# Hands-on, minds-on activities to construct the concept of energy in primary school: Experiments, games and group discussions

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(Received 27 July 2011; accepted 14 November 2011)

## Abstract

In this article we present hands-on and minds-on activities about teaching and learning the concept of energy in primary school. The concept of energy is constructed by starting from the cause-effect relationship and focusing on the differences of potentials (increases and decreases in potentials) of the extensive quantities involved in the process of interaction being analysed. Subsequently, in order to lay the foundations for the concept of conservation, students are guided by the teacher to grasp the relationship between potential differences and the associated extensive quantity currents to build a (qualitative) budget law (relationships of direct or inverse proportionality): some increase in potential (effect) of an amount of an extensive quantity, at the expense of some reduction in potential (cause) of another amount of extensive quantity. The energy concept, then, arises from the identification of the "proportion" between two processes taking part in an interaction. The activities we propose are guided by the teacher following a didactic cycle with a semiotic approach designed to overcome the fact that the child may remain unaware of the connection between the concrete experiment and its underlying scientific concepts. This cycle, that leads to the transition from the concrete experiential level to that of the decontextualization and building of scientific meanings, includes experimental activities and games, individual production of outputs (oral and written texts, drawings, sketches, gestures, gazes and sounds...) and group discussions. We will present the activities and the didactic materials experimented with in a 5th grade classroom as well as the linguistic criteria defined and used to analyse pupil worksheets and conversations. We will also share the results which highlight evidence how children express their thoughts using "signs" that the teacher can then use to create a link between the concrete experiential plane and the conceptual one.

**Keywords:** Concept of energy, Force Dynamic Gestalts, Semiotic mediation.

## Resumen

Este artículo presenta un conjunto de hands-on minds-on experiencias educativas que tratan el cocepto físico de energía en la escuela primaria. El concepto de energía se construye a partir de la relación causa-efecto y se centra en las diferencias de potencial (aumentos y disminuciones en los potenciales) de las cantidades extensas involucradas en el proceso de interacción que se analiza. Posteriormente, con el fin de sentar las bases para explicar el concepto de conservación, los estudiantes son guiados por los docentes a comprender la relación entre las diferencias de potencial y la cantidades extensas de corrientes asociadas a la construcción de una ley de relaciones de proporcionalidad directa o inversa: cierto aumento en el potencial (efecto) de una cantidad extensa, a expensas de una reducción en el potencial (causa) de otra cantidad extensa. El concepto de energía, entonces, surge de la identificación de la "proporción" entre los dos procesos que participan en la interacción. Las actividades que presentamos han sido propuestas y guiadas por los docentes durante un ciclo didáctico basado en un enfoque semiótico diseñado para que el niño advierta la conexión entre las experiencias concretas y los conceptos científicos subyacentes. Este ciclo permite la transición desde el nivel de la experiencia concreta a la de descontextualización y construcción de significados científicos e incluye actividades de experimentación y juegos, elaboración individual de textos orales y escritos, dibujos, bocetos, gestos, miradas y sonidos y también discusiones de grupo. Se describen las actividades y los materiales didácticos utilizados para la experimentación con una clase de 5º grado (10-11 años), así como los criterios lingüísticos definidos y utilizados para analizar las hojas de trabajo de los alumnos y las conversaciones. También se especifican los resultados que ponen de relieve cómo los niños expresan su pensamiento con "signos", lo cual puede ser utilizado por el docente para crear un vínculo entre el plano concreto de la experiencia y el conceptual.

**Palabras clave:** Concepto de Energía, Fuerza Dinámica Gestalts, Mediación Semiótica.

**PACS:** 01.40eg, 01.40.gb, 01.40.J-, 01.40.Di, 01.40.G, 01.50.fh,01.50.Wg **ISSN 1870-9095**

# I. INTRODUCTION

The proposed hands-on, minds-on activities, addressed to primary school students, meet the following requirements:

1) They follow pathways that aim at a continuum between everyday experience and interpretation of spontaneous and scientific knowledge;
2) They achieve this continuity coherently with the children's reasoning;
3) They promote the guiding role of the teacher in constructing meaning;

The presentation of the activities for teaching/learning the concept of energy requires a brief introduction of the theoretical and methodological frameworks to which they relate.

## A. Theoretical-disciplinary framework

We refer to the results of cognitive linguistics [1, 2, 3]. These authors study basic figurative structures of the human mind which are used to conceptualize natural, psychological, and social phenomena and processes. These figures of thought are based on schematic structures that develop early in the life of a child and are used to interpret reality through their metaphorical projection onto phenomena. Fuchs [4] has identified a structure, the Force Dynamic Gestalt (FDG), which underlies both everyday language and that of formal science. The three schemas that form the basis of the FDG are quantity (size), quality (intensity and its differences), and force or power. The third of these schematic aspects is the source for the notion of energy. Our hypothesis is that we can construct the scientific concept of energy starting in early childhood if we nurture these everyday figurative conceptualizations that are, at the same time, the schematic structures of formal science.

In our path, the foundations of the concept of energy lie within the cause-effect relationship (force/power) because this is the child's point of view. The energy concept is developed through identifying the association between falls and rises of the various potentials, the flow of extensive quantities involved in the interaction processes under analysis. The basic concept of energy, then, arises from identifying the "proportion" (semi-quantitative in primary school) between products of fluxes of quantities and of potential differences [5].

## B Didactic methodological framework

Hands-on, minds-on activities may be appropriately designed according to the Vygotskian hypothesis that shared meanings are generated within the social use of artifacts while carrying out a task. For the semiotic potential of an artifact to emerge, both a task and connections with personal meanings and scientific knowledge are required. Without these connections the child may remain unaware of the relationship between the concrete experiment and its underlying scientific meaning [6]. Overcoming this difficulty, which leads to the transition from the concrete experiential level to that of the decontextualisation and construction of scientific meanings, requires the fundamental guiding role of the teacher. The child, stimulated by contextualised questions, expresses his/her thought through language which makes use of particular words, images, gestures, and sounds. The teacher should be trained to pay attention to the pupils' discourses, to recognise and emphasise particular "pivot signs" which can be used to create the link between the experiential plane and the conceptual one through individual, group or collective discussions.

In this paper, we present the strategies used in the hands-on activities in order to stimulate children's thinking. We also present the results of the evolution of pupils' language as shown in their written answers given on worksheets and in their conversations, and the analysis in terms of pivot words that correspond to the underlying path concepts. Teachers may be trained in this methodology to stimulate children's thinking, to conduct discussions and to evaluate the effectiveness of their actions.

# II. ACTIVITIES AND MATERIALS

The materials consist of a story, worksheets and a suitcase containing games for laboratory activities. They have been used for a course of 6 lessons, each lesson lasting two hours. They respond to the following two aims:

1) Facilitating the identification of relevant variables, *i.e.*, quantity (size), quality (intensity) and its differences in cause-effect relationships and their mutual relations;

2) Fostering the decontextualisation of the identified variables, that is accompanied by a gradual evolution in language, moving from a common and natural language towards an increasingly precise and formal one.

In this paper, we highlight the different types of questions we used to guide the various activities and discussions. These questions are the elements that are specifically designed to promote the transition from hands-on to minds- on activities.

In the energy path, two types of questions were used: "artifact" questions that invite observing and investigating how a device (a toy) functions, and "embodied" questions that require students' self-identification of the extensive quantities involved in the process being studied. Both questions are included in the path through a story that serves as the background for all of the activities [7]. The story is divided into two parts, each with different purposes:
I) The first part, which incorporates experimental activities, is aimed at recognizing the relevant variables of the processes. It describes two problematic situations: moving a cart filled with pots of flowers to a swimming pool with the help of the wind (see Fig. 1); moving a cart loaded down by stones with the help of an inflated balloon.

Against this narrative backdrop the experimental activities are incorporated: the wind is generated using a hairdryer, the cart is represented by a toy car that can be moved by reaction using an inflated balloon that is mounted on it.

**FIGURE 1.** A scene from the story.

In the worksheet with “artifact” questions, pupils are asked to give an individual or a group answer concerning:

- The structure and functioning of the experimental apparatus;
- The relationships between its parts;
- How the problematic situations posed by the task may be solved;
- Their prediction of the behaviour of the apparatus under initial conditions;
- Their interpretation of the observations.

The "embodied" questions, by contrast, awaken children’s imagination whereby they picture themselves as an extensive quantity or its quality during the different stages of the interaction. For example, in the activity with the toy car and the hairdryer we asked the following questions:

- Imagine the hairdryer is still off and that you are the car. What do you feel?
- You are the ambient air. What do you feel?
- Imagine now that the hairdryer is turned on and that you are the air passing through. What do you feel?
- You are the air exiting the hairdryer. What do you feel?
- You are the air hitting the car. What do you feel?
- Now you are the toy car when the air arrives. What do you feel?
- Finally, you are the car just when the hairdryer is turned off. What do you feel?

This activity was followed by a group game in which each pupil had to imitate an action (*e.g.*, cycling, moving a windmill, inflating a bicycle tire, burning some pieces of wood). The other groups had to guess the action. Finally, the members of each group had to describe and explain what they had represented. The aim of this last phase was to evaluate whether children were able to correctly use the linguistic expressions that were the focus of the previous activities.

Before beginning the second part of the story, additional laboratory group work was carried out. Each group was assigned to explore a game (a windmill with led light, a pot-pot boat, a dynamo torch, a solar panel frog) using an “artifact” worksheet and then to describe and explain to their peers the objects and the process they observed and played.

II) The aim of the second part of the story was to guide children toward the decontextualisation and the generalization of the concepts. The main activity was the discussion led by the teacher. The story offered different contexts in which pupils could recognize extensive quantities and their potential (a hot and cold lake, rivers falling from different heights, sandwiches filled with foods of different nutritional value) and processes (a storm, the wind blowing on wind turbines, photovoltaic panels illuminated by the sun, an overflowing dam, discharging walkie-talkies, a sawmill operated by a water mill, ...).

After reading the story relating to these scenarios, the pictures from the story were then shown again to the children and they were asked to describe and interpret what they had observed, possibly using the words that were previously shared. This discussion was followed by a final group activity that consisted in observing and exploring the same game (sand mill) and sharing the results. This last activity was not accompanied by worksheets and was used as a final test.

## III. ANALYSES OF THE PUPILS’ WORK-SHEETS AND CONVERSATIONS

The results of the evolution of language relate to the whole path. The analysis of the pivot words, as a means of tracing the linguistic evolution, only refer to a representative segment of the path.

In this work, we draw on Talmy's Force Dynamic Pattern (FDP) [3, 8] for the following three reasons:

a) FDP is Talmy's semantic category used to express how entities interact in force/power contexts. Thus, it includes the linguistic notion of "causative" reasoning;

b) Since this linguistic structure is part of the naive way of children’s thinking, it should be easy and consistent to detect;

c) We expect it to evolve if the child moves from a "primitive" and natural way of thinking to a "scientific" way of thinking as led by the teaching process.

We consider the Steady-State FDP, that underlies all more complex FD patterns. Talmy has identified it as the opposition of two forces. The language distinguishes the role between two entities exerting their force in the interaction: the Agonist, the focal force, and the Antagonist, its opposing force. The salient issue in the interaction is whether the Agonist entity is able to manifest its tendency or whether it is overcome by the Antagonist entity.

The Steady-State FDP is taken by us as a descriptive, rather than an interpretive, structure because it expresses the Aristotelian idea that the agonist “exerts a force by virtue of having an intrinsic tendency toward manifesting it” [3]. In order to build a quantitative tool for analysis, we consider that the language reaches a higher level if terms that denote variables and the specification of relationships between them are added to this basic structure. The language evolution reflects the meaning construction of the scientific concept of energy, in which the ideas of interaction and cause-effect are complemented by the identification of energy as a constant amount that flows. Based on these considerations, we have developed a scale (Table I) for describing language evolution in ascending order from 0 to 5.

Level 0 indicates the presence of a more primitive structure of Talmy's pattern where we find the Agonist or the Antagonist alone (*e.g., the blades move; you correctly direct the wind, as far as it goes*) or where both entities are present in the sentence without there being an interaction but are related only to verbs of motion (*e.g., the wind moves the blades*). We similarly place in this level Talmy's FDP in which the cause of the process is attributed to an external factor and not directly involved in a cause-effect relation (*e.g., it works with the switch on*), without properly identifying the Agonist or the Antagonist.

Level 1 indicates the presence of both the Agonist and the Antagonist in typical FDP with verbs that underline the implicit idea of a force exerted between them (*e.g., the hairdryer makes the air move; the windmill is driven by the wind; the wind cannot move the blades*).

Level 2 is associated with linguistic structures that show an implicit modulation of the Agonist and the Antagonist or an explicit modulation addressed to only one entity (*e.g., paper, but the packaging is a bit too heavy?; You could move it by using the force of Rupert and Aielmo to move the toy car, you can load one vessel at a time*).

Level 3 is characterized by a focus on the opposing entity in the process and by verbs expressing opposition (*e.g.: one thing that resists is the weight of the pots; the car resists*).

Level 4 is characterized by the explicit modulation of the two entities (*e.g., by changing position there is less air and then the toy car goes slower; if you have weak water, a dam that is not very resistent is enough*).

Level 5 is similar to level 4 but it includes the identification of the potential difference in the interaction with the device and the verbalisation of all the variables (e.g., *Teacher: So if it blocks, what does it do? Child 1: It makes resistance, the water loses its speed, its impetuosity because the water slams; Teacher: What does the water falling on the blades do? Child: It slows down. Teacher: And the blade? Child: It accelerates*).

This scale from 0 to 5 shows a gradation of increasing quality in the language used to express the identification of variables in accordance with the conceptual framework adopted.

However, this "vertical" scale does not take into account either the richness of a description or the number of elements identified in a cause-effect interaction. Therefore, in order to better analyze and evaluate the path as a whole and the specific contribution of various materials, it was necessary to add a second tool of analysis, that we call the horizontal scale. It is divided into the following 3 levels:

Level 1s is attributed to sentences with no explicit reference to the chain and no information on the device.

Level 2s corresponds to a series of at least 3 identified cause-effect relationships (*e.g., hairdryer-air-toy car-motion; electricity-fan-air)* and some elements or objects that are related to the device (the current, the plug, the fan of the hyrdryer, the numerous wheels of the gear, ...).

Level 3s is characterized by a series of at least 4 cause-effect relationships and by the evaluation of how physical characteristics (size, weight, material, type of surface, ...) of the structural device can influence the process.

Table I shows the results of the analysis of children's individual responses and their collective discussions according to these two scales. The types of questions are indicated.

The data show that:

a) Children's language at the beginning of the path (pre-test) ranges from levels 0 to 2 on the vertical scale and is at level 1s on the horizontal one;

b) Compared to the pre-test, the various laboratory activities guided by "artifact" questions led to an increase in the elaborateness of answers lying between level 2s and 3s on the horizontal scale. Moreover, in the case of "artifact" questions, referred to while doing the experiment, we notice an evolution in language (24% and 30% of answers are at level 4 in the I and II lesson, respectively);

c) The "embodied" questions facilitated an increase in level on the linguistic scale (II and III lessons).

d) Level 4 is maintained in the final discussion (taken as the final assessment) where children have observed, described and interpreted a game without the help of leading questions. In the dialogues of the last two lessons, Level 5 was reached only if children were prompted by the teacher with specific questions.

In summary, "embodied" questions and "artifact" questions each have their own specific role.

"Embodied" questions favor the identification of variables with common language because they systematically force their verbalization.

"Artifact" questions improve the ability to observe and describe the phenomena, to consider the device as well as the evolution of language.

We must not forget that these results were established by the teacher during the collective discussions that followed the individual answers given on the worksheets and promoted the standardization of individual results. In particular, the discussions that follow the "embodied" questions are essential because they allow children to share and select, among the terms belonging to the common language, those words which are more suited to scientific language.

In Table II, a look at the pivot words, that is, the most frequent words present in the children's sentences which can be related to variable identification, confirms the results previously highlighted in the discussion of Table I.

The expressions obtained from the "artifact" questions that are placed at level 0 are linguistically poor but nevertheless rich in the identification of structural and mechanical elements, which are necessary both to describe the chain and to understand the role of devices that behave as resistance in the process. By contrast, the pivot words identified in embodied answers are mostly useful for identifying the effect of interactions and the quality (potential and difference of potential) of the extensive quantity that flows.

We conclude that the two question types are complementary in bringing out the elements that are necessary to describe and interpret the cause-effect relationship and to didactically move towards the construction of the concept of energy, according to our disciplinary framework. In this context hands-on activities become both minds-on and educational activities.

## IV. CONCLUSIONS

We have presented specific and structured questions that support teachers in enabling children to move from purely descriptive and manipulative (hands-on) activities to interpretive (minds-on) ones. If teachers develop the habit of stimulating children, recognizing pivot words and following the evolution of children's language, they get a double benefit: they anchor their teaching practice in the children's language and they use children's words to evaluate learning.

This pathway for constructing the concept of energy is amenable to further curricular development, from the early years of primary school: initially in a qualitative and contextualised way, then later in a quantitative and more decontextualised way, studied with the simple relationship of proportionality, in continuity with the secondary school level.

## ACKNOWLEDGEMENTS

We wish to acknowledge the Instituto Comprensivo of Castel Franco Emilia (Modena, Italy) for the financial support and their kind participation in this research.

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# APPENDIX A

**TABLE I.** Answers to the different types of questions are related to the language vertical stair and the horizontal stair. Percentages over 20% are shown in colour.

| Lesson | Type of question and discussion | Activity | Language level evolution (% of cases) | | | | | | Cognitive tool evolution | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 1s | 2s | 3s |
| I (pre- test) | | Discussion: which game will you choose to represent the story situation? | 53 | 29 | 18 | | | | x | | |
| | Artifact | Before doing the experiment (hairdryer-car) | 54 | | 28 | 16 | | | | x | |
| I | Artifact | Doing the experiment (hairdryer-car) | 8 | | | 68 | 24 | | | x | |
| II-III | Embodied | Doing the experiment (hairdryer-car) | | | | | | 90 * | x | | |
| | Artifact | Before doing the experiment (car with balloon) | 45 | 55 | | | | | | x | |
| | Artifact | Doing the experiment (car with balloon) | 15 | 30 | 20 | | 30 | 5 | | x | |
| | Embodied | Doing the experiment (car with balloon) | | | | | | 90 * | x | | |
| IV | Describe as a journalist | Mime game | 50 | 50 | | | | | | x | |
| | Explain as a scientist | | | | | | 90 | 10 | | x | |
| V | How do we make it work? | Doing the experiment (wind mill, dynamo torch, pot-pot boat, solar panel frog) | 50 | 50 | | | | | | x | |
| | How can it work better? | | | | | | 75 | 25 | | | x |
| VI (post- test) | Describe and interpret process in the story (part 2) | Discussion using the words that were shared in the collective discussions | | | | | 75 | 25 | | x | |
| | Describe and interpret sand mill game | | | | | | 75 | 25 | | | x |

*10% of children's answers were missing.

## APPENDIX B

**TABLE II.** Relationship between artifact and embodied questions, pivot words and energy chain.

| Questions | Pivot words | | | | | | Number of elements in the chain |
|---|---|---|---|---|---|---|---|
| | Quantity | Quality (input) | Quality (output) | Difference of Quality | Interaction | Device and mechanical element | |
| Artifact | Air<br>Wind<br>Hairdryer<br>Electricity | Less air<br>More air<br>More distance<br>Less distance | Faster<br>Slower<br>Very fast | | Earth<br>Car<br>Weight | Plug;<br>Cogwheel;<br>Wheels;<br>Switch;<br>Key;<br>Sprocket;<br>Radius of the fan wheel;<br>Electrical cables | 1,2,3,4 |
| Embodied | | Still; Calm, Moved, Tickled, Pushed, Resting, Beginning; Keeping to | Fast and later slow; Calm | Velocity | Resistance | | |