The Role of Playing in the Representation of the Concept of Energy: A Lab Experience for Future Primary School Teachers

Alessandra Landini, Enrico Giliberti and Federico Corni

Abstract Energy, particularly in introductory physics at primary school level, is often taught in terms of list of different "forms of energy" and seldom as a unifying concept underlying many aspects of the world. However, the "substance" ontology for energy seems to be particularly productive in developing understanding of energy and energy transfers. From a methodological point of view, narratives and forms of "playing" are valuable and significant representations that allow learning scientific concepts. Through a physical experience, in the form of role play, we help developing the concept of energy flow/current and storage. In this contribution, we propose a laboratory activity in which future primary school teachers represent the process of energy exchange among energy carriers. The participants are required to study a simple toy, finding the energy carriers, and the role of each of them; additionally, they have to write a story, with as many characters as the energy carriers, telling how they exchange energy in the parts of the toy. Energy conservation and heat production are perceivable in the act of exchanging confetti which represent energy. The Energy Play helps the participants to visualize the energy as a substance, even though it is imperceptible. The analysis of the students' role plays and the information collected from questionnaires give feedback about students' conceptualization of some of the most significant aspects of energy.

Keywords Energy · Role-play · Quasi-material substance metaphor

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Introduction

In the field of science education, the complexity of the concept of energy has been highlighted in several studies centered on the difficulties of learning an "imponderable" idea. Moreover, the concept itself is very common inside and outside the scientific discourse [1]. As argued by Lancor: "The way energy is conceptualized varies depending on context […] Scientists, generally, do not share a common language, even within a particular discipline […]. The interdisciplinarity of energy issues in today's society means that special attention should be paid to differences in discourse between disciplines" [2]. Besides this complexity, the possibility of misconceptions arises [3, 4], stressing the need to look at a cross-disciplinary approach.

According to linguistic research, scientists were and are often able to investigate the multifaceted concept of energy, using models that employ conceptual metaphors [5, 6]. Furthermore, they usually formulate narratives of physical phenomena involving energy and explore these phenomena within the narrative [7–9]. In a recent article, Harrer notes that "the development of the modern energy concept is reviewed to show that the use of metaphors always has been and still is necessary for physicists to make sense of and communicate ideas about energy" [10]. Fundamentally, at the heart of a narrative about energy we can find different ontological metaphors and we can better uncover students' model of energy thanks to language: "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 in comprehension of a narrative." [11]. This is the reason that moved us to take advantage of students' mental model and of the narrative way we all use to make sense of phenomena.

Theoretical Framework

We agree with Lancor when she says: "Viewing science as a set of coherent metaphors is not very different from thinking of science as a set of models; the way that we communicate scientific models is often metaphorical. Furthermore, multiple conceptual metaphors may be necessary to describe one scientific model, as is the case with energy." [2]. For this reason, we decided to focus on conceptual metaphor studies [12–14] and embodied cognition. The cognitive and learning value of using metaphor and analogy to understand a target concept are well-established: according to Treagust and Duit [15] metaphors and analogies "permeate all discourses, are fundamental to human thought and are not simply teaching tools", they are "a fundamental principle of thought and action" [16].

Lancor [2] studied students' ideas on energy by analysing examples of metaphorical language and explicit analogies, according to the theory of the embodied cognition of Lakoff and Johnson [12, 13]. The goal was to underline the use of common conceptual metaphors across different disciplines. She describes different energy mapping as follows:

- energy as a substance that can be accounted for
- energy as a substance that can change form
- energy as a substance that can flow
- energy as a substance that can be carried
- energy as a substance that can be lost from a system
- energy as a substance that can be stored, added or produced

The first mapping, describing energy as a substance residing in "containers", is very common in various disciplines: it is reinforced through graphical representation and, as the author summarizes, gives scientists "a tool to apply energy conservation quantitatively", tracking energy changes at the same time. The metaphor of "ENERGY AS A SUBSTANCE" facilitates the concepts of conservation and transfer aspects of energy.

The third metaphor, "energy flows", is often used in textbooks. Lancor highlights the usefulness of this metaphor, talking about energy transfer in a system: "Thus this metaphor highlights the transfer of energy downplaying energy transformation". She concludes valuating this metaphor as a convenient way to discuss continuous, uniform energy transfer through a system.

The fourth metaphor focalizes on the substance contained and carried through energy carriers. Lancor argues: "it is more scientifically accurate to view an energy transformation as energy being transferred from one carrier to another. (…) The energy has a different carrier". This is right also for Falk et al. when they suggest that it is more scientifically accurate rather than thinking of energy as changing form [17].

Lancor's studies emphasize the models and the metaphoric framework of students' comprehension of energy, taking into account that they form "a set of coherent conceptual metaphors for energy" [2]. Although the limitations of the substance metaphor are well recognized in several studies [18–20], Lancor supports the idea to use this metaphoric framework as a formative assessment tool, useful to monitor students' conceptual development.

This formative assessment should be a part of the teaching-learning process. Metaphors are sometimes difficult to interpret, but they are very useful in the evaluation process: the students' ideas of energy and the underlying substance metaphor could be considered as a way of evaluating their ideas on this complex concept. For this reason, it is essential that teachers are aware and make use of these aspects in the evaluation process of pupils.

Close and Scherr [21] selected the substance metaphor for energy "as a primary focus of our instruction because of its advantages teaching conservation, transfer and flow". According to the author it shows the following features:

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

The authors claim: “These features constitute a powerful conceptual model of energy that may be used to explain and predict energy phenomena”.

Purpose and Methods of the Study

While agreeing with Close and Scherr [21] on the ontological choice, in this research activity we highlight some considerations about instruments that could be used to allow a slightly different representation of energy during the teaching-learning process.

To facilitate this process, teachers need a good experiential project. In our proposal, this project should be:

- coherent with the above set of metaphors;
- based on the idea of embodied cognition.

We are suggesting here a set of training activities, addressed to pre-school teachers, in the form of Research Based Learning, in which a narrative approach to energy, together with a well-built context of playing and embodied simulation, allows teachers to have experiences that can lead to a good formalization of the concept of energy. The aim is a conceptualization of energy that explains everyday experience and, at the same time, fosters a deep scientific comprehension of energy.

We have already presented a revised use of Energy Flow Diagrams, assessed during an innovative path for the energy concept comprehension [22–25]. This cognitive and didactic tool, based on the quasi-material substance metaphor, and figuratively representing the metaphorical aspects of energy through the natural language, allows a narrative process of explanation supported by graphic symbols. The symbols, specifically designed to represent the energy flow through energy carriers, seem to support a better use of the language according to energy features as a fluid substance [25].

We suggest the image of a substance-like conserved quantity transfer to account for the proportionality between the quantity and intensity drop of the “acting” force (available energy) and the quantity and intensity rise of the “driven” force (absorbed energy). This use of the language and the related natural metaphorical expressions seem to incorporate the aspects of conservation, accumulation, transportability and transferability of energy. Furthermore, energy is introduced because of the need of accounting for phenomena where two natural phenomena interact in a device (e.g. wind and rotation in a windmill as in Fig. 1), whose operation can be narratively and formally described.

The purpose of this study is to analyse a specific use of these energy flow diagrams and a form of role-play (as a narrative simulation of processes), connected to the fluid substance metaphor and the theory of embodied cognition, both to suggest students’ comprehension and to investigate their conceptualization of energy. In this sense, the role-play is seen as a metacognitive context for the expression of the mind through

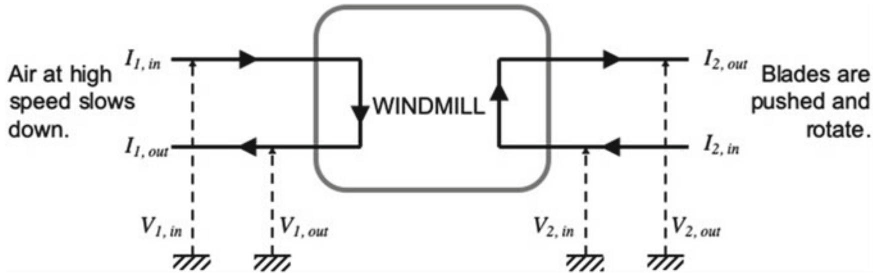

Fig. 1 Air and angular momentum interact in a windmill

the body, in which the language becomes fertile ground for the authentic evaluation of the understanding of natural phenomena.

The specific research question addressed in this study is: «To what extent does the metaphorical use of language and the related role-play affect students' comprehension of energy features?»

The science literature and linguistic and cognitive studies outlined above led us to hypothesize that the development of understanding of the energy concept could be facilitated by the quasi-material substance metaphor and confident use of language during the laboratories [26]. Furthermore, we hypothesized that specific use of diagrams connected to narratives and a specific use of role-play, connected to sensory-motor experience, could be conceptually productive.

In terms of Formative Assessment for Learning [27] we decided to analyse role-plays realized by pre-service teacher students of the Faculty of Education in Bressanone (UNIBZ) during an energy lab, coherent with the theoretical framework presented above. The study consisted of a 4 h activity for 59 students in their first year of university who had not completed their planned physics course yet.[1] The purpose of the lab for the students was to produce role-plays concerning energy for didactic use: after a narrative introduction to the topic through the vision of an animated tale, students studied a toy with its parts and mechanisms in groups and were asked to identify energy carriers and their roles. Then they wrote a narration, with as many characters as the energy carriers, telling how they act and exchange energy in the parts of the toy. Finally, students were asked to represent the energy carriers in a play, with confetti playing the role of the energy carried. The focus of the representation was energy and its transfer among carriers through different exchanges, showing the effects on qualitative aspects of the carriers. As a final activity, students viewed and commented all the role-plays.

Students' role-plays were then analysed. The research included two main steps:

1. role-play analysis, from the narrative and metaphorical point of view;

[1]The duration of the laboratory was dictated by organizational needs of the university to which the research group adapted this very first experimentation. Following the experimentation, which gave encouraging results, the laboratory was proposed in a training course for pre-service teachers in the third year of their Masters degree with a total duration of 16 h.

2. analysis of students' conceptualizations using video, integrating language analysis with gesture analysis.

In addition, evidence of the development of students' understanding of energy was collected in two different ways: by a questionnaire set after the Lab experience and by logbooks (cognitive autobiography) set one week later. The two assessment tools will be the subject of further study.

In this work we will specifically present the results of the role play and of a questionnaire analysis to emphasize the use of a Narrative Assessment for Learning to understand students' conceptualizations and to investigate their metaphorical use of language and gestures.

Role-Play as Incarnate Simulation: A Possibility to Make Energy "Ponderable"

The role-play generally involves a situation, that is a dynamic context where at least two subjects can be distinguished, with their role relationships, into a place, concerning a topic. In our case the agents are the energy carriers and the energy exchangers who, with their role relationships, into a system/space and their reactions, share the situation where the energy (confetti) is transferred.

For each situation/story it is necessary to identify [28]:

- where (place/part of the system) it happens,
- when it happens (time),
- who happens to (carriers/agents; exchangers/patients),
- what relationships are there (correlations/relationships with potential differences),
- what it is (situation/problem).

The advantages of our Energy Play are on different levels:

- on the semiotic level, this narrative technique combines words with facial expressions, gestures, and objects, which are actually manipulated or suggested by the gesture itself, take shape and life;
- on the psychological level, being a simulation, it is experienced as a game, stimulating an active and emotional participation;
- on the neurocognitive level the incarnate simulation and the "physicalization" of inanimate objects, activates sense-motor areas of the brain that asymmetrically refer to other areas of language and understanding;
- the social level also falls into role-play comprehension mechanisms: the latter can be a kind of apprenticeship of relational and emotional models and serve as experiential context for understanding reality.

Analysis and Results

This work on student role-play concerning energy arose out of studies regarding the relationship of mind with body and studies on representation. Moreover, this research is designed to examine a much broader spectrum of energy features, including the contribution of gesture, bodily perceptions and interaction. The story and the number of sequences are necessarily small, but the theoretical structure used in this analysis can serve as an example of integrated reading, where oral and body narration make a contribution to describing the procedures and the conceptualization processes in progress. We have distinguished some nodes of interest to evaluate the conceptualization of energy according to the ontology of the fluid substance: Were all parts of the energy diagram there? Which carriers were present? Which energy exchangers were present? Was there a relation that showed the difference of potential before and during the exchange? Does energy conservation emerge? Is the metaphor of the fluid substance present?

The following pages show a role-play analysis for a "Windmill generator"[2] and some considerations about the results of this "narrative incarnate simulation". Table 1 is the result of a qualitative analysis autonomously realized by three researchers and then shared according to the criteria outlined above.

The results obtained, relating to the research questions, can be summarized as follows:

- all the carriers are present and correct;
- all exchangers are present, but during the role-play, we found that they were acted more as agents rather than simply mechanisms that allow the energy exchange;
- the difference in potential is not significant.

The use of the energy flow diagram, connected to the metaphorical use of language and the related role-play, seems to affect students' comprehension of the energy features, but we could not find a clear conceptualization of potential difference. The idea of energy conservation is present.

In this paper, we cannot provide a full analysis: semiotic, psychological and social factors would deserve a more thorough and deeper discussion. However, two themes that are at the basis of the theoretical framework need to be emphasized: the connection between natural language use and the use of the body in the narrated simulation. From the linguistic point of view, students' concepts of energy appear to arise from narration, especially in the form of quasi-material substance metaphor; moreover, the analysis draws attention to a multi-metaphorical space around the fluid substance metaphor: More is up, Changes Are Movements, Causation, and Part/Whole schemata, to name but a few. Integrating oral and visual metaphors and gestures

[2]The energy flow in the toy can be outlined as follows: First Carrier: Free Air/Wind—Exchanger: Rotor—Second Carrier: Angular Momentum—Exchanger: Gears—Third Carrier: Angular Momentum—Exchanger: Dynamo—Fourth Carrier: Electricity—Exchanger: Lamp—Fifth Carrier: Light.

Table 1 Video sequence from 1 to 7

Sequence	Narration and linguistic indicators	Gestural indicators	Energy conceptualization as a quasi-material substance
1st sequence	*The wind is full of force and will to play* The potential is high (the wind is a container of a fluid substance; it is associated with a spatial location, even if it seems spread out)	Two students are smiling, keeping confetti in the hands, dancing excited (the emotion is in the container and the level is up-more is up)	The potential is high. (energy as an amount of substance in a container) The carrier MOTION (wind) seems to have a certain amount of energy in itself
2nd sequence	*It (wind) meets a nice sleeping rotor and he desired to play with him* (change of level: from sleeping to awake) (causation: playing with the rotor causes the rotor to wake up)	The two students look at the rotor, they look each other, smile, and start to move forward to the rotor (causation: the wind provides the effect on the rotor, which it will turn)	The carrier MOTION (wind) moves to the rotor (energy flows) The wind brings energy to the rotor (energy is transferred)
3rd sequence	*The Wind runs to meet him [the rotor] and the blades, crazy of joy, started to rotate* (causation: the blades turns because of the wind) (change of potential: from low speed to high speed)	Students head off quickly against the blades, represented by four other students, who, happy, begin to spin on themselves, simulating the rotation of the rotor and bringing the confetti. The wind goes away. As the four students turn around, they drop a little amount of confetti (causation) (exchange of confetti) (loss of confetti) (the carrier WIND disappears)	MOTION brings energy from LINEAR MOMENTUM to the ANGULAR MOMENTUM (Flow of energy from the wind to the blades; the energy flows through the exchanger (blades) the energy flows There is a loss of energy during the exchange)

(continued)

Table 1 (continued)

Sequence	Narration and linguistic indicators	Gestural indicators	Energy conceptualization as a quasi-material substance
4th sequence	*She did not notice, however, that there were two very hungry gears next to her, so hungry to devour much of the energy* (interaction) (energetic state as a resource)	Three students begin to rotate representing the largest toothed wheel, two other students simultaneously move and represent the smallest wheel: while turning, they pretend to eat the confetti and lose a bit of it (interaction) (confetti are transferred from one gear to the other) (energetic state is a possession)	Flow of energy through the gears: The energy flows through the exchanger-gears. During the transfer there is a loss of energy
5th sequence	*Full and tired of eating, they gave part of the energy to their dynamo friend, who slowly began to move her fingers, producing electricity* Causation (whole/part metaphor)	The gears, represented by the five girls, simulating satiety and fatigue, pass the confetti to the dynamo represented by three crouched girls, who stand up thanks to the confetti (interaction) (confetti are transferred from one gear to the dynamo)	There is a decrease in speed through the gears, due to friction The energy flows thanks to the ANGULAR MOMENTUM through the dynamo. The angular momentum has a high potential, but we cannot notice the difference in potential after the exchange

(continued)

Table 1 (continued)

Sequence	Narration and linguistic indicators	Gestural indicators	Energy conceptualization as a quasi-material substance
6th sequence	*The generous and gentle electricity decides to accompany her friend energy to the doxy bulb* (desire is moving: the electricity flows to the doxy bulb)	Two students, representing electricity, receive confetti from the dynamo; some confetti are lost The electricity seems to have high potential (students are again excited) quickly bring it to an immobile student, representing the light bulb Interaction Confetti are transferred from the dynamo to the bulb (potential change from low to high)	The ELECTRICITY carrier receives the energy from the ANGULAR MOMENTUM carrier through the dynamo Energy is carried by electricity Some energy is lost during the transfer
7th sequence	*The bulb happily animated, generating light and illuminating the whole world* (causation) (Change of potential from low to high)	Through the lamp you can see confetti flowing to the last student, who impersonates the final carrier, the light. The confetti, arrived at the end of the path, are less than those at the beginning of the journey, because a part of them has been lost in the transfer from one carrier to the other. However, the total amount of confetti present on the scene remains the same (interaction) (source-path-goal schema) (part/whole schema) (real value is substance) (balance schema)	Through the lamp the electricity carrier makes the energy flow to the LIGHT While flowing through the lamp, the energy decreases again, which causes the production of entropy The amount of energy that enters into the system is the same amount of energy that comes out of the system Electricity brings energy to light through the bulb Some energy is lost in the transfer Conservation of the amount of energy

seems to enrich the experience: different Image Schemas are connected, and this seems to create inter-textual and intra-textual coherence in the narration [29].[3]

In the first sequence, for instance, the narrator says: "The wind is full of force and will to play"; the underlying analysis is "The wind is a container of a fluid substance; it is associated with a spatial location, even if it seems to be spread out". At the same time narration implicitly focuses on "Energy as an amount in a container". This quantitative aspect has been integrated by gesture and facial expressions, which stress the qualitative aspect of the phenomena: Two students are smiling, keeping confetti in their hands, dancing excitedly (the emotion is in the container and the level is up-More is up). This seems to support the idea that the carrier, air in motion, has a certain amount of energy in itself with a high level of potential.

In order to evaluate the functionality of the laboratory with respect to the development of the scientific concept of energy, self-assessment questionnaires were given to the 59 students attending the laboratory. We will show the analysis of the answers related to the question: "Describe briefly what happened to the energy-confetti during the playing that you have represented together with your companions". We analysed the answers/narratives in qualitative terms, based on three main themes: (1) Presence of the Fluid substance paradigm; (2) Presence of carriers and exchangers; (3) Conservation of energy. In summary, the data show:

- theme 1 present in 26 narratives out of 59
- theme 2 present in 36 narratives out of 59
- theme 3 present in 32 narratives out of 59

Seventeen narratives comprise all three themes, and 26 contain at least two of the themes, bringing to more than half the number of narratives with elements of the chosen energy paradigm. We would like to highlight how in a 4 h workshop it was possible to involve first-year students who had not attended the Physics course yet in the conceptualization of such a complex subject. The paradigm presented, although difficult, interested them and has been productive for the initial conceptual development, which has brought new and complex themes in half of their narratives, while in the 29% of student's stories all three main themes have been introduced.

[3]Kovecses says: "I suggest that image schemas, domains, and frames are all conceptual structures that can be found at what, in previous work, I called the supraindividual level. This is the realm that informs the basic ontology of conceptual systems. These are the structures that we have in long-term memory and that provide the conceptual substrate of meaning in general and meaning in language in particular".

When we embed these structures in an embodied narration, in a "communicative" representation of a phenomenon, we think to perceive another level of structure; Kövecses adds "we put this huge amount of tacit knowledge to use in order to achieve particular goals (social, expressive, rhetorical, etc.). The job is performed online by individual speakers in specific contexts who manipulate and modify the conceptual structures in long-term memory according to their communicative goals. The conceptualization process and the language that is used are, in this case, fully contextualized. It is at this level that we utilize mental spaces, or, equivalently, scenes or scenarios, as suggested by Musolff, that are not part of our routinely used cognitive and linguistic repertoire".

Conclusions

Energy role-plays are useful to enhance the idea of energy as a substance and, at the same time, to evaluate the students' level of conceptualization: moreover, they help to visualize the flow of energy together with the energy carriers and to "show" the interaction between the carriers in terms of change of potential. These findings support the idea that embodied simulations and "physicalization" of inanimate objects can improve students' comprehension of energy features. Energy Play connect the simulation to the metaphorical conceptualization and affectively engage the actors, creating a contextualised and communicative situation.

Understanding energy as a substance, unaltered and distinct from both the carriers and the exchangers, could avoid confusing conceptualization of this imponderable and important subject. In such a way, we suggest that the concepts of *energy flow* and *conservation* should be introduced after a specific training activity to primary teachers and then to children, followed by other aspects of energy, deepen through incarnate simulation and dynamic representations in the form of Energy Play.

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