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From naive to scientific understanding of motion and its causes

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Summary. — The difference in the descriptions of motion phenomena made by pupils in the first grades of secondary school and physicists is quite evident. Conceptual metaphors hidden in language suggest that there is continuity between the conceptual structure involved in the description and the interpretation of motion of experts and laypersons. In this paper the presence of such a continuity is shown through a metaphor analysis of linguistic expressions from both groups.

1. – Introduction

We know from literature (DiSessa, 1993; McCloskey, Caramazza, and Green, 1980) that students face difficulties in studying motion and its causes. We argue that if we want to address these problems, we have to investigate the conceptualization of motion.

We are going to investigate the conceptual structure involved in the description of motion of laypersons, *i.e.* students, and of experts, *i.e.* teachers, scientists, physicists. We argue that some kind of continuity should be present between these two kinds of conceptualization and that physics education should be built upon it.

In the first part of this article we are going to illustrate how it is possible to understand how the concept of motion is constructed in the human mind. A theory that relates mind and language is presented starting from the works of Lakoff, Johnson, Turner and Fauconnier.

In the second part we will show the analyses carried out of two different sources of language, the first representing the scientific conceptualization, the second the lay one.

In the last part the evidence and the results of the analyses are presented and discussed.

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2. – A theory of mind

In cognitive linguistics, conceptual metaphor is defined as understanding one conceptual domain (target domain) in terms of another conceptual domain (source domain). Lakoff, Johnson and Turner underline the deep and strong connection between language and mind. According to these authors, the nature of the conceptual structure that we use to think, speak and act is figurative. As a consequence, conceptual metaphors play an important role in structuring knowledge. They are systematic in that there is a fixed correspondence between the structure of the domain to be understood (*e.g.*, death) and the structure of the domain in terms of which we are understanding it (*e.g.*, departure). We usually understand them in terms of common experiences. They are largely unconscious, though attention may be drawn to them. Their operation in cognition is almost automatic. And they are widely conventionalized in language, that is, there are a great number of words and idiomatic expressions in our language whose meanings depend upon those conceptual metaphors (Lakoff and Turner, 1989). Metaphor is no longer seen as a mere linguistic and aesthetic feature: the cognitive role of metaphor emerges in the process of structuring and acquiring new knowledge. In synthesis, a *concept* is *constituted* by the *metaphor* (Lakoff and Johnson, 1980).

Moreover, according to Fauconnier and Turner, in the human mind there are entire networks of projections between conceptual spaces leading to what have been known as *conceptual integration networks* (Fauconnier and Turner, 1998, 2002; Fauconnier, 1994, 1997).

As a consequence, we can understand the way we think about our conceptualization of motion, looking at the way we speak, in particular at the conceptual metaphors implied in the language we use to talk and describe motion.

We have to make a distinction between metaphor and metaphoric linguistic expression: the latter is what we hear or read when somebody uses a metaphor, the former is a figure of the mind, we might say the actual concept. We will show an example in order to evidence the difference.

Heat flows through the walls of the building

is the metaphorical expression of the metaphor:

Heat Is A Fluid Substance

We will use small caps in order to distinguish between the conceptual metaphors and the metaphorical expressions.

3. – Language analyses

In order to compare the two forms of conceptualization of motion we selected two sources of sentences about motion: the first volume of "The Feynman lectures on Physics" (Feynman, 1965) as a source of scientific language, and recordings of college students enrolled in physics courses collected in the paper "Common sense concepts about motion" by Halloun and Hestenes as a source of lay language (Halloun and Hestenes, 1985).

We looked for the sentences containing the word "force" and we tried to see the underlying conceptual metaphor. We constructed the categories of conceptual metaphors in a recursive way in order to have the most general and encompassing ones. We developed the conceptual metaphor categorization starting from the Force Dynamic Gestalt theory (Fuchs, 2007), image schemas (Johnson, 1990) and event structures (Lakoff and Johnson, 1999).

Here we present the list of metaphors involved in the description of the word "force".

- Force Is A Substance-Like Quantity
  - Force Is A Product
  - Force Is A Quantity
  - Force Is A Possession
- Force Is An Agent
  - Force Is A Compulsion
  - Force Is A Resistance
- Force Is A Medium
- Force Is A Path
  - Force Is A Line
  - Force Is A Connection
- Force Is A Scale
- Force Is Balance

The complete list of categorized sentences is presented in the following tables I–VI. The first observation is that sentences from both expert and lay language are metaphorical expressions contained in all these categories.

Table I. – Force Is A Substance-Like Quantity *expressions.*

Conceptual metaphor sub-category	Feynman expressions	Students expressions
Force Is A Product	*This potentiality for producing a force is called an electric field. A source of the force.*	*The speed creates a force. The force behind it…coming from the throw.*
Force Is A Quantity	*How much force would there be? More or less force is required. There is very little force at any appreciable distance.*	*As it goes down, the force of gravity increases…and that's why the speed increases until [gravity] equals this amount of force. It provides the ball with more and more force as it goes down.*
Force Is A Possession	*A spinning top has the same weight as a still one. The weight of the atom. These forces are within the nuclei of atoms.*	*If the mass of block X is greater than the force [of pull] of Y, block X stays in place…it could not be moved. [The moving body] has still got some force inside.*

TABLE II. – FORCE IS AN AGENT *expressions.*

Conceptual metaphor sub-category	Feynman expressions	Students expressions
(unsorted)	*The first charge will feel a certain reaction force.*	*There is not a force [acting] on the ball. Gravity means the same force pulls on different objects.*
FORCE IS A COMPULSION	*Because of the action of a force, the velocity changes. The force which controls, let us say, Jupiter in going around the sun.*	*A force only starts the motion. A force is just changing the direction of motion.*
FORCE IS A RESISTANCE	*It is a question of electrical forces against which we are working. No tangential force is needed to keep a planet in its orbit.*	*A force has nothing to do with the speed, it only has to keep the ball moving.*

TABLE III. – FORCE IS A MEDIUM *expressions.*

Feynman expressions	Students expressions
We shall have to hold the piston down by a certain force. The gas exerts a jittery force.	*That maximum speed is always equal to the force you apply.*

TABLE IV. – FORCE IS A PATH *expressions.*

Conceptual metaphor sub-category	Feynman expressions	Students expressions
FORCE IS A LINE	*The force in the vertical direction due to gravity. The force is directed along the line joining the planet to the sun.*	*The ball goes out in the direction of the resultant [of the forces].*
FORCE IS A CONNECTION	*The true nature of the forces between the atoms.*	none

TABLE V. – FORCE IS A SCALE *expressions.*

Feynman expressions	Students expressions
The force weakens as we go higher. The more massive a thing is, the stronger the force required to produce a given acceleration.	none

Table VI. – Force Is Balance *expressions.*

Feynman expressions	Students expressions
If the force between them were not balanced. *Talk only about excess forces.* *All the internal forces will balance out.*	none

Besides that, we also found some differences in the metaphorical expressions from the two sources.

The Force Is A Product conceptual metaphor (table I) tells us that force could be "produced". The possible "producers" in Feynman's expressions are the basic interactions between objects, *i.e.* electrical and gravitational, while in students' expressions the "producers" are speed and aspects of motion.

In Force Is A Quantity metaphorical expressions (table I), Feynman only speaks about the intensity of force, while in students' language we find expressions that are related to the concept of momentum or energy of a moving object.

Finally, the metaphorical expressions of Force Is A Possession (table I) in Feynman are only about weight, while in laypersons we have expressions involving moving objects, devices that produce movement (*i.e.* a cannon), and more abstract concepts as power, inertia and velocity.

Some metaphorical expressions found in Feynman are not present in students' expressions, but we think this could be due to the set of data chosen for this purpose. We are almost sure that similar sentences could be found in students' expressions if only we could have a larger collection.

The metaphorical sentences in lay language often involved the terms "speed" or "velocity". In order to deepen our investigations we repeated the same analysis for the sentences containing these two words.

The conceptual metaphors we found are listed below.

- Speed Is A Substance-like quantity
  - Speed Is A Possession
  - Speed Is A Quantity
- Speed Is A Location
  - Speed Is A Level
  - Speed Is A Scale
- Speed Is An Agent
  - Speed Is A Force
  - Speed Is A Maker

Table VII collects the categorization of the metaphorical sentences found in both sets of data.

All the expressions belonging to the two sources fitted all these categories with only one exception. Metaphorical expressions belonging to Speed Is An Agent can only be found in students' language.

TABLE VII. – *Speed and Velocity metaphors and metaphorical expressions.*

Conceptual metaphor category	Conceptual metaphor sub-category	Feynman expressions	Students expressions
SPEED IS A SUBSTANCE-LIKE QUANTITY	SPEED IS A POSSESSION	*Motion of a body. If she kept going with the same speed. The velocity of the falling ball.*	*Its speed remains constant. Their speed gets greater and greater. Both should have the same speed.*
	SPEED IS A QUANTITY	*[...] if we increase the speed of the atoms.*	*Its velocity keeps increasing. The speed is smaller. A new speed bigger than the one it had before.*
SPEED IS A LOCATION	SPEED IS A LEVEL	*At what speed is the radius increasing? She is going at that speed. Some car can get from rest to 60 miles an hour.*	*The ball must go at constant speed. They can reach a speed limit.*
	SPEED IS A SCALE	*It speeds up. The car was slowing down. High speeds.*	*It speeds up for a short while. It slows down.*
SPEED IS AN AGENT	SPEED IS A FORCE	none	*The force due to the air overcomes the initial velocity. The force of velocity.*
	SPEED IS A MAKER	none	*The speed creates a force.*

4. – Results and conclusions

This metaphor analysis is a powerful and sensible tool that allows us to investigate the conceptual structure that both scientists and students use to understand and to explain phenomena.

The first important result is that the metaphorical expressions coming from both lay and expert language share the majority of the metaphors. This allows us to claim that there is continuity between the two kinds of language.

We also revealed a metaphorical and conceptual mismatch involving velocity and speed. In the analysis we discovered that SPEED IS AN AGENT is a conceptual metaphor only present in lay language (students). Therefore we could say that speed (and velocity) is perceived and conceptualized as an agent only by laypersons (students), while this is not true for scientists and experts (Feynman, 1965).

Another important result is that some aspects coming from the Force Dynamic Gestalt theory, such as quantity, quality, intensity (Fuchs, 2007) are present in the metaphorical expressions. Moreover they are not completely differentiated in lay language.

The presence of continuity tells us that it is possible to teach starting from the knowledge pupils have already developed during their previous experience: we could use conceptual metaphor as a basis for developing a physics curriculum.

Physics teachers should be aware of the conceptual metaphors and how they relate and overlap in order to create comprehension (*i.e.* conceptual integration networks). In this sense we could say that an education based on conceptual metaphors could help students to be aware of them in order to understand and relate the aspects involved in the interpretation of motion and its causes.

In order to do so, further analysis should be done to reveal the logical connections and the dependencies between concepts involved in the description of motion (momentum, energy). A refined analysis should be done taking different language sources, both oral and written.

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