

Investigating the Proposed Affordances and Limitations of the Substance Metaphor for Energy

Lisa M. Goodhew and Amy D. Robertson, Seattle Pacific University Department of Physics

Affordances of the substance metaphor:

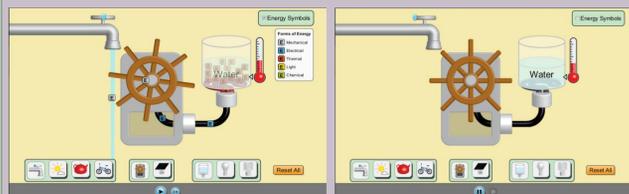
- (a) Energy is conserved
- (b) Energy transfers among objects
- (c) Energy is localized, even if spread out
- (d) Energy can be located in objects
- (e) Energy can change form
- (f) Energy can accumulate in objects

Does (1) instruction that explicitly embeds the substance metaphor for energy and (2) student use of the substance metaphor for energy promote the **affordances** and **limitations** of this metaphor identified in the literature?

Limitations of the substance metaphor:

- (i) Energy does not share all qualities of substances (*e.g.*, having mass and volume, or being affected by Newtonian gravity)
- (ii) Potential energy is not located in a single object
- (iii) Energy is frame-dependent
- (iv) Energy can be negative

Context for Investigation: Energy Forms and Changes (EFAC) PhET Simulation



With explicit representation of substance metaphor for energy.

Without explicit representation of substance metaphor for energy.

Research Methods

- Interviewed eight introductory physics students using EFAC simulation. Interviews began with symbols off. Several minutes in, interviewer prompted students to turn symbols on.
- Coded interviews for instances of substance metaphor use and for specific affordances and limitations. For example:

Affordances (b), (c), and (d): "...So it starts here, then transfers to there, the wheel transfers its energy to this thing..."

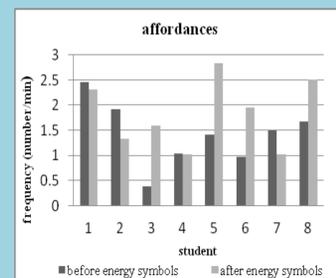
Limitation (i): "...mechanical energy, when it hits, um, what is this called? Water wheel?"
(substance metaphor language italicized)

Hypothesis 1:

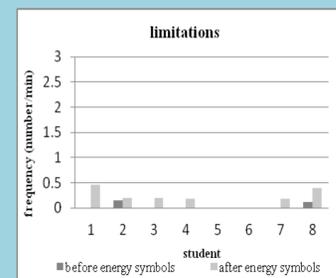
If instruction that explicitly embeds the substance metaphor promotes specific affordances and limitations, we expect the frequency of affordances and limitations to be greater *after* the symbols are turned on than *before*.

Result 1:

The overall frequency of affordances was greater than the frequency of limitations. Conservation, transfer, and localization were mentioned more frequently with the energy symbols on, while location in objects, transformation, and accumulation were not.



Frequency of affordances for individual students before and after energy symbols were turned on



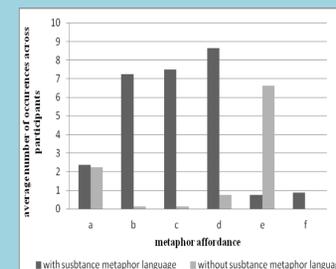
Frequency of limitations for individual students before and after energy symbols were turned on.

Hypothesis 2:

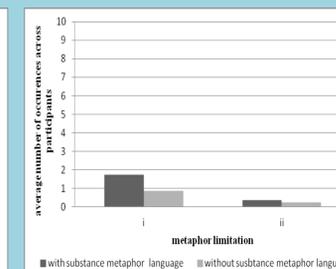
If student use of the substance metaphor promotes specific affordances and limitations, we expect that both would more often co-occur *with* substance metaphor language than *without*.

Result 2:

Language about transfer, localization, and location in objects more often co-occurred with substance metaphor language than without



Occurrence of individual affordances with and without substance metaphor language.



Occurrence of individual limitations with and without substance metaphor language.

Hypothesis 3:

If these two hypotheses are correct, we expect to see plausible qualitative connections between hypothesized causes and hypothesized effects.

Result 3:

Qualitative evidence from our interviews further corroborates our sense that the explicit embedding of the substance metaphor promotes affordance (a).

Interviewer: ...Do you think that they [the energy symbols] help you like describe the concept of energy to someone in any way?

Student 4: I think they do...that I guess shows the transfer from one type of energy into another, and I guess it seems like it's conserved... I mean you do lose some, there still remains like energy forms...it shows the transfer ... it remains, the amount of energy being used, but in a different type of energy.

Student 2: "I don't really think of energy as a tangible thing,"

Student 4: "[Energy is] not actually like physical... it's not a physical object but an amount of... work being done or something that can be transferred."

Our preliminary investigation suggests that the substance metaphor is helpful for instruction and discourse, both in the representation used by the simulation and in the language used by students.

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