Energy as a Crosscutting Concept

Arthur Eisenkraft
Alan Alda’s Competition

• What is flame?

• What is time?

• What is color?

• Maybe next year: What is energy?
Encyclopedia of Physics

“Whatever energy is (and we have no satisfactory conceptual definition of that underlying quantity, although we know its various manifestations) it is conserved.”
• Test assumption
  – Your research: What are the energy considerations?

• Umbrella
Heat Transfer—Conduction

- Physics

\[ Q = \frac{kA \left( T_{\text{Hot}} - T_{\text{Cold}} \right) t}{d} \]

- Earth Science

- Biology
“Whatever energy is
(and we have no satisfactory conceptual definition of
that underlying quantity, although we know its various
manifestations)
it is conserved.”

TEST QUESTION: Define ‘energy’
STUDENT ANSWER: I can’t.
GRADE: A
Energy

- Disciplinary core idea

- Crosscutting concept

- Not about energy resources but the ability of people to understand about energy resources.
Energy as a Crosscutting Concept

- Movement of my muscles (KE)
- Molecules of ATP (Chemical Energy)
  - $7 \times 10^{18}$ molecules of ATP every minute
- Carbohydrates ingested earlier
- Sunlight on wheat fields
- Nuclear fusion in the Sun
  - $10^{11}$ atoms of hydrogen in the Sun
How many calories?

• Rank order
  – 1 cup coffee    2
  – 1 soft drink   95
  – 1 muffin       380
  – 1 Big Mac      550
• 7-Eleven's 44-Ounce Super Big Gulp

• The damage:
  – 512 calories,
  – 128 grams of sugar,
  – 0 grams fat

• (each cube of sugar has 4 g of sugar)
How many calories

How do they get the number for the “Nutrition Facts”

<table>
<thead>
<tr>
<th>Nutrition Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serving Size 2/3 cup (55g)</td>
</tr>
<tr>
<td>Servings Per Container About 8</td>
</tr>
<tr>
<td>Amount Per Serving</td>
</tr>
<tr>
<td>Calories</td>
</tr>
<tr>
<td>% Daily Value*</td>
</tr>
<tr>
<td>Total Fat</td>
</tr>
<tr>
<td>Saturated Fat</td>
</tr>
<tr>
<td>Trans Fat</td>
</tr>
<tr>
<td>Cholesterol</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Total Carbohydrate</td>
</tr>
<tr>
<td>Dietary Fiber</td>
</tr>
<tr>
<td>Sugars</td>
</tr>
<tr>
<td>Protein</td>
</tr>
</tbody>
</table>

*Percent Daily Values are based on a 2,000 calorie diet. Your daily value may be higher or lower depending on your calorie needs.

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<tr>
<th>Calories:</th>
<th>2,000</th>
<th>2,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fat</td>
<td>Less than 65g</td>
<td>80g</td>
</tr>
<tr>
<td>Sat Fat</td>
<td>Less than 20g</td>
<td>25g</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Less than 300mg</td>
<td>300mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>Less than 2,400mg</td>
<td>2,400mg</td>
</tr>
<tr>
<td>Total Carbohydrate</td>
<td>Less than 300g</td>
<td>375g</td>
</tr>
<tr>
<td>Dietary Fiber</td>
<td>Less than 25g</td>
<td>30g</td>
</tr>
</tbody>
</table>
The Peanut Lab

• Also done as “The Cheeto Lab”

• Burn a peanut or cheeto

• And then what? How do you do the peanut lab?
The Peanut Lab

• Burn peanut and heat up water
• Research Question: Is the energy content of the peanut on the food label correct?
The Peanut Lab

• Burn peanut and heat up water
• Research Question: Is the energy content of the peanut on the food label correct?
• Measure the temperature gain of the water.
  – Calculate the energy gain of the water
The Peanut Lab

- Determine the energy content of the peanut
  - Energy gained by the water = energy loss of nut
- Compare the calculated value of the energy content of the peanut with the food label energy content
- Calculate the percent error.
  - Account for this percent error.
Are we almost there?

1990s

1990s-2009

Phase I

Phase II

Phase III

Assessments

Curriculum Development

Teacher education

Instruction

1/2010 - 7/2011

7/2010 – April 2013

Slide designed by Joe Krajcik
A Framework for K-12 Science Education – National Academy of Sciences

The Three Dimensions of the Framework

1. Scientific and Engineering Practices

2. Crosscutting Concepts

3. Disciplinary Core Ideas
Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematic and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information
Crosscutting Concepts

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quality
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change
Disciplinary Core Ideas

Physical Sciences

PS 1: Matter and its interactions
PS 2: Motion and stability – Forces and interactions
PS 3: Energy
PS 4: Waves and their applications in technologies for information transfer
Disciplinary Core Ideas

Life Sciences

LS 1: From molecules to organisms: Structures and processes

LS 2: Ecosystems: Interactions, energy, and dynamics

LS 3: Heredity – Inheritance and variation of traits

LS 4: Biological evolution – Unity and diversity
Disciplinary Core Ideas

Earth and Space Sciences
ESS 1: Earth’s place in the universe
ESS 2: Earth’s systems
ESS 3: Earth and human activity

Engineering, Technology, and the Applications of Science
ETS 1: Engineering design
ETS 2: Links among engineering, technology, science and society
Energy

• Disciplinary Core Idea
  – ATP in biology
  – Activation energy in chemistry
  – Kinetic energy in physics

• Crosscutting Concept
Research Question: Is the energy content of the peanut on the food label correct?

New Research Question: Is energy conserved?
Revised Lesson with Crosscutting Concept in Foreground

- Burn peanut and heat up water
- Research Question: Is energy conserved?
- Measure the temperature gain of the water.
  - Calculate the energy gain of the water
Revised Lesson with Crosscutting Concept in Foreground

- Calculate the energy loss of the peanut
  - Use the food label information
- Determine if energy is conserved
- Account for the loss of energy (i.e. the energy loss of the peanut is greater than the energy gain of the water.)
<table>
<thead>
<tr>
<th>Disciplinary Core Ideas in Foreground</th>
<th>Crosscutting Concepts in Foreground</th>
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<tbody>
<tr>
<td>Burn peanut and heat up water</td>
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<td>Calculate the energy loss of peanut using food label</td>
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<td>Determine the energy content of the peanut</td>
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<tr>
<td>Compare the calculated with the food label</td>
<td>Account for the loss of energy</td>
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<td>Calculate percent error.</td>
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<td>Account for this percent error.</td>
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Not a trivial change

• Googled: “peanut lab calorimetry”
• 1st 23 sets of lab instructions
• Only 7 mentioned
  – Energy conservation (1 lab)
  – Conservation of energy (3 labs)
  – Law of conservation of energy (1 lab)
  – Energy loss = energy gain (2 labs)
• In remaining 16 labs: implied but unstated
• No others (e.g. total energy remains constant)
• What did they say?
  – “The chemical energy stored in the peanut was released and converted into heat energy. The heat energy raised the temperature of the water in the small can.”
  – “The peanut burned completely. It changed in mass. The water temperature was raised. When the peanut was burned, stored chemical energy was converted into heat energy, thereby raising the temperature of the water.”
• Teachers are not mentioning energy conservation in their written materials,
• Teachers in their instruction may also only imply the conservation of energy
• By placing the energy concept in the foreground as in our lesson shift, we emphasize the crosscutting concept and insure that this important “big idea” takes center stage.
7E: Engage

• Read the calorie label to the students.
• Treadmill: 20 minutes = 100 calories.
• Do you take this into account when you eat a snack?
7E: Elicit

• “How do the food suppliers know the calorie count of the foods that they display on the label.”
7E: Explore

• Use the “calorie content” of the foods to determine if the energy loss of the food (peanut) is equal to the energy gain of water being heated. (calories/gram and calories/serving.)

• Qualitative “explore” - students compare the temperature change of water heated with one peanut or three peanuts.
7E: Explore

- Quantitative explore - students measure the temperature change of the water.
- “Is energy conserved?”
  - students calculate the energy gain of the water and
  - compare this with the energy loss of the peanut from the food label.
7E: Explain

- Students discuss how to calculate $E_n = \text{energy loss of the nut}$.
- Students also discuss how to calculate $E_w = \text{energy gain of the water}$.
- Conservation of energy requires that $E_n = E_w$. In the experiment, all groups will probably find that $E_n > E_w$.
- **Energy is not conserved**!
- Students must now consider possible explanations for energy not being conserved.
7E: Explain

• Explanation 1: The conservation of energy as a principle of science is incorrect.

• An organizing principle of energy conservation cannot be discarded on the basis of a single 30 minute experiment.
7E: Explain

• Explanation 2: The food label was incorrect.

• Some food labels have been found to be incorrect.

• Since they all agree, probably not a problem.
7E: Explain

- Explanation 3: We made an error in the calculations.
- Once again, explanation 3 as a claim is not supported by the evidence.
7E: Explain

- Explanation 4: Poor design of the experiment

- The energy loss occurs because the nut and water are not a closed system.
7E: Elaborate

• ELABORATE: Students suggest improvements in the design of the laboratory investigation.

• As a further “elaborate” students can compare their experimental design to that of food scientists who use a bomb calorimeter.
7E: Extend

• EXTEND: The peanut lesson can now be extended to discussions of
  – molecular bonding,
  – energy content of different foods,
  – human digestion,
  – specific heat
Grade Level Bands

• 4th grade: Burning (digesting) food provides energy.

•

• 8th grade: How does this lab relate to our study of digestion?

•

• 12th grade: Can the energy content of the nut be determined from an analysis of the combustion reaction.
7E: Evaluate

• EVALUATE: The evaluation takes place during all phases of the lesson (engage, elicit, explore, elaborate, extend).

• A test can also be constructed where students have to measure the energy content of another food product and answer questions of the material in the lesson.
Scientific and Engineering Practices

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Energy in Education

• Energy in the new Framework for K-12
  – Energy as a “disciplinary core idea”
  – Energy as a crosscutting concept
• How do we present energy?
• Can we bring our presentations more in line with the 3-dimensions of the Framework
  – Scientific and Engineering Practices
  – Crosscutting Concepts
  – Disciplinary Core Ideas
## Types of Energy

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Equation</th>
<th>What We Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPE</td>
<td>mgh or –GMm/R</td>
<td>height</td>
</tr>
<tr>
<td>KE</td>
<td>1/2mv^2</td>
<td>velocity</td>
</tr>
<tr>
<td>SPE</td>
<td>½ kx^2</td>
<td>compression</td>
</tr>
<tr>
<td>Electrostatic PE</td>
<td>-kqq/R</td>
<td>charge</td>
</tr>
<tr>
<td>Heat</td>
<td>mc&lt;delta&gt;T</td>
<td>temperature</td>
</tr>
<tr>
<td>Light</td>
<td>hf</td>
<td>frequency</td>
</tr>
<tr>
<td>Nuclear</td>
<td>mc^2</td>
<td></td>
</tr>
<tr>
<td>Sound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binding energy</td>
<td></td>
<td></td>
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<tr>
<td>Activation energy</td>
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<tr>
<td>Solar energy</td>
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<tr>
<td>Magnetic</td>
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<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>Vlt</td>
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Feynman’s 28 Blocks

• Day 1 - 28 blocks; Day 2 – 28 blocks; etc.
• 27 (but one is under the couch)
• 25 (but box is heavier)
  – We can write an equation:
    • (number of blocks seen) + (weight of box – 150 g)/20g = 28
• 26 (but water level in pail is higher)
  – We can write a new equation
    • (number seen) + (weight...) + (height of water – 2cm)/0.5 cm) = 28
• How else could blocks be hidden?
Energy Analogy

• First – a new level of abstraction – there are NO blocks
  – Take away the first term in the equations
    \((# \text{ seen}) + (\text{weight...}) + (\text{ht of water} - 2\text{cm})/0.5 \text{ cm}) = 28\)
• Second – Calculate energy (we don’t measure energy)
• Third – use the same units (Joules, calories, BTU, gallons of gas, eV....)
• Fourth – in a closed system – the sum is constant
Conservation of Energy

• A closed system
• Different forms – each form has an equation
  – GPE, KE, elastic energy, heat energy, chemical energy, radiant energy, nuclear energy
• The total of all of these numbers is constant.

• WE HAVE NO KNOWLEDGE OF WHAT ENERGY IS. We only know how to calculate energy and the total always remains the same.
Our Faith in Energy Conservation

• Beta decay problems
  – Energy was not conserved

• Wolfgang Pauli solution in 1931
  – There must be a neutral particle unseen (neutron?)
  – Chadwick discovers neutron in 1932 but is too massive for solution
Our Faith in Energy Conservation

• Enrico Fermi in 1934 – theory of weak interactions
  – Neutrino with no charge, no mass
  – But energy will be conserved

  – Rejected by Nature ("it contained speculations too remote from reality to be of interest to the reader")
Our Faith in Energy Conservation

• Enrico Fermi in 1934 – theory of weak interactions
• 1956 – the neutrino is experimentally discovered
  – Clyde Cowan and Fred Reines (Nobel Prize 1995)
• 1962 – not all neutrinos are identical
Energy in Education

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  – Energy as a “disciplinary core idea”
  – Energy as a crosscutting concept

• How do we present energy?

• Can we bring our presentations more in line with the 3-dimensions of the Framework
  – Scientific and Engineering Practices
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  – Disciplinary Core Ideas
Energy in Education

• Energy in the new Framework for K-12
  – Energy as a “disciplinary core idea”
  – Energy as only one crosscutting concept

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6. Structure and function
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• A closed system
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  – GPE, KE, elastic energy, heat energy, chemical energy, radiant energy, nuclear energy
• The total of all of these numbers is constant.

• WE HAVE NO KNOWLEDGE OF WHAT ENERGY IS. We only know how to calculate energy and the total always remains the same.
4 messages for K-12 students

• Only changes in energy matter (who cares how much you have if most of it is not negotiable).
• Any change in energy is balanced by some other change in energy (you can’t make or destroy energy, only move it around).
• Energy availability governs what can happen (you can’t do anything without energy).
• Energy tends to spread itself around as much as possible (you cannot prevent losses from a system).
Four Organizing Principles

Energy Forms & Transformations

Energy Systems

Conservation of Energy

Energy Resources
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The Vision of the Framework/NGSS
Energy as a Crosscutting Concept

“Whatever energy is (and we have no satisfactory conceptual definition of that underlying quantity, although we know its various manifestations) it is conserved.”
• Please check out our website: www.cosmic.umb.edu

Or email with questions: arthur.eisenkraft@umb.edu