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Visual and gestural metaphors for introducing energy to student teachers of primary school and kindergarten levels

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Abstract. The linguistic expressions scientists and educators use for energy are in most cases expressions of the principal metaphor of substance, although energy is an imponderable concept. The substance metaphor is embodied and familiar to students, so we can rely on it as useful for helping them develop a productive framework for understanding energy.

In this paper we will introduce a laboratory course for student teachers of primary school and kindergarten levels using visual and gestural metaphors for introducing energy,

1. Introduction

From the perspective of an embodied mind, our conceptual system, in terms of how we both think and act, is fundamentally metaphorical in nature [1]. Language does not refer directly to the world, but rather to mental models and components thereof. Words serve to activate, elaborate or modify mental models, as it happens in the process of comprehension of a narrative [2]. On these premises we want to treat the issue of the construction of the concept of energy for the specific aim of primary school and kindergarten science education.

Although energy is an imponderable concept, physicists and scientists are able to develop a sophisticated understanding of energy that goes beyond a mere mathematical description and formalism. They investigate the multifaceted concept of energy by using models that employ conceptual metaphors [3]. Conceptual metaphors allow us to understand one idea in terms of another; they let us consider an imponderable idea in terms of a more experiential, “ponderable” idea.

The same holds for every attempt to develop a notion of energy that is significant and relevant to experience, even for children and their teachers.

Following the method presented by Lakoff and Johnson [1,4], specific examples of metaphorical language and explicit analogies describing energy have been identified in textbooks and the science education literature. These instances, grouped into themes that represent conceptual metaphors, provide a fruitful means for describing (and understanding) energy. The resulting scenario is that of a number of conceptual metaphors: energy is a phenomenon so complex that multiple coherent but not necessarily consistent, metaphors are necessary to characterize and describe it. Multiple metaphors often work together to illustrate complimentary aspects of energy.

The awareness and use of multiple metaphors are expected to be a productive resource for thinking and communicating ideas about energy.

In this paper we will review some key conceptual metaphor studies about the energy concept and discuss the substance ontology of energy. Then we will introduce a possible embodied representation for energy by means of a movie, evidencing the various kinds of metaphors at its base. Finally, we will describe the activities of a didactic laboratory for student teachers of primary school and kindergarten employing the movie as an initial hint, with a synthesis of the specific achievements of the students.

2. Conceptual metaphor studies about the energy concept

2.1. The substance ontology



Different areas of physics use different models and metaphors for energy and therefore conceptualize energy in different ways, but no matter the particular sub-discipline, energy is described using the substance metaphor, which results from our experience with the material world [3]. According to Lakoff & Johnson “Understanding our experiences in terms of objects and substances allows us to [...] refer to them, categorize them, group them, and quantify them – and, by this means, reason about them” [1].

The metaphors physicists commonly use in research activity are:

- energy is deposited
- energy is cause (enables a particular phenomenon)
- energy is fuel (a resource).

All these metaphors are expressions of the principal substance metaphor. Also thinking in terms of forms of energy is a consequence of the substance-like metaphor for energy.

Lancor shows that the particular concept called to mind when one hears “energy” depends on the context. Most scientists have a working definition of energy that is useful in their field of research [5]. From an investigation across different scientific contexts, 5 qualities that characterize the role of energy have been identified:

1. energy conservation (energy can neither be created nor destroyed)
2. energy degradation (the total amount of usable energy in a system may decrease over time)
3. energy transformation (energy can be transformed from one form to another)
4. energy transfer (energy can be transferred between components in a system)
5. energy source (energy can be added to a system).

Again, all these characteristics are part of the principal substance metaphor.

The analysis of textbooks and of science education literature for biology, chemistry, and physics, highlights conceptual metaphors that, together, confer to energy the previous 5 qualities (in parentheses):

- energy as a substance that can be accounted for (1)
- energy as a substance that can change forms (1, 3)
- energy as a substance that can flow (4, 5)
- energy as a substance that can be carried (4)
- energy as a substance that can be lost from a system (2, 5)
- energy as a substance that can be stored, added, or produced. (4, 5).

Scherr et al. use a theoretical perspective based upon embodied cognition for understanding energy and identify three main ontologies for energy in physics discourse of learners and experts [6]:

- energy is a substance-like quantity
- energy is a stimulus
- energy is vertical location.

For these authors, a substance-like ontology for energy supports the following features:

- energy is conserved
- energy is localized
- energy is located in objects
- energy can change form
- energy is transferred among objects and can accumulate in objects.

From this synthetic analysis of literature, we find a coherent multifaceted picture for the conceptualization of energy; nevertheless, a common ontology as a substance-like quantity is used, both in the scientific disciplines and in its didactics.

Students’ use of the substance metaphor has often been considered a misconception, reflecting a flawed, unscientific understanding of energy. However, on the basis of the previous analysis, the vast majority of discourse about energy implies that it is a substance, so we can see the use of this metaphor as a productive resource for making progress toward the development of the scientific concept of energy and its effective use in the interpretation of the dynamics of real systems.

Care must be taken about the possible misleading qualities of material substances that are not applicable to energy, such as material substances can be pushed, are subject to friction, can be

consumed, have inertia and are sensitive to gravity, have a volume and a surface. Nevertheless, evidence suggests that learners are able to navigate the subtleties involved in thinking of energy as a substance-like quantity rather than a material substance [7,8].

2.2. *The embodied representation for energy*

Standard graphical representations of energy – bar charts, pie charts, sketches, diagrams, support the learning goals of conservation and tracking. These tools represent energy as being conserved, localized, and changing form, but they do not give a dynamic representation, showing energy accumulating in objects, or representing the complexity of energy transfers and transformations as physical processes unfold in the real world.

Embodied representations are both visual and gestural rendering of scientific phenomena, and learning activities in which participants act jointly to construct scientific ideas.

An embodied representation is richer than a simple verbal or graphical representation: in addition to verbal and visual metaphors, we can have gestural metaphors unfolding in time. Embodied representations support the coordination of multiple sign systems for displaying meaning, the scaling of imagined events to human size, and the symbolic identification of the self with a physical entity [9]. An example of embodied representation of energy is *The Energy Theater* [9]. It uses the human body to symbolize physical entities and it makes explicit use of a quasi-material substance metaphor. Each participant identifies as a unit of energy, that have one and only one form at any given time. The enactment represents the energy transfers and transformations in a specific physical scenario. Objects correspond to regions on the floor.

As energy moves and changes form in the scenario, participants move to different locations on the floor.

In our didactic laboratory, we propose an activity of embodied representation of energy that is coherent with the substance-like ontology, but different from *The Energy Theater* in an important aspect. It is introduced by a movie that suggests the roles of actors, the scenario of the play, and the process of making energy available and using and exchanging it.

3. A didactic laboratory for student teachers of primary school and kindergarten level

3.1. *The “Perpetuum Mobile” movie*

The movie presents an allegory of the Earth as an open flow system. An inventor attempts to create a perpetuum mobile consisting of a series of devices in a circle (Fig. 1a): a lamp, a solar cell, an electric water pump, a water wheel and a generator feeding back to the lamp [10]. The working quantities between these devices (electricity, light, water, and motion) are symbolized as spirits that carry and hand over dust (energy) as the processes in the machine are running (Fig. 1b). In every energy exchange, some energy is lost and causes the production of heat (symbolized as a snake spirit) (Fig. 1c). At the end, to make the machine work, the energy losses are replaced by an external source, the Sun (Fig. 1d).

The energy representation in the “Perpetuum Mobile” movie is coherent with the continuum physics paradigm: energy takes the same form in every branch of classical physics. It is not considered the cause of a particular process, rather, it is a principle regulating the interplay of natural phenomena. We need to understand the behavior of the underlying extensive quantities and their potentials (and potential differences) if we want to describe phenomena and apply the concept of energy. These quantities are the actual agents that work: in their interactions, they release energy (make it available, when their potentials drop) and absorb or use energy (when their potentials rise). They are energy carriers: an energy chain can be thought of as a series of carrier quantities that make energy flow [11]. Energy is conceptualized as substance-like conserved quantity; electricity, light, water, and motion are agents (or patients) that exhibit several aspects: they are fluid-like substances, their intensities are levels, they are containers of energy, and carry it from element to element. Table 1 reports the metaphor analysis of the verbal language of the narrator. The visual and gestural metaphors used in the movie can be synthesized as follows:

1. Energy is a substance-like quantity that:
 - Can be poured

- Can be absorbed
 - Can be emitted
 - Can be exchanged (made available and used)
 - Can be lost
2. Electricity, water, light, motion, and heat are
 - agents
 - containers of energy
 - carriers of energy
 3. States (intensities) of electricity, water, light, motion, and heat are vertical levels
 4. The sun is a source of energy

3.2. An energy laboratory with the “Perpetuum Mobile”

The movie is used in a physics course for about 160 student teachers of primary school and kindergarten levels of the Master’s Degree in Primary Education at the University of Modena and Reggio Emilia and at the Free University of Bolzano, Italy.

In the laboratory accompanying the courses, the students, after watching the movie and discussing its features, are requested to:

- Explore structure and functioning of a toy
i.e. carefully analyse the toy and draw its anatomy (the parts which it is composed of) and its physiology (the dynamics of the toy by means of graphical symbols like arrows, trajectory lines etc...)
- Identify the agents that represent processes (forces of nature)
i.e. list the extensive quantities that interact in the toy and work as energy carriers
- Identify the elements or devices where the agents hand over and receive energy
i.e. find the places where the interaction of agents occurs and where the potential of one agent drops (as it releases/hands over energy) and the potential of the other raises (as it absorbs/uses energy)
- Draw process diagrams with the energy carriers, the devices, and the energy fluxes
i.e. represent graphically the series of carriers with the energy fluxes, using conventional symbols for extensive quantity and energy flows, energy made available and used, extensive quantities and energy storage [12,13]
- Design and dramatize an embodied *Energy Play*: a dynamic representation of the functioning of the toy according to the process diagram and similar to the “Perpetuum Mobile” movie.

In the embodied *Energy Play* students act as the agents, and carry and exchange energy, symbolized by confetti [14], see Fig. 2. In Table 2, we summarize the rules for the design of the Energy Play and compare them to those of The Energy Theater [9]. In the Energy Play, energy has only one form: energy (confetti). Processes are the results of the agents (the students) acting across the system and interacting in specific devices (places where students exchange confetti). The students can use their behaviour and attitude to adequately represent the changes occurring in the agents, i.e. the potential drops and rises. The energy loss and consequent increase of entropy are represented by the confetti falling on the floor during the exchanges and being picked up by the new (thermal) agent being generated.

4. Results from students

Information about the students’ learning is obtained from a session of the final exams after the laboratory. Students have to present and discuss their process diagrams of the functioning of the toy.

The students, in general, show that they are able to:

- Conserve energy
- Identify all the agents (energy carriers)
- Recognize that each agent has different states: it is at high or at low potential
- Interpret the energy made available as due to a drop of potential
- Interpret energy absorption/use as due to a rise of potential

- Recognize that every interaction involves the production of heat
- Identify processes of accumulation in and of release of energy from stores
- Explain the notion of energetic efficiency

Moreover, students are able to explain, in just a few minutes, the functioning of a complex toy (The Drinking Bird: https://en.wikipedia.org/wiki/Drinking_bird) shown them for the first time during the exam (typical results: roughly but correctly: 70%, correctly in detail: 30%).

5. Summary

We have shown how it is possible to treat the concept of energy with student teachers of primary school and kindergarten levels using visual, gestural as well as verbal metaphors belonging from the principal substance metaphor for energy.

After a review of some key conceptual metaphor studies about the energy concept and discuss the substance ontology of energy, we have introduced a possible embodied representation for energy by means of a movie, evidencing the various kinds of metaphors at its base. We have described the activities of a didactic laboratory for student teachers employing the movie as an initial hint and given a synthesis of the specific learning results of the students.



a



b

d



c



Figure 1: a) the whole perpetual mobile; b) the light energy carrier handing over energy; c) the heat energy carrier; d) external supply of energy that makes the machine working.

Table 1. Metaphor analysis of the movie verbal language.

VERBAL EXPRESSIONS	CONCEPTUAL METAPHORS
It was supposed to be the best invention ever: The perpetuum mobile, a machine that powers itself.	A machine is an agent mechanism
An unending cycle made up of light, electricity, water and motion.	Light, electricity, water, and motion are agents (as agents, they will exhibit several aspects)
However, the machine initially stands still, at rest in a state of equilibrium. It will need a push in order to start running.	-----
The push makes energy go into the generator. This energy is taken up by the electricity, causing its voltage to rise.	Energy is a substance Electricity is an agent Electricity is a container of energy Voltage is a level (aspect of agent)
The electricity uses the energy to make the lamp shine. In turn, this light becomes the energy carrier. At the same time, the electricity flows back to its original level.	Electricity is an agent Energy is a (usable) substance Light is a container of energy Voltage is a level (aspect of agent) Electricity is a fluid substance (aspect of agent)
Wherever the light shines on the solar cell, the energy is used to raise the voltage. Unfortunately, the electricity only takes a part of the energy with it...	Light is a container of energy Light is an agent Energy is a (usable) substance Electricity is a container of energy
The electricity now drives the pump that forces the water with high pressure through the pipe leading to a higher level. In the process, it gives its energy to the water and the electric voltage is lowered again.	Electricity is an agent Water is a patient Water is a fluid substance (aspect of agent) Pressure is a level (aspect of agent) Energy is a substance Water is a container of energy Voltage is a level (aspect of agent)
Gravity causes the water to flow downward by itself, releasing its energy. Via the water wheel, the energy is taken up by the momentum of the wheel.	Gravity is an agent Water is a fluid substance (aspect of agent) Water is a patient Water is a container of energy Energy is a substance Momentum is an agent Momentum is a container for energy
The motion carries the energy from the water wheel over the drive belt and wheels to the generator—and the cycle of the perpetuum mobile begins all over again.	Momentum is a carrier for energy Momentum is a fluid substance (aspect of agent) Energy is a substance
However, whenever energy is transferred, a part of it gets lost. Eventually there is not enough of it left over to start the next process.	Energy is a substance
This alleged miracle machine will never work.	A machine is a mechanism
Written off as a useless curiosity, it might find its way into a glass case in a corner of a museum where it is eventually forgotten.	-----
If the room in the museum is not totally windowless and the machine is positioned just right at a window, a new element can come into play!	-----
The sunlight shining on the machine is so strong that the amount of energy it carries is more than enough to drive the electricity in the solar cell—causing the cycle	Light is an agent Light is a carrier of energy Energy is a substance

to begin again.	Electricity is an agent/patient
The energy that is unused does not get lost.	Energy is a (conserved) substance
It causes heat to form.	Heat is a patient
As long as the sun shines, the processes continue to run. However, they must accomplish more because much more energy is coming into the machine:	Energy is a substance Electricity, water, light and motion are agents
The wheels turn faster.	Angular velocity is a level (aspect of agent)
The light burns brighter.	Brightness is a level (aspect of agent)
And it gets hotter inside the glass case.	Temperature is a level (aspect of agent)
This is because wherever energy leaves the cycle, there is friction causing the heat to increase. As long as the sun supplies energy, the amount of heat will increase expanding the air inside the glass case until...	The cycle is a mechanism Energy is a substance Heat is a substance Sun is a source of energy Heat is an agent
Now the cycle has been broken:	The cycle is a mechanism
The sun brings energy.	Sun is a source of energy Energy is a substance
It is transferred from process to process, and it is distributed without increasing or decreasing and is finally carried by the hat back into the atmosphere.	Energy is a (conserved) substance Heat is a container of energy Heat is a fluid substance (aspect of agent)

Table 2. Comparison of the rules for the design of the Energy Play and the Energy Theater (9).

	Energy Theater [9]	Energy Play (this paper)
Energy	Each participant is a unit of a certain form of energy	Confetti is quantity of energy
Extensive quantities (energy carriers)	—	Each participant is an amount of an extensive quantity
Objects/devices	Regions on the floor	Regions on the floor where confetti are exchanged
Energy flows	Participants move to different locations	Participants, carrying confetti, move to different locations
Energy changes form	Participants exit the play and others enter in their place.	Not needed



Figure 2. Instants of an Energy Play. Students pretend to be the agents, interact and exchange energy.

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