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Conceptual metaphor in teaching/learning electric circuits for student teachers of primary school and kindergarten

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Abstract. Integration between cognitive linguistic aspects and physics has been performed in the Physics Education course of the Master's Degree for prospective primary teachers at the University of Udine in Italy. Conceptual metaphors have been introduced to the students, who were then invited to apply the ideas to the electric circuits. In this contribution we present some relevant results of this activity pointing out how students have worked with metaphors, gaining better conceptual understanding on the disciplinary topic.

1. Introduction

Prospective kindergarten and primary school teachers need to gain transversal competences and, in particular, those ones integrating in a unique cultural framework instruments and methods for scientific way of thinking and humanities. It is fundamental for the professional education of teachers of primary school and kindergarten to integrate and to transform into competences [1-3] the formative contributions of pedagogical and disciplinary areas for Pedagogical Content Knowledge [4]. In the 5 yearlong Italian organization of prospective primary teacher education a cluster of courses is offered including, on one side, a strong preparation in pedagogic, linguistic, and psychologic disciplines, and, on the other side, the contents and methods of the discipline education with a few numbers of hours for educational Labs and an important area for apprenticeship. The important integration able to produce the professional competences, as well as the gain of transversal competences and soft skills, is left to the single prospective teachers [5].

In recent years, efforts in the integration of natural sciences and human sciences have led to didactic innovation in student teachers physics education [6-9]. In this perspective, we will present structure and result of a formative intervention module where prospective primary teachers at the 3rd year of the Master in Primary Education of the University of Udine in Italy have been invited to reflect on their own way of treating electric circuits using conceptual metaphors.

In paragraph "2. Conceptual metaphor theory", we first briefly introduce conceptual metaphor theory in its general aspects and evidence its importance in science and in science education. Then, in "3. Conceptual metaphors in electric circuits", we report about some topics of literature discussion on metaphors in electric circuits in particular to frame the aim of the present research. In paragraph "4. Intervention and data analysis" we describe the didactic intervention and the results of the qualitative analysis of the students' reactions. Finally, in "5. Summary and discussion", we summarize and discuss the findings.

2. Conceptual metaphor theory

It is superficially adopted that what we say, think, and understand relates directly to (an outer) reality—language and thought are supposed to be literal. However, the studies on conceptual metaphor started in the late 1970's by Michael Reddy and George Lakoff and developed to present show that "metaphor is primarily conceptual, and secondarily linguistic, gestural, and visual" [10-12]. The large majority of linguistic expressions we use show that our mind must be working figuratively: it makes use of the schematic figures, forms, or shapes created in experience. Metaphorical projection is one of the main tools of figurative thought. A conceptual metaphor is a projection of a known (source) domain, i.e. the conceptual domain from which we draw metaphorical expressions, onto an unknown (target) domain, i.e. the conceptual domain that we try to understand. The popular metaphor LIFE IS A JOURNEY conceptualizes life, the complex domain we want to (partially) explain, by means of abstractions we have learnt from journeys. So, life has a beginning and an end, we follow paths and tracks, we travel alone or in the company of someone else, we have goals, we get lost, we are tired or energetic, etc. "Metaphor is not […] a form of speech— [it is] a form of thought…" [13].

Many linguistic expressions, in common language [9], in scientific language [14], and even in mathematics [15], are the result of such a mental operation. We often have no way of expressing ourselves except by using metaphors, and we do so mostly unconsciously. For example, the expression "The cash flow of our company is negative" applies the schema of FLUID-LIKE SUBSTANCE to money, or "Temperature is rising all over the Planet" applies the schema of VERTICALITY or SCALE/LEVEL to temperature. Money is not actually flowing out of the company borders, or temperature is not concretely going upwards, but it is useful to our mind to employ such figures of imagination to give sense or understand money and temperature behaviors (it is not by chance that a thermometer is normally hung vertically on a wall…). It is worth pointing out that a metaphor or a metaphoric expression (a linguistic expression relying on a metaphor) does not define exhaustively a subject, especially if complex or abstract, but it throws light on an aspect of it, and, in doing this, may obscure other aspects [16]. In other words, metaphor theory emphasizes the inadequacy of the myth of objective or of literal thought.

The fundamental and simplest abstractions recruited in metaphors, called in this case *primary* conceptual metaphors, are the *image schemas*, small-scale embodied structures, we could think of as the bricks of thought. An image schema is a condensed redescription of perceptual experience for the purpose of mapping spatial structure onto conceptual structure. Table 1 summarizes and classifies the main image schemas from different studies [17-20].

Table 1. Categories and image schemas as collected from different literature sources [17-20].

Polarity	light-dark, warm-cold, female-male, good-bad, just-unjust, slow-fast
Space	up-down, front-back, left-right, near-far, center-periphery, verticality, contact, path, scale, level
Process	process, state, cycle
Container	containment, in-out, surface, full-empty, content
Force/causation	balance, counterforce, compulsion, restraint, enablement, blockage, diversion, attraction, manipulation
Unity/multiplicity	merging, collecting, splitting, iteration, part-whole, mass-count, link
Identity	matching, superimposition
Existence	removal, bounded space, object, (fluid-like) substance

We can spot different abstractions used in physics, like CONTAINER, FORCE, BALANCE, or FLUID-LIKE SUBSTANCE. From the point of view of conceptual metaphor theory, it is unavoidable, even in physics as an outcome of our figurative mind, to speak of any topic using metaphorical expressions, the most common of them coming from image schema projection (see below for example in the field of electricity). It must be emphasized, if not yet clear, that though our mind extracts or abstracts the image schemas from experience, however it (metaphorically) projects them back to experience as true abstractions. For example, "electric current" is a metaphorical expression of the metaphor ELECTRICITY

IS A FLUID-LIKE SUBSTANCE, but no one would attribute to the electric current the characteristic of wetting the surfaces or of being viscous like water or oil currents.

3. Conceptual metaphors in electric circuits

Conceptual metaphors, including – in a more general sense as commonly found in literature – (alternative) conceptions, images and models are powerful points of view of research in physics education. Investigation on alternative conceptions of students as well as teachers about electric circuits has been extensively conducted [21, 22]. Studies concerning metaphors for electricity are useful to frame the topic of this paper. Mulhall et al. [23] emphasizes that electricity involves extremely complex and highly abstract concepts and is thus totally dependent on models/analogies/metaphors. They conclude, however, that the poor understanding students prove after the teaching of electricity is to be put in relation with the absence of any systemic consensus about what models/analogies/metaphors are appropriate for students at different grades and, consequently, what are the appropriate learning outcomes in every level. Shaffer & McDermott (see [24]) and Psillos et al. [25, 26] for example adopt opposite position about the appropriateness of the electric current metaphors and of the potential difference/energy metaphors as starting points for the systematic study of electricity at senior high school/undergraduate level. Moreover, McDermott strongly argues that flow analogies are inappropriate, while Schwedes and Dudeck [27] argue strongly the opposite. Stocklmayer and Treagust [28] investigated the images students at various ages use for electricity. The model of current which is universally accepted is the one of moving electrons in a wire, responding to a difference of potential across the ends of the wire. Teachers then work on this image of electricity with their students, but the authors point out that expert scientists hold a field concept rather than a particle one.

A fair position about metaphors in general and electricity in particular, especially in view of physics education of primary school and kindergarten student teachers, comes from remembering the role of metaphors themselves in the construction of meaning. We are not primarily interested in which conceptual metaphor is didactically and scientifically better or worse, because we know that metaphors highlight aspects, not the whole meaning. We are more importantly interested in the extent to which such a cognitive tool is learnt and mastered by student teachers, how critically and consciously they use it, and what is their attitude toward it.

So, research questions of the topic of this paper are:

- to what extent student teachers learn and apply conceptual metaphors to electric circuits?
- how do they react to an activity where they are engaged to deal with conceptual metaphors?

4. Intervention and data analysis

The intervention dealt here involves 120 student teachers of the 3rd year of the Master Degree in Education of the University of Udine in Italy. It started with a two-hour seminar during the semester. After an introduction about embodied cognition, conceptual metaphor theory has been developed with examples from everyday language and from scientific language. Table 1 of image schema has been presented to students and taken as reference for the metaphor analysis of the examples. Didactical implications were discussed with students during the seminar concerning the importance of language care, the possibility of building on the abstractions (image schemas) already possessed by children, the opportunity for conceptual development rather than conceptual change as aim of the didactic practice, and the power of metaphors in probing and understanding the children thought and learning. No explicit reference to electricity and electric circuit was done; the specific scientific theme taken as example was energy.

Immediately after the seminar, the scientific content of electricity and electric circuits has been treated with the conventional approach as in the previous academic years, with no more reference to conceptual metaphor. At the end, a questionnaire on electricity and electrical circuits consisting of open-ended questions was administered to the students. Then students have been engaged in a metaphoric analysis work on the basis of contents learnt in the two-hour seminar. As base material, a small number of expressions have been selected from their own answers to the questionnaire. Table 2 lists the material: there are three questions taken from the questionnaire and, for each of them, two selected answers. Students had (i) to evidence the metaphor(s) behind the linguistic expressions in the answers, (ii) to suitably reformulate the expressions on the basis of their analysis, and (iii) to motivate their choices. As a support, they had at disposal the table of image schemas. Moreover, (iv) they were invited to write a comment in reaction to the whole activity about conceptual metaphors.

Table 2. Answers selected for the students' metaphorical analysis. Second column lists the image schemas of the corresponding metaphors.

Questions and answers	Image schema
1. I insert a switch in a battery-bulb circuit. I make myself small and enter the copper wire of the circuit. What do I see when the switch is open?	
1.1 If the switch is open, I can see the electrons stopping! They can no longer flow.	numerable substance fluid-like substance
1.2 The current does not flow because the circuit is interrupted.	fluid-like substance path/cycle
2. What do I see in the connecting wire when the switch is closed?	
2.1 The current intensity passes through the whole circuit.	fluid-like substance level/intensity
2.2 In the wire, the electrons move from one pole to another due to the difference of potential.	numerable substance path/cycle level/intensity
3. How does it change what I see if I enter the wire before the bulb or after the bulb?	
3.1 If I enter the wire before the bulb, the current carried will be very much, instead if I enter after the bulb that the current will be very little because the bulb has stolen a part of it.	container fluid-like substance
3.2 There is a voltage drop.	level/intensity

The students worked individually through an on-line form and their products have been collected in a file. The expressions of 24 randomly chosen students have been analyzed by our research group in different ways. In the metaphorical analysis (i) the image schemas evidenced by the students have been categorized, (ii) the reformulations have been evaluated in terms of content correctness and (iii) of correspondence to the motivation.
We first report analytically the results of the analyses for the single answers, then we will focus on some relevant aspects.

Sample answer 1.1: If the switch is open, I can see the electrons stopping! They can no longer flow.
21 students detected both FLUID-LIKE and NUMERABLE SUBSTANCE metaphors, 3 students detected only one of the two.
17 students correctly rephrase the statement using only one metaphor (12 students use the FLUID-LIKE SUBSTANCE metaphor, 5 students use the NUMERABLE SUBSTANCE one – students prefer the FLUID-LIKE METAPHOR for electricity); 6 students rephrase using both metaphors.
20 students explicitly point out that only one metaphor must be used in the same statement.

Sample answer 1.2: The current does not flow because the circuit is interrupted.
23 students detect the FLUID-LIKE SUBSTANCE metaphor, and 5 ones add the PATH/CIRCLE metaphor.
20 students correctly rephrase the statement. 21 students use the FLUID-LIKE SUBSTANCE metaphor, 1 student uses the NUMERABLE SUBSTANCE metaphor.
14 students correctly motivate their reformulation, 3 ones give a wrong motivation.
4 students reiterate that only one metaphor must be used in the same statement.

Sample answer 2.1: The current intensity passes through the whole circuit.
20 students detect the VERTICAL LEVEL/INTENSITY metaphor, 8 students detect the FLUID-LIKE SUBSTANCE metaphor and 5 students detect the PATH/CYCLE metaphor.

23 students correctly rephrase the statement. 21 ones use the FLUID-LIKE SUBSTANCE metaphor, 6 ones add the LEVEL/INTENSITY metaphor, 11 use the PATH/CYCLE metaphor.
24 students correctly motivate their reformulations: 16 of them explicitly point out that LEVEL/INTENSITY and FLUID-LIKE SUBSTANCE metaphors must be differentiated.

Sample answer 2.2: In the wire, the electrons move from one pole to another due to the difference of potential.
19 students detect the LEVEL/INTENSITY metaphor, 21 ones the numerable SUBSTANCE METAPHOR and 2 students detect the PATH/CYCLE metaphor.
20 students correctly rephrase the statement; 22 students use the NUMERABLE SUBSTANCE metaphor, 19 ones the LEVEL/INTENSITY metaphor and 6 the PATH/CYCLE metaphor.
17 students correctly motivate their reformulations, 3 ones do not explicitly motivate because they accept the statement as it is, and 4 students write wrong motivations.

Sample answer 3.1: If I enter the wire before the bulb, the current carried will be very much, instead if I enter after the bulb that the current will be very little because the bulb has stolen a part of it.
23 students indicate the FLUID-LIKE SUBSTANCE metaphor and 10 students the CONTAINER metaphor
21 students correctly rephrase the statement; 14 ones use the FLUID-LIKE SUBSTANCE metaphor and 8 ones the NUMERABLE SUBSTANCE metaphor, 6 ones the CONTAINER and 5 the PATH/CYCLE METAPHOR.
All students correctly motivate their reformulations.

Sample answer 3.2: There is a voltage drop.
21 students indicate the LEVEL/INTENSITY metaphor.
23 students correctly rephrase the sentence, 22 ones use the LEVEL/INTENSITY metaphor, 3 ones use the FLUID-LIKE SUBSTANCE metaphor.
17 students correctly motivate their reformulations, 4 ones do not explicitly motivate because they accept the statement as it is.

In general, students have been able to detects the conceptual metaphors in the sample expressions, to evidence conceptual errors or inconsistencies, and to improve the language in their reformulations. In most cases, they also made didactic considerations, like for example, that metaphors must be differentiated and that only one metaphor must be used in the same statement.
We want now to focus, in particular, on those metaphors we would call main metaphors for electricity (and for every physics context), i.e. the FLUID-LIKE SUBSTANCE, the NUMERABLE SUBSTANCE and the LEVEL/INTENSITY metaphors. The importance of these metaphors comes from the fact that they are at the root of the notion of extensive and intensive quantities present in the various fields of physics. So, like for fluids we have volume and pressure, or for linear motion we have momentum and velocity, for electricity we have electric charge and electric potential (and their synonymous). Table 3 synthesizes the students' results regarding these main metaphors specifically. In answer 1.1, due to its formulation, we report the students' analyses if they mention both FLUID-LIKE and NUMERABLE SUBSTANCE metaphors, while in 2.1 and 2.2 answers we report the occurrence of the two metaphors separately.

The percentages reached by the students are very high, higher than every expectation, considering the so short training they have had about metaphors and metaphoric analysis. This means that this kind of activity has stimulated in the students the reflection about the extensive and the intensive aspects of electricity and has made them able to differentiate electric charge or current from electric potential and tension.

Table 3. Students' results concerning the FLUID-LIKE and NUMERABLE SUBSTANCE in particular.

Answer	Main metaphors	Metaphors correctly detected	Correct rephrase	Correct motivation
1.1	fluid-like substance and numerable substance	21 88%	17 71%	19 79%
1.2	fluid-like substance	23 96%	20 83%	14 58%
2.1	level/intensity + fluid-like substance	20 + 8 83% + 33%	23 96%	24 100%
2.2	numerable substance + level/intensity	21 + 19 88% + 79%	20 83%	20 83%
3.1	fluid-like substance	23 96%	21 88%	24 100%
3.2	level/intensity	21 88%	23 96%	21 88%

The feedback reactions written by the students were in general an appreciation of the whole activity. We report below some of their representative testimonies.
Student 1.
I find that this work helps to strengthen the critical capacity of interpretation of another person's thought, because seeing his answers you can see how the student or the other person in general has formed ideas inside his head; by understanding what these ideas are, you can think of an intervention to try to "fix" them.

Student 2.
In my opinion this work helps to a critical examination of one's own language, because every word can lead to a different image in the minds of children. If the terms used will not be correct, they could lead to a wrong construction of knowledge and therefore to serious conceptual errors (e.g. confusion is often made between charge and energy, between energy and substance).

Student 3.
Nowadays, metaphors are often used in everyday life. It is nice to see how metaphors can be applied to different disciplines (history, language, science, etc.). The metaphor allows you to reflect on the true meaning of what you want to express.

Student 4.
As future teachers, [conceptual metaphor] is useful in order to learn to look at things "with the eyes" of our students. By being able to understand their structures and the way they interpret concepts, it is easier to understand how to fill in the gaps.

5. Summary and discussion

In summary, the results presented in this paper show that student teachers easily become able to carry out conceptual metaphor analysis of sentences about electric circuits, applying schemas of FLUID-LIKE

SUBSTANCE, NUMERABLE SUBSTANCE, LEVEL/INTENSITY and other secondary schemas like PATH/CYCLE and CONTAINER.

They acquire competence in evaluating correctness of sentences and to rephrase both the correct and (in particular) the wrong ones in a clearer language. Students adequately motivate the choices, showing that their use of metaphors becomes conscious and deliberate.

All this is probably due to the fact that this type of theme, bridging natural sciences and human sciences, fosters the humanistic background of student teachers and stimulates them to a deeper and meaningful understanding of physics. This is also confirmed by the students' feedbacks where they point out the perception of usefulness of conceptual metaphors for their professional development and express positive attitude and inclination.

In conclusion, we have shown that conceptual metaphor is a powerful tool for student teachers, especially for the understanding of abstract topics like electricity. Student teachers take advantage from conceptual metaphor to analyze their own language and gain a deeper and more critical insight of the disciplinary topic. Student teachers must be trained to do metaphorical analysis, to consciously use the different metaphors of a given subject and to master and differentiate them.

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