Conserving energy in physics and society: An integrated model of energy for K-12 teachers and students

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(with apologies to Stamatis Vokos and Lane Seeley)

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ENERGY PROJECT

Seattle Pacific University

FACET INNOVATIONS

NSF

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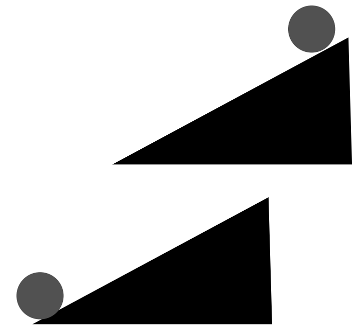
A physicist's take on sustainability

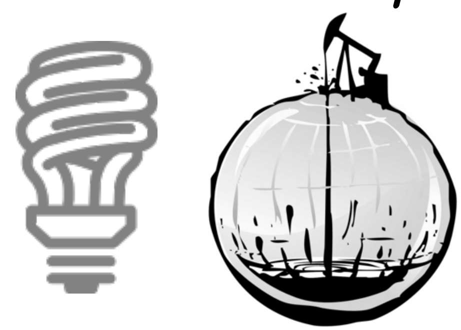
Learners should prepare
to meet socially relevant needs
by understanding
energy conservation
in both its physics sense
and its sociopolitical sense.

K-12 teachers
especially want
responsible connections
to urgent sociopolitical issues.



Energy is *conserved*

Energy is *used up*



The Energy Project

Professional development program for K-12 teachers on the learning of energy and practices of formative assessment

Research program on:

- teaching and learning of energy
- learning theory development
- assessment of teacher learning
- **relating "school energy" to sociopolitical concerns**

Energy Project team and collaborators

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Lane Seeley

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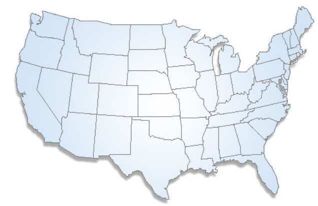

Hunter Close

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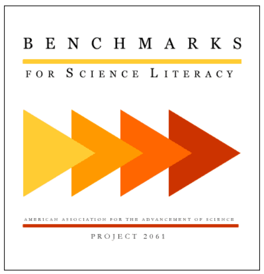
Outline

- **Teaching conservation of energy**
  - Learning goals for energy tracking
  - Energy Tracking Representations
- **Teaching conservation of *useful* energy**
  - Learning goals for energy degradation
  - Learning goals for the second law of thermodynamics
- **Summary**

Goals for energy learning

E1. Learners should **conserve** energy locally in space and time as they **track** the transfers and transformations of energy within, into, or out of systems of interest in complex processes.



e.g., "Students should trace where energy comes from and goes next in examples that that involve several different forms of energy along the way"

Distinct from approaches in which energy is a numerical quantity and energy conservation means mathematical balancing.

E2. Learners should theorize mechanisms for energy transfers and transformations.

An initial step towards optimizing systems to maximize some energy transfers and transformations and minimize others

Aphorisms are insufficient

Analogy:

"Track the transfers and transformations of assets within, into, or out of systems of interest in the American economy."

"Identify the means to optimize the effect of the Federal Reserve's quantitative easing on unemployment, bond prices, or interest rates."

"A rising tide lifts all boats"

"Energy is neither created nor destroyed"

Example

Scenario: **Box pushed across floor at constant speed.**

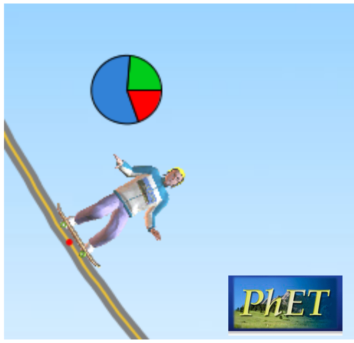
Challenge: **Show what's going on with the energy.**

Participants: K-12 teachers in summer PD course at SPU

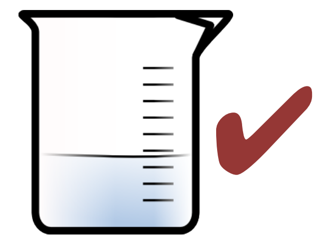
- Energy flows from hand to box, box to air/floor.
- Constant amount of kinetic energy in the box.
- Constantly decreasing chemical energy in hand.
- Increasing thermal energy in box, air, and floor.

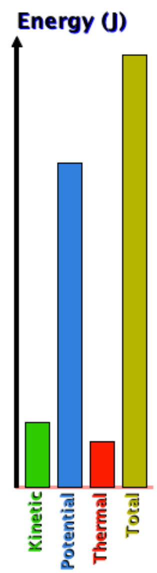
How to manage all this information?

Familiar representations of energy



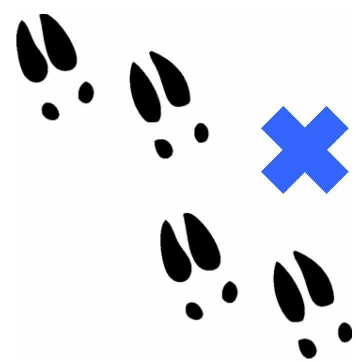
Pie charts and bar charts show the proportion of different kinds of energy in a system or object.





They can be made to obey energy **conservation,**

but they do not support **tracking** energy (because they do not show energy transfers).



(Scherr, Close, McKagan, and Vokos, PRST-PER 2012)

Novel representations of energy

“Energy Theater”

You are a unit of energy.

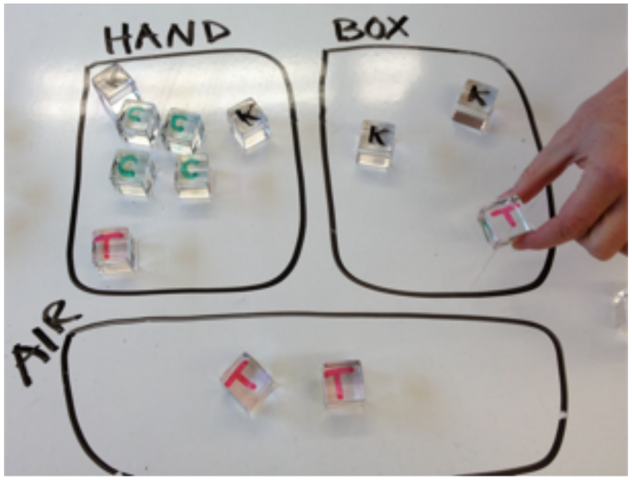
Objects in the scenario correspond to areas on the floor.

You indicate your form with a hand sign.

As energy transfers and transforms among objects, you move to different areas on the floor and change hand sign.

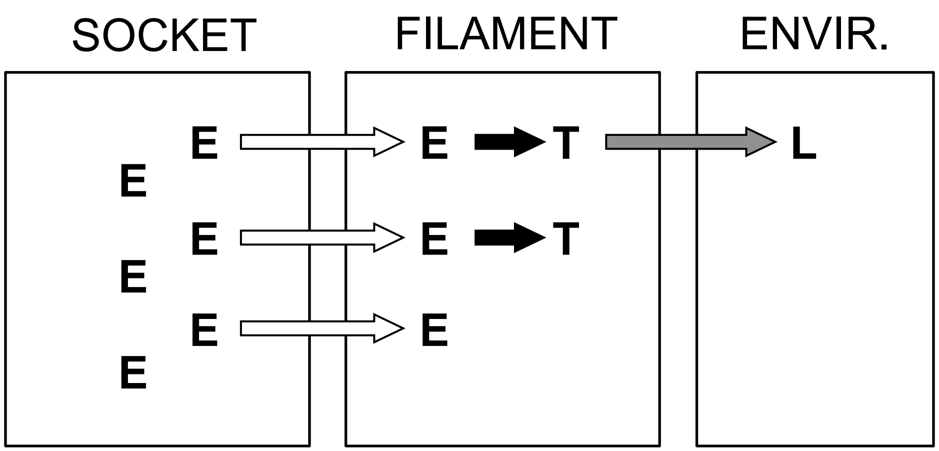
(Scherr, Close, Close, and Vokos, PRST-PER 2012)

Novel representations of energy



"Energy Cubes"

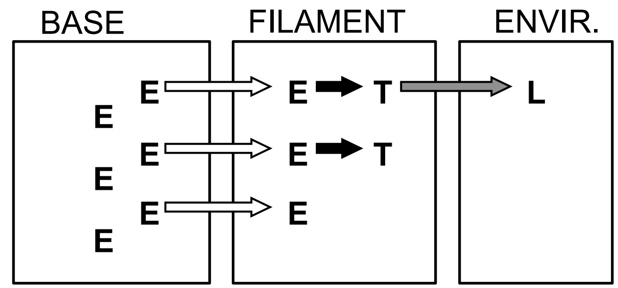
Blocks are units of energy;
forms are written on their sides.
Objects are areas on a whiteboard.
As energy transfers and transforms,
blocks move and flip.

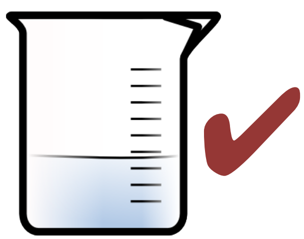


"Energy Tracking Diagram"

Letters are units of energy.
Objects are schematic areas.
Arrows show transfer and
transformation.
Arrow color shows process.

Energy Tracking Representations





Energy Tracking Reps. structure our PD

Every year:
Week-long course for 50 elementary teachers
Two-week course for 50 secondary teachers

Professional development supports teachers in conserving and tracking energy by teaching Energy Tracking Representations.

- Kinesthetic learning activities
- White boarding
- Small-group discussions
- Large-group consensus building

Teachers cooperatively create, analyze, critique, and refine representations in order to learn about energy and learn the constraints and affordances of each representation.

Instructional framework adapted from The Algebra Project.

(Moses, 2001; Close, DeWater, Close, Scherr, & McKagan, 2010)

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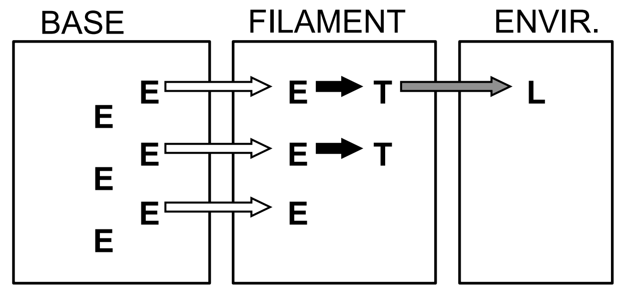
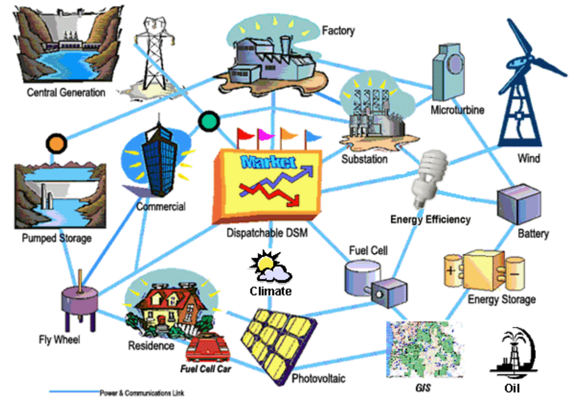
“School energy”



In a school context,
“conservation” refers to the fact that
energy is neither created nor destroyed.

“Sociopolitical energy”



In a sociopolitical context,

- “conservation” refers to the fact that we have to guard against energy being wasted or used up.
- energy is both created (in power plants) and destroyed (in processes that render it unavailable for human purposes).

Teachers know we need more

Jennifer: I was thinking about how in both Energy Theater and in the Energy Cubes,

Adding "usefulness" to Energy Theater

Energy loses value though the total amount is constant.

Spontaneous learner interest in usefulness

"Energy's value has decreased."

"The quality of the energy decreases as it dissipates."

"Energy is used up and becomes less available."

"When is energy useful?"

"Energy degrades into a less useful form."

Also seen in:

- Duit (1984)
- Kesidou & Duit (1993)
- Papadouris and Constantinou (2010)
- Pinto, Couso, & Gutierrez (2004)
- Solomon (1982, 1985, 1992)

When is energy “useful”?

Our everyday sense that energy can be “useful” or “used up” has its counterpart in the formal physics concepts of **free** and **degraded energy.**

Free energy is (and **degraded** energy is not) available for

- the production of mechanical work [OR]
- the process of mechanical energy transfer

Free energy is useful, and can be used up.

Free*:*
Energy used to propel the car

Degraded*:*
Thermal energy dissipated to environment

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These will be the basis of instructional activities and representations.

Learning goals for energy degradation

D1. Learners should distinguish between free and degraded energy in specific systems.

D2. Learners should identify changes in free and degraded energy as they track the transfers and transformations of energy within, into, or out of a closed system..

D3. Learners should equate the total energy in a system to the sum of the free and degraded energy

The total energy is conserved
even though the free energy may be reduced.

Learning goals for energy degradation

Jennifer: "The energy becomes less useful, like if it's sound or heat or something like that."

Irene: "Especially as heat because it's wasted."

Kate: "Although heat *can* be useful, because if you burn coal then heat is useful."

Jennifer: "Right, but, what's useful, is, you know like burning coal heats water, the steam turns the turbine, so what's really useful is the mechanical energy of the turbine moving."

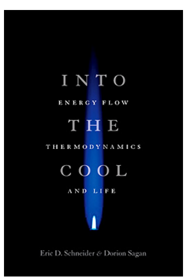
- ✔ *Distinguishing between "useful" and "not useful" energy*
- ✔ *Tracking changes in energy usefulness*

Learning goals for the second law

S1. Learners should identify overall energy degradation in closed systems.

The "Running Down Principle": *(Solomon, 1992)*
In all energy changes there is a running down towards sameness in which some of the energy becomes useless.

S2. Learners should account for increases in degraded energy with movement of a quantity towards equilibrium.



"Nature abhors a gradient."

Learning goals for entropy?

The second law of thermo is often stated in terms of **entropy,**

e.g., "the total entropy of the universe does not change when a reversible process occurs ($\Delta S_{universe}$ = 0 J/K) and increases when an irreversible process occurs ($\Delta S_{universe}$ > 0 J/K)."

Entropy is commonly described mathematically and associated with disorder, probability, and multiplicity.

It is not typically integrated with a model of energy.

$$S = - k_B \Sigma P \ln P$$

$$dS = \delta Q / T$$

…

Learning goals for entropy?

We aim to
develop a model of entropy that is K-12 appropriate.

- Connected to concepts that are constructible from everyday experience
- Minimally mathematical
- Integrated with our energy model

The discipline of physics can benefit from teachers' conceptualizations of entropy in terms that are of use to them and their students.

Summary: Reconciling "conservation"

- **Energy Tracking Representations** embody learning goals of energy conservation and tracking.
- **K-12 teachers have valuable resources** for distinguishing energy (conserved) from free energy ("useful" and "used up").
- *Next steps:* **Develop representations and concepts** to support K-12 teachers in learning energy degradation.