Creating and Using a Model of Energy

We are working together to build a scientific model of energy and use it to reason about various real-world scenarios. There is no fully agreed-upon definition of a scientific model, but many experts agree on these aspects:

- It seeks to describe, explain, or predict something in the world.
- It is limited in that it focuses only on certain aspects that are of interest.
- It includes entities that may or may not be directly observable, *and rules* for how those entities behave, and for how their behavior has observable consequences.
- It is testable, public, and subject to revision.

For example, classic Mendelian genetics sought to explain and predict how characteristics are transmitted from parents to offspring. It focused only on certain observable characteristics, such as the height of a plant; it didn't attempt to account for the shape and placement of every leaf. It postulated the existence of genes (dominant and recessive), which at the time were purely hypothetical and unobservable. It set out rules for how the genes of the parents combine in the offspring, and for how the resulting combination of genes would determine the offspring's observable characteristics. It made testable predictions, was made public for use and criticism, and has been revised and refined repeatedly over the subsequent 150 years.

We can talk about the height of a pea plant without reference to a model, but whenever we talk about energy we're using a scientific model, even if we're not aware of it. Energy can't be directly measured like the height of a plant. It's inherently abstract and unobservable, even with the most sophisticated instruments. Nevertheless, there are rules that describe its behavior – most importantly, that energy is never created or destroyed – and energy and energy changes are connected to observable characteristics, like the speed of a train, and can be calculated with great precision from those observable properties. As we consider new scenarios we gradually revise our model of energy to account for what we observe. The Energy Tracking Lens helps us use the scientific model of energy to

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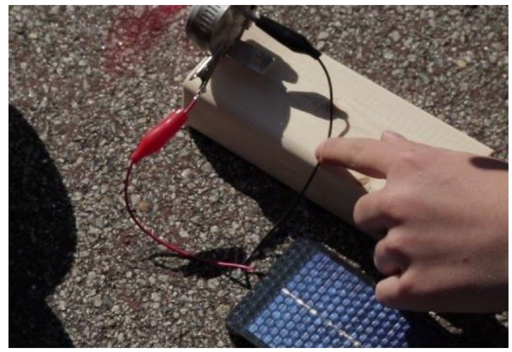
explain and predict some – but only some – aspects of the behavior of *any* system in the physical world.

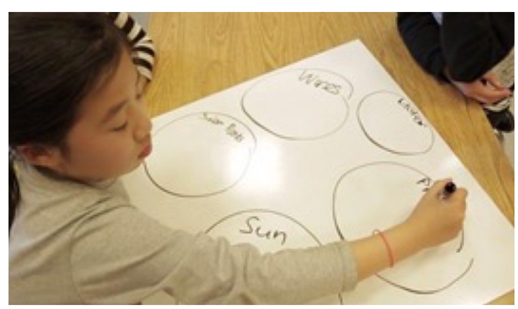
Creating and using models almost always involves creating and using representations. They might be pictures, diagrams, graphs, mathematical formulas, physical objects that we manipulate, or even ourselves. The representations help us think through and improve our understanding, and communicate our ideas to others.

To see what this looks like in practice, let's take a look at some fourth-grade students as they tell the energy story of a solar cell driving a motor and propeller. After taking the materials outdoors and experimenting with them, they worked together to interpret, represent and explain their observations using the energy cube representation. You can view a video at https://foeworkshop.terc.edu. In this activity their goal is to ***describe*** *and* ***explain*** a ***limited aspect*** of the real world phenomenon: the flow of energy through the system. Although the students never use the word "model," the entire activity is one of developing and using models.



The solar panel/motor/propeller system .

They use the energy cube representation to help them work out their explanation. The circles and cubes represent the ***entities*** of the model: The circles represent the observable components of the system, while the cubes represent the invisible entity that we call "energy." The cube representation embodies the ***rules*** that govern how the entities behave within the model. Cubes can be moved among the circles to show energy transfer and flipped to show changes of form, but they cannot be added to or removed from the board, or be placed outside the circles. These representational rules correspond to the principles that energy can change form and move from one object to another, but is always with a part of the physical system, and the total amount cannot change.



Students drawing and labeling circles to represent the components of the system.

Their model of the system is ***public*** within the group and to the teacher, and in a classroom setting might also be shared with the larger group.

In working out which components to include in their representation, they ***revise*** their model by adding or combining components.

> TEACHER: What are the components? Let's start there.
>
> […]
>
> STUDENT[1]: The sun, the solar panel, the wires, the motor thing, and the propeller.
>
> […]
>
> SARAH: The solar panel and the wires would be one conjoined--
>
> STUDENT: I think two, because the solar panel--
>
> JASON: No, they're two different--
>
> MELISSA: The solar panel is like a transfer, and then the wires are all electrical.
>
> SARAH: But wouldn't the wires be part of it, too?
>
> KIM: Well, I think the wires should be a box of their own–
>
> […]
>
> JASON: Wires are all electrical.
>
> [INTERPOSING VOICES]
>
> MELISSA: One of them to the motor and the propeller, together.
>
> SARAH: And then that's the environment.
>
> JASON: No, because the motor transfer makes the energy, then the propeller--
>
> SARAH: So then we also need the environment--
>
> […]
>
> STUDENT: Solar panels, then to the wires. Then to the motor, to the propeller, to the environment.

Their discussion isn't just about what object they see, but about the role each piece of the system plays in their model of energy flow. The wires are treated as a separate component because in the wires the energy is purely electrical, unlike the solar panel and the motor, where the energy undergoes transformation. The motor is separate from the propeller because that's where the transformation from electrical energy to motion takes place. Finally, the students decide to include the environment, because

[1] It was not always possible to identify which student was speaking; when it is unclear the speaker is identified simply as "STUDENT".

the ***rules*** of their model of energy imply that the energy from the system can't just disappear, but must be transferred into the environment.

Next, the students, with a prompt from the teacher, face the question of what to call the initial energy from the sun:

STUDENT: The sun's where it all begins.
TEACHER: So I think the tricky part is we're not really sure what kind of energy that is, right?
STUDENT: Yeah.
[…]
STUDENT: First the sun shines down.
[…]
SARAH: So the solar panels are unknown--
MELISSA: Unknown-- this is still unknown.
TEACHER: Why is this unknown?
[INTERPOSING VOICES]
KIM: It's sunshine.
TEACHER: Well, what do you think happens inside the solar panel?
JASON: It transforms into electric.

The students' initial model of energy included four known forms: motion, elastic, thermal, and electrical. Yet the rules of their energy model demand that *some* kind of energy be provided by the sunlight. They have already determined, by showing that the motor stops when the solar panel is turned upside down, that thermal energy is not at work here, and none of the others make sense. They therefore ***revise*** their energy model by inventing a new, as yet unnamed form of energy, turn up a blank cube face, and proceed. This is precisely the kind of model-based reasoning through which the scientific community identifies forms of energy.

Students collaboratively discuss and manipulate the energy cubes to decide how best to represent the energy story. The top image shows the energy cubes in the Sun's circle with blank faces turned up, representing the "unknown" energy in sunlight.

In this activity the students are not making ***testable predictions***, but they could. Their model predicts, for example, that another source of electrical energy, such as a battery or generator, should also work, and that the solar cell should be able to drive other devices that convert electrical energy into other forms, such as a light.

In explaining the flow of energy in this, or any system, the students are using models at two different levels. They have a general model of energy, and they create a specific instantiation of that model for this particular scenario. In the course of their analysis they revise both the specific model, when they decide what components to include and how to manipulate the cubes, and the more general model, when they add a previously unknown form of energy.