasters, electric circuits, phase changes, combustion engines, and photosynthesis) and requires little prior energy instruction. The rules of Energy Theater enforce both the law of conservation of energy and the concepts of energy transfer and transformation implicitly, whether or not students have learned them formally. This flexibility makes Energy Theater appropriate for different student populations at different levels, even in the same scenario.

Energy Theater promotes robust discussions about the nature of energy. The open-ended nature of this activity encourages students to analyze scenarios in detail. Rather than seeking a single "correct" answer, students continually refine their models as new evidence and ideas are contributed. Throughout this process, instructors have multiple opportunities to listen to students' discussions, allowing for targeted feedback and productive learner engagement.

Implementation

Setup: In a typical implementation of Energy Theater, the instructor presents the rules and assigns students to represent a particular scenario, such as someone pushing a box across the floor at a constant speed or a rubber ball bouncing. When introducing Energy Theater, it is useful to have both the scenario and rules posted prominently. We have found that a preliminary demonstration using a small group of students for a simple scenario helps students understand the rules quickly and experience the type of conversation that is expected during their collaboration. Students should be made aware that there are many possible correct representations for a given scenario in Energy Theater.

Energy Theater works best for participants in grades six and higher working in groups of seven to nine students. Groups with fewer than seven members may not have enough energy units to represent the transfers and transformations in many scenarios. Groups with more than nine students tend to have decreased overall participation. When students do Energy Theater, the classroom quickly becomes a noisy, motion-filled collaboration space. If possible, students should be provided with separate spaces in which to work.

Energy Theater can be organized into three stages: Choreography, Performance, and Reflection and Assessment. In the Choreography stage, students work together to represent the energy in a scenario. In the Performance stage, different groups share their ideas by acting out their representation. Finally, students revise and reflect on their representations in the Reflection and Assessment stage.

Choreography: After the introduction of Energy Theater rules and expectations, the Choreography stage usually lasts 20 to 30 minutes. The open-ended nature of Energy Theater encourages rich conversations between students about the details of a given scenario. Often discussions during the Choreography stage focus on a particular detail of the scenario: in such cases, the group may not complete their Energy Theater. For example, in the second author's physics class, a group of seniors had a lively discussion about the difference between light and heat, but ran out of time to finish choreographing. If time constraints are important, a protocol can be used to keep students from spending too much time on one aspect of the planning process. A possible protocol to use for the Choreography stage is as follows:

1. Identify the relevant objects involved and choose locations on the floor for those objects. (*two minutes*)
2. Select a hand sign for each form of energy in the scenario. (*three minutes*)
3. Track the energy transfers and transformations through the scenario.[5] (*10-15 minutes*)
4. Decide what track and form of energy each person will represent. (*three minutes*)
5. Rehearse for the Energy Theater performance. (*two minutes*)

In Step 1, a group of students considers the objects involved in the scenario and places ropes on the ground in large loops, one for each object. Each student standing inside a loop of rope corresponds to an energy unit contained in that object. In Step 2, they identify the forms of energy present in the scenario (e.g., chemical potential, thermal, kinetic, etc.) and pick appropriate hand signals for each form (e.g., students in Fig. 3 are using their bodies to make the shape of a "K" for kinetic energy). Students can invent forms they need based on their indicators (e.g., some students use "motion energy" instead of kinetic energy). Once Steps 1 and 2 are completed (in either order), students determine which form of energy each group member represents at the beginning of the

Fig. 3. Eighth-grade students participating in the Energy Theater of a ball bouncing. They stand in two loops of rope to represent energy in a ball and the ground. A "K" body shape signifies kinetic energy.

Fig. 4. Seventh-grade science students perform Energy Theater of sunlight hitting a solar bag (a large black bag of air that swells in the Sun).

scenario, where and when they move among object-regions, and which hand signals they will use at which points in the scenario. Groups are encouraged to rehearse their enactment at least once before performing.

During the Choreography stage, instructors should observe the discussions and check for adherence to the rules (e.g., that students act as units of energy, not objects in the scenario). All students should be expected to collaborate with their peers and actively participate in knowledge construction during Energy Theater. Students should direct questions and comments to their group, with the teacher acting as a referee. One way to help students work together effectively is to assign roles (such as time-keeper or narrator) that promote self-regulation. Having roles reinforces the norm that every student's contribution is valuable and necessary for the group's progress. Informing students in advance that they will be expected to individually demonstrate their understanding post-performance can also encourage participation.

Certain groups might reach consensus about their representation faster than others. Instructors can promote more in-depth analysis by asking students to: 1) consider the scenario microscopically if their representation uses macroscopic energy transfers, 2) identify evidence that supports their model of energy transfers and transformations, or 3) identify where the energy comes from before the scenario starts or where it goes after the end of the scenario. We do not recommend assigning more than one scenario at a time because it can cause confusion during whole class discussion.

Performance: A typical group's performance for Energy Theater lasts two to three minutes. Because different groups will likely have chosen different objects, forms of energy, and hand signals, it is helpful if each group explains its choices to the audience prior to the performance. For example, seventh-grade students in Fig. 4 enact the energy scenario of sunlight hitting a solar bag. To facilitate comprehension of their enactment, they first explain that the rope on the left represents the solar bag and the rope on the right represents the surrounding air. Then, they demonstrate the hand signals chosen for light and thermal energy. Finally, these students perform the scenario twice, narrating their actions each time.

In another performance, a group of seven high school students (from the second author's physics course) enact Energy Theater for a hand pushing a box across the floor at constant speed. They arrange loops of rope to represent the hand, the box, and the environment. Six students are located in the region designated for the hand, five holding their hands in a "C" shape to represent chemical potential energy and one jogging in place to represent kinetic energy. The remaining student is located in the region designated for the box and jogs in place, again representing kinetic energy. As one of the five "C" students transforms from chemical to kinetic energy in the hand (starts to jog in place), the jogging student in the hand moves to the box and continues to jog, representing a transfer of kinetic energy. Her arrival prompts the jogging student originally in the box to move from the box to the surrounding environment, where he transforms into thermal energy (stops jogging and starts fanning his face). This sequence continues until all five students who originally represented chemical energy in the hand have become thermal energy in the environment.

Reflection and assessment: The process of setup, choreography, and performance usually can be completed within a 45-minute class. However, the performance should not be the end of the learning experience; reflection and assessment are critical for student growth. The time needed for this stage varies depending on the activities used.

- ***Compare and contrast performances***

Post-performance, it is ideal to immediately facilitate a discussion about: 1) the similarities and differences between groups' performances, 2) the supporting evidence for each transfer and transformation, and 3) the consistency of students' models with this evidence. It may be useful to prime students with these prompts prior to the performances.

- ***Share and Critique***

Comparison of students' Energy Theater performances is greatly facilitated if students record them in writing.[6] Students can individually design written representations of their Energy Theater performance either collaboratively in class (perhaps on a poster or whiteboard) or as homework. Figure 5 is an example of a representation of Energy Theater for a simple circuit used in the second author's high school physics course. Here, letters represent energy forms and arrows show transfers (across object boundaries) and transformations (within objects) of an energy unit. The drawing represents four students' tracks, all of which started as chemical energy. This drawing shows that the chemical energy in the battery transforms into kinetic energy and potential energy. That energy transfers to the wire and then transforms into kinetic, light, and thermal energy in the bulb. Two energy units transfer to the environment as light and thermal energy, and the remaining kinetic units transfer and transform back into the battery through another wire. Teachers can use these diagrams to ask clarifying questions about students' thinking, such as, "What do you mean by potential energy?" Students can use these diagrams to compare their models with their peers' models, or write a paragraph describing the energy processes and record any remaining questions or concerns.

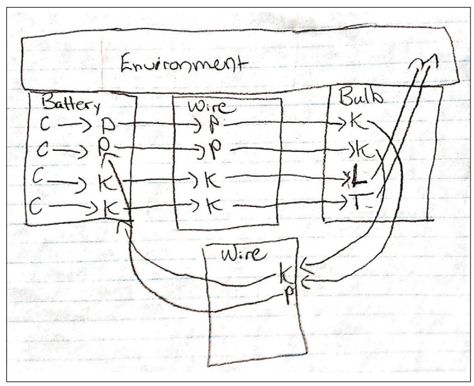

Fig. 5. A 12th-grade physics student's drawing of Energy Theater representing the energy flow in a circuit. C, P, K, L, and T stand for chemical, potential, kinetic, light, and thermal energy, respectively.

Table I. Common student ideas and possible instructor actions.

Common Student Ideas	Manifestations of Student Ideas in Energy Theater	Possible Instructor Actions
Students might: – think of energy as a consumable substance (i.e., food, fuel).[9] – not distinguish matter from energy.[1] Younger students might think everything that exists is matter, including heat, light, and electricity.[10]	Students sometimes: – act as objects instead of units of energy, (e.g., if a ball is moving, they move the way the ball moves). In this case, students sometimes associate loops of rope with forms of energy instead of objects. – represent microscopic objects (e.g., electrons) as energy.	Instructors can ask students to articulate what they represent and what is represented by the locations on the floor.
Students might think: – energy is not measurable or quantifiable.[11] – energy can be used up or lost to the environment.[12]	Students might show: – units of energy increasing (or decreasing) in magnitude by students standing taller, crouching down low, moving faster or slower, or leaving the loops of rope. – no energy remaining at the end of a process by lying on the floor.	Instructors can: – remind students about the rule that people are units of energy, which cannot be created or destroyed. – prompt students to search for evidence that energy may have been transformed or transferred in order to explain an apparent "loss" of energy.
Students might not consider the appropriate system and environment, presenting apparent contradictions with the principle of conservation of energy.[13]	Students might: – choose to include objects not relevant to the energy processes. – not agree on the beginning and end of the scenario (e.g., the end of the energy transfers and transformations).	Instructors can: – ask students to clarify the spatial and temporal boundaries of the scenario. – require students to justify their reasoning for including (or not including) particular objects, but remind the class that multiple interpretations might be correct.

All of these strategies for formative assessment of Energy Theater can help students critically examine and revise their ideas about energy. These more permanent representations may also be used for grading purposes and individual feedback. Other options for reflection on and assessment of Energy Theater performances are described on a website designed to support teachers in implementing Energy Theater.[7,8]

Common student ideas

Energy Theater gives instructors the opportunity to discover students' ideas about energy during all stages of the activity, as students make their thinking visible through speech, body movements, gestures, and so on.[1] A few common student ideas appear regularly in our observations of middle and high school classroom implementation of Energy Theater. Table I summarizes these common ideas along with instructor approaches that may help student growth.

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