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Article

Training Prospective Primary and Kindergarten Teachers on Electric Circuits Using Conceptual Metaphors

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Abstract: The awareness and use of conceptual metaphors available in ordinary language should be a relevant part of teaching strategies, yet it is still rather neglected in teacher education. With a specific activity, we integrated a class of prospective kindergarten and primary school teachers on electric circuits with a reflection on the cognitive and linguistic aspects of metaphor. To understand how effective this integration proved to be, both in terms of learning and in terms of developing teaching skills, we conducted a single case study with a mixed qualitative–quantitative methodology. Student teachers were invited to analyze and discuss expressions on electric circuits selected from those they themselves had formulated at an earlier time. Here, we present some relevant results from the analysis of the students' elaborations, highlighting how they worked with metaphors. They demonstrated a better understanding of the subject matter and greater awareness of teaching as well, in particular for what concerns the use of language and identifying and overcoming implicit ideas.

Keywords: K-5 and kindergarten teachers' education; electric circuits; conceptual metaphor

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1. Introduction

"[...] metaphor is primarily conceptual, and secondarily linguistic, gestural, and visual. There are metaphorical ideas everywhere and they affect how we act" [1]. As a consequence, it is crucial for teachers to be able to both understand the concepts conveyed by children's language when they speak and the implications of what they themselves say when they teach. Normally, during their training in science and science education, teachers are not made adequately aware of the power of language in conveying concepts, nor are they instructed to identify potential misunderstandings through linguistic analysis.

Indeed, during the Italian five-year university program for prospective kindergarten and K-5 teachers, a set of courses is traditionally offered that includes, on the one hand, a solid preparation in pedagogy, linguistics, and psychology, and, on the other hand, contents and methods of subject education in various disciplines, with the integration of a number of hours dedicated to laboratories and internships [2]. Student teachers, however, need to acquire transversal skills, in particular, to integrate into a single cultural framework, tools and methods typical of the sciences with those of the humanities and to transform into competences [3–5] the educational contributions from the pedagogical area with those of the disciplinary spectrum in order to achieve Pedagogical Content Knowledge [6–13]. Nevertheless, no matter how thoroughly student teachers could be prepared within the individual areas of training and disciplinary subjects, this important integration, capable of producing authentic expertise, as well as the acquisition of soft skills and transversal competences, is mostly left to the initiative and innate talent of the individual student teacher [14].

In recent years, efforts in the integration of natural sciences and humanities have led to didactic innovation in student teachers' physics education, both for prospective kindergarten and primary school teachers [15–18] and secondary school teachers (see, for example, [19,20]). We find it interesting to ask how to teach future teachers the power of a metaphorical approach in teaching and learning physics that is able to highlight the conceptualizations conveyed by language and that form the very basis of thinking.

In this perspective, we present the structure and outcomes of a formative, research-based intervention module where prospective primary teachers of the 3rd year of the Master in Primary Education at the University of Udine in Italy have been invited to reflect in terms of conceptual metaphors on their own way of treating electric circuits. Within this master's program [2], 300 university credits (awarded for attending theoretical courses and passing related examinations, laboratory, and internship activities) are to be acquired by each prospective teacher. Each credit corresponds to 25 h of commitment. Eight credits are assigned to physics education, corresponding to 56 h of lectures (plus the accompanying study), and one credit to laboratories. Topics include measurement and units, density and Archimedes' principle, the fundamentals of mechanics and celestial mechanics, the basics of acoustics, thermology and thermodynamics, and elements of electrostatics and electric circuits.

With this paper, we aim to understand how student teachers respond to an activity that engages them in dealing with conceptual metaphors on electric circuits. In addition, in light of the multifaceted (pedagogical, psychological, and disciplinary across a broad spectrum of disciplines) training required for student teachers and the complexity and intensity of their teaching commitment, we question whether it is worth reflecting on cognitive and linguistic aspects in the context of physics preparation.

In the second section, we briefly introduce the conceptual metaphor theory in its general aspects and highlight its relevance in science and science education. Then, in "3. Conceptual metaphor in electric circuits and purpose of this work", we report on some topics of the literature's discussion on metaphors in electric circuits, in particular, to frame the aim of the present research. The fourth section, "Methodology and data analysis", contains the methodological grounds and the description of the didactic intervention, the results of the analysis of students' feedback, and their metacognitive reflections about the intervention. Then, in the fifth section, we discuss the most relevant outcomes, and in "6. Summary", we summarize the scope and meaning of our investigation.

2. Conceptual Metaphor Theory: A Brief Outline

It is superficially assumed 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 1970s by Michael Reddy and George Lakoff and developed to the present, show that "metaphor is primarily conceptual, and secondarily linguistic, gestural, and visual" [21–23]. Most linguistic expressions we use reveal that our mind works figuratively: it makes use of 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 that we want to (partially) explain, by means of abstractions we have learned from journeys. So, we project "journey" onto "life" and say expressions where life has a beginning and an end, where 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. Using Gibb's expression, "Metaphor is not [. . .] a form of speech—[it is] a form of thought. . . " [24] (p. 122).

Metaphor (and metaphorical projection) is an interesting meeting ground between disciplinary branches, perhaps not yet fully explored and exploited by scholars. For example, the linguistic approach championed by Galileo, one of the recognized founding fathers of modern science, is a highly figurative one [25]: his expressions are not only a beautiful way of saying things, but a means to evidence their deeper structures. One should take into consideration the famous sentence, "Philosophy is written in this grand book, the universe, which stands continually open to our gaze. [. . .] It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures. . . " [26] (pp. 183–84) or the pictorial description of motion's relativity: "Shut yourself up with some friend in the main cabin below decks on some large ship. . . " [27] (pp. 186–87). Through metaphor (respectively, "NATURE IS A BOOK" and "PLANET EARTH IS A SHIP"), Galileo conveys the meaning and structure of the object of his thought.

Many linguistic expressions, in common language [18], in scientific language [28], and even in mathematics [29], 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, and temperature is not concretely going upwards, but it is useful to our mind to employ such figures of imagination to give a sense or understand aspects of money and temperature (it is not by chance that a thermometer is normally hung vertically on a wall, even if it would also work horizontally). It is worth pointing out that a metaphor or a metaphoric expression (a linguistic expression relying on a metaphor) does not exhaustively define a subject, especially if complex or abstract, but it sheds light on an aspect of it, and, doing this, may obscure other aspects [22]. Applied to the world of physics and its teaching, such as in Lancor [30], this results in the realization that, for instance, when teaching energy and its characteristics "The conceptual metaphors highlight and obscure the characteristics of energy to varying degrees [. . .] Additionally, multiple metaphors often work together to illustrate complementary aspects of energy." In other words, metaphor theory emphasizes the inadequacy of the myth of objective or 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 a conceptual structure. Table 1 lists the image schemes that, of all others, are considered the fundamental ones in numerous studies [31–33] and by a comprehensive bibliography [34].

Table 1. Main categories and image schemas as collected from different literature sources [31–34].

Category	Image Schemas
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 (Agent/Patient)	balance, counterforce, compulsion, restraint, enablement, blockage, diversion, attraction, manipulation
Unity/Multiplicity	merging, collecting, splitting, iteration, part-whole, mass-count, numerable, link
Identity	matching, superimposition
Existence	removal, bounded space, object, (fluid-like) substance

We can spot various abstractions used in physics, such as CONTAINER, FORCE, BALANCE, or FLUID-LIKE SUBSTANCE. From the point of view of conceptual metaphor theory, it is inevitable, even in physics as an outcome of our figurative mind, to talk about many topics 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, it (metaphorically) projects them back to experience as true abstractions. For example, "electric current" is a metaphorical expression of the metaphor that ELECTRICITY IS A FLUID-

LIKE SUBSTANCE, but no one would attribute to the electric current the characteristics of wetting surfaces or of being viscous like water or oil currents.

3. Conceptual Metaphor in Electric Circuits and Purpose of This Work

Conceptual metaphors, including—in a more general sense, as commonly found in the literature—(alternative) conceptions, images, and models, are powerful points of view for research in physics education. Investigation into the alternative conceptions of students as well as teachers about electric circuits has been extensively conducted [35,36]. Studies concerning metaphors for electricity are useful to frame the topic of this paper. Mulhall et al. [37] emphasize 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 show after being taught electricity is to be put in relation to 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 and McDermott (see [38]) and Psillos et al. [39,40], for example, adopt opposite positions 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 the senior high school/undergraduate level. Moreover, McDermott strongly argues that flow analogies are inappropriate, while Schwedes and Dudeck [41] strongly argue the opposite. Stocklmayer and Treagust [42] investigated the images students at various ages use for electricity. The model of current, which is universally accepted, is the one of moving electrons on 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.

In addition to these investigations, there are several others that highlight the difficulties of learning the subject even if not referring to metaphor [43–49]. To a certain extent, these misunderstandings may be concretely addressed if the teacher is aware of the implicit use of metaphors and is prepared to expose and use them to increase the effectiveness of his or her teaching.

A fair position about metaphors in general, and electricity in particular, especially in view of the 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—referring back to the theory of conceptual metaphor—we know that metaphors highlight aspects, not the whole meaning. Moreover, Lakoff and Johnson [22] argue that metaphors must be coherent, but not consistent. That means metaphors do not need to make sense when you put them all together, but they cannot contradict each other when we look at what they tell us about the underlying concept. We are more importantly interested in the extent to which such a cognitive tool is learned and mastered by student teachers, how critically and consciously they use it, and what is their attitude toward it.

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

RQ1: To what extent do student teachers learn and apply conceptual metaphors to electric circuits?
RQ2: How do they react to an activity where they are engaged to deal with conceptual metaphors?
RQ3: In light of the multifaceted training necessary for student teachers, is it worth reflecting on cognitive and linguistic aspects, even when aiming at preparation in physics, taking time away from in-depth disciplinary study?

4. Methodology and Data Analysis

This research takes the form of a single case study [50] of a mixed type, i.e., both qualitative and quantitative [51]. In the first qualitative phase, we wanted to actively engage the students taking part in our survey and gave them a test with open questions on the disciplinary content. In fact, we felt that our intervention would be more effective if it was able to involve the students in first-person, making them express a topic just covered in class, on which they had to prepare themselves and, not secondarily, which they would one day have to teach. Then, in a second test, we made them reflect on some of their own expressions taken from the first one, using conceptual metaphors explicitly. Finally, in order to be able to describe and synthesize the students' results, we conducted a quantitative analysis going through the interpretation of their expressions and the categorization of the metaphors they contained. A purely quantitative analysis with a preconstructed questionnaire would have been less effective, relegating students to a passive role and not allowing them to feel directly involved. On the other hand, a purely qualitative analysis would not have allowed us to formulate a summary of the effectiveness of this intervention.

The research involves 120 3rd-year students of the master's degree in education at the University of Udine in Italy. It started with a two-hour seminar during the semester. After an introduction to embodied cognition, conceptual metaphor theory was developed with examples from everyday language and from scientific language. Table 1, the image schema, was presented to students and taken as a reference for the metaphorical analysis of the examples. Teaching implications were discussed with the students during the seminar concerning the importance of taking care of language, the possibility of building on the abstractions (image schemas) already possessed by children, the opportunity for conceptual development rather than conceptual change as the aim of the didactic practice, and the power of metaphors in probing and understanding the children's thought and learning. No explicit reference to electricity and electric circuits was given; the specific scientific theme taken as an example was energy.

Immediately after the seminar, the scientific content of electricity and electric circuits has been treated as in previous academic years, with no explicit reference to conceptual metaphor. The rationale of the path is articulated starting from educational proposals for kindergarten and primary school centered on conceptual learning. The approach is from the idea of tension or electrical potential, introduced in electrostatics as "a motor for moving charges between different metals" to introduce the electric battery of Volta and focus on the power supply role. The problem of how to identify an electric circuit is posed operationally by asking to turn on a light bulb with a battery and electrical wires. The resulting circuit addresses the topological problem of equivalence between different positions of the utilizer with respect to the power supply in the circuit. The brightness of bulbs in circuits in which the way of connecting bulbs and batteries is varied is examined introducing the meaning of circuits in series and in parallel. The replacement of parts of the circuit with different materials stimulates the development of the notion of the resistance of conductors and insulators, which influences the brightness of the bulb and the electric current. The introduction of voltmeter and ammeter is aimed at measuring voltage and current in simple circuits to identify Ohm's and Kirchhoff's laws. The electrical power concludes the content part. The course includes a historical overview of the interpretations of phenomena in electrostatics and electrodynamics and an analysis of 10 physics education research papers on common sense ideas and didactic proposals to overcome conceptual knots. At the end of the course, an online test on electricity and electrical circuits consisting of open-ended questions was administered to the students.

Then, student teachers were engaged in a metaphorical analysis work in accordance with the contents learned in the two-hour seminar. As a base material, a set of expressions were selected from their own answers to the test. These expressions were selected with consideration of the fact that they contained the metaphors we were most interested in (such as those related to image schemas such as NUMERABLE and FLUID-LIKE SUBSTANCE, or VERTICAL SCALE and LEVEL) and that lent themselves most easily to analysis by students. Some expressions were chosen because they were scientifically incorrect so that students could correctly reformulate them. Table 2 lists the selected expressions: there are two or three answers selected from four questions taken from the test.

Table 2. Expressions selected for the students' metaphorical analysis. The 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 in 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 when 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
4. If I were the electric charge, what "experience" would I have while the circuit is working: (a) In the wire before the bulb; (b) In the bulb; (c) In the wire after the bulb; (d) Inside the battery.	
4.1 (a) In the first phase, I would be in the company of other electrons. (b) I would lose some of my electron friends in the light bulb. (c) In the wire after the bulb I would be with fewer friends. (d) Inside the battery I would be gathering new friends.	NUMERABLE SUBSTANCE REMOVAL, PATIENT, CONTAINMENT, MERGING
4.2 (a) I would flow very happily because I am positive. (b) The light bulb steals all my happiness and turns it into light. (c) I would flow, but be sad because the light bulb stole all my happiness! (d) The battery makes me happy again.	FLUID-LIKE SUBSTANCE, STATE, REMOVAL, PATIENT, FULL-EMPTY, CYCLE
4.3 (a) I flow, charged with energy, towards the light bulb. (b) I undergo a transformation. (c) I leave the light bulb less charged than when I entered. (d) I become charged with energy.	FLUID-LIKE SUBSTANCE, PROCESS, PATIENT, LEVEL/INTENSITY

Student teachers had to (i) evidence the metaphor(s) behind the linguistic expressions in the answers, (ii) suitably reformulate the expressions on the basis of their analysis, and (iii) motivate their choices. As a support, they had at their disposal the table of image schemas. Moreover, (iv) they were invited to answer metacognitive questions and to write a comment in reaction to the whole activity about conceptual metaphor. Student teachers worked individually through a second online, open question test, and the outcomes were collected in a file. The preliminary results of this research were presented by one of the authors (F.C.) at the GIREP Webinar Conference 2020 organized by the University of Malta.

The anonymized answers 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. These analyses were made by two of us independently, so as to minimize the possibility of misinterpretation and to check the validity and robustness of the interpretation and categorization that were conducted.

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.*

Twenty-one students detected both FLUID-LIKE and NUMERABLE SUBSTANCE metaphors, and three students detected only one of the two.

Seventeen students correctly rephrased the statement using only one metaphor (12 students used the FLUID-LIKE SUBSTANCE metaphor, 5 students used the NUMERABLE SUBSTANCE); six students rephrased using both metaphors.

Twenty students explicitly pointed 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.*

Twenty-three students detected the FLUID-LIKE SUBSTANCE metaphor, and five added the PATH/CYCLE metaphor.

Twenty students correctly rephrased the statement. Twenty-one students used the FLUID-LIKE SUBSTANCE metaphor, and one student used the NUMERABLE SUBSTANCE metaphor.

Fourteen students correctly motivated their reformulation, three gave the wrong motivation.

Four students reiterated that only one metaphor must be used in the same statement.

Sample answer 2.1: *The current intensity passes through the whole circuit.*

Twenty students detected the vertical LEVEL/INTENSITY metaphor, eight students detected the FLUID-LIKE SUBSTANCE metaphor, and five students detected the PATH/CYCLE metaphor.

Twenty-three students correctly rephrased the statement. Twenty-one used the FLUID-LIKE SUBSTANCE metaphor, six added the LEVEL/INTENSITY metaphor, and eleven used the PATH/CYCLE metaphor.

Twenty-four students correctly motivated their reformulations: sixteen of them explicitly pointed 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 in potential.*

Nineteen students detected the LEVEL/INTENSITY metaphor, twenty-one the NUMERABLE SUBSTANCE metaphor, and two students detected the PATH/CYCLE metaphor.

Twenty students correctly rephrased the statement; twenty-two students used the NUMERABLE SUBSTANCE metaphor, nineteen the LEVEL/INTENSITY metaphor, and six the PATH/CYCLE metaphor.

Seventeen students correctly motivated their reformulations, three did not explicitly motivate because they accepted the statement as it is, and four students wrote the 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 when the current will be very little because the bulb has stolen a part of it.*

Twenty-three students indicate the FLUID-LIKE SUBSTANCE metaphor and ten students the CONTAINER metaphor.

Twenty-one students correctly rephrase the statement; fourteen use the FLUID-LIKE SUBSTANCE metaphor, eight the NUMERABLE SUBSTANCE metaphor, six the CONTAINER, and five the PATH/CYCLE metaphor. All students correctly motivated their reformulations.

Sample answer 3.2: *There is a voltage drop.*

Twenty-one students indicated the LEVEL/INTENSITY metaphor.

Twenty-three students correctly rephrased the sentence, twenty-two used the LEVEL/INTENSITY metaphor, and three used the FLUID-LIKE SUBSTANCE metaphor.

Seventeen students correctly motivated their reformulations, four did not explicitly motivate because they accepted the statement as it is.

Sample answer 4.1:

(a) In the first phase, I would be in the company of other electrons.

Twenty-four students indicated the NUMERABLE SUBSTANCE metaphor; sixteen students reformulated the sentence, but only one correctly motivated, including a reference to a LEVEL/INTENSITY metaphor.

(b) I would lose some of my electron friends in the light bulb.

Twenty-one students indicated the NUMERABLE SUBSTANCE metaphor; seventeen students correctly rephrased the statement, explicitly addressing the misconception that current would be depleted in flowing through the light bulb and using the LEVEL/INTENSITY metaphor for the loss of energy (rather than the loss of current).

(c) In the wire after the bulb I would be with fewer friends.

Twenty-two students indicated the NUMERABLE SUBSTANCE metaphor; nineteen students reformulated the sentence correctly, specifying that it is not the number of electrons that changes but the energy that is transported, finding then more suitable the LEVEL/INTENSITY metaphor rather than that of NUMERABLE SUBSTANCE.

(d) Inside the battery, I would be gathering new friends.

Eighteen students indicated the NUMERABLE SUBSTANCE metaphor; eighteen students rephrased the statement correctly, indicating, as in the previous case, that in the battery (previously, in the light bulb) there is not a variation of a numerable substance (the number of electrons) but a variation of the transported energy, therefore highlighting, as the most appropriate metaphor, that of LEVEL/INTENSITY.

Sample answer 4.2:

(a) I would flow very happily because I am positive.

Eighteen students indicated the FLUID-LIKE SUBSTANCE metaphor; twenty-three students found the word "positive" ambiguous because while it could metaphorically refer to a high value of a quantity (e.g., energy), it could also be taken as a reference to the charge of the particle, that is, it gives rise to a dangerous mismatch of two different metaphors; nevertheless, in rephrasing, many incurred various mistakes, imprecisions, or overall confusion.

(b) The light bulb steals all my happiness and turns it into light.

Twenty-two students indicated the AGENT/PATIENT metaphor; eighteen correctly reformulated the sentence.

(c) I would flow but be sad because the light bulb stole all my happiness!

Sixteen students indicated the FLUID-LIKE SUBSTANCE metaphor, eighteen students the AGENT/PATIENT metaphor; twenty-one students accepted the sentence as it is or reformulated it just to specify that sadness is a metaphor for the loss of energy.

(d) The battery makes me happy again.

Eighteen students indicated the AGENT/PATIENT metaphor; seventeen did not reformulate or reformulated specifying that happiness is a metaphor for energy fullness.

Sample answer 4.3:

(a) I flow, charged with energy, towards the light bulb.

Nineteen students indicated the FLUID-LIKE SUBSTANCE metaphor; eighteen students did not reformulate or slightly reformulated the sentence.

(b) I undergo a transformation.

Twenty-two students recognized the AGENT/PATIENT metaphor; fourteen students correctly reformulated the sentence, in most cases just to specify the nature of this transformation (loss of energy by the particle).

(c) I leave the light bulb less charged than when I entered.

Twelve students indicated the LEVEL/INTENSITY metaphor; nineteen students reformulated the sentence, fifteen of them finding it correct but at the same time feeling that despite being inferable by previous sentences a) and b) (in the same set of answers), it would be preferable to specify that in the language of the author, "charge" refers to a "load" of energy rather than the actual electric charge of the particle.

(d) I become charged with energy.

Fourteen students indicated the AGENT/PATIENT metaphor. Twelve students rephrased the sentence, seven of whom only specified again that the term "charge" concerns energy and not electric charge.

The students' reactions to the whole activity were investigated through the answers to 6 questions and an open comment the students could add. Here, we qualitatively summarize the main information obtained.

4.1. Question 1: What Did I Learn about Teaching Competence through This Activity?

57% of the students answered that they learned to focus on the language they use when they are teaching; 54% were enlightened to the importance of identifying the metaphors; 50% felt urged to reflect more on the physics concepts they learned.

4.2. Question 2: Which Metaphors Are Most Easily Recognizable?

According to 87% of the students, the FLUID-LIKE SUBSTANCE metaphor is the most recognizable one.

4.3. Question 3: Does This Approach Help to Enhance Critical Skills in Interpreting Another Person's Thinking? Explain

Almost all students (98%) recognized that yes, this approach makes it easier to understand what kind of mental image the other person carries and, when this is the case, to recognize the error and take action to amend it.

4.4. Question 4: Does This Work Help to Critically Examine One's Own Language? Explain with Examples

As with the previous question, nearly all students (96%) affirmed that this work enhances the focus on the language we use and stimulates us to be critical of it. The examples they offered concern preconceptions and the use of linguistic expressions without reflecting on the images aroused by the words and which may therefore convey unintended meanings, always in strict connections with classroom situations.

4.5. Question 5: What Aspects Does This Activity Contribute If It Comes to Teaching Expertise?

For 83% of the students, this activity helped in tracking the misconceptions of the pupils; 60% of them also saw it as a way to enhance awareness of the language and the didactical approach used in the classroom.

4.6. Question 6: In the Study of Circuits, Which Activity Is Most Important for Teacher Training? Explain and Grade Each Activity: (a) the Analysis of Learning Nodes, (b) Proposals of Experiments, (c) the Formalization of Laws, and (d) the Study of Metaphors

Outcomes are described in Figure 1. Essentially, all four aspects were rated as important or very important. In particular, the novel activity of reflecting on the conceptual metaphors made available by ordinary language was very well received. The rating students assigned to it with respect to their training as prospective teachers tended to be at least comparable to, if not even higher than, the formal study of the laws of physics and surely comparable to focusing on conceptual nodes and the practice of experiments.

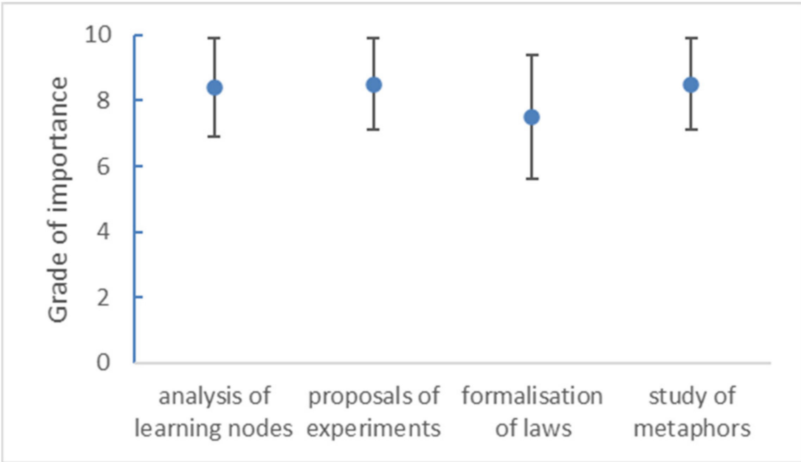

Figure 1. Average and standard deviation of students' evaluation on a scale from 1 to 10 of the importance they assigned to different activities concerning learning physics within their training as prospective kindergarten and primary school teachers.

Finally, we report some of the most notable comments left by the students.

4.7. 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.

4.8. 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).

4.9. 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.

4.10. 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.

4.11. Student 5

I think all teachers should do this analysis of themselves and their own disciplinary and non-disciplinary language.

5. Discussion

In general, student teachers were able to detect the conceptual metaphors in the sample expressions, evidence conceptual errors or inconsistencies, and improve the language in their reformulations. In most cases, they also commented on educational aspects, such as, for example, that metaphors must be differentiated and that one metaphor at a time should be used in the same statement.

It is likewise evident that sometimes students identified the metaphor in the first of a series of related sentences, simply forgetting or failing to recall it in subsequent sentences, and this explains the inflections in the number of students recognizing the same metaphor within the same set of answers. For example, in the set of answers 4.2, 18 students recognized the FLUID-LIKE SUBSTANCE in sentence a), while 16 students recognized it in sentence 4.2 c).

It is worth pointing out that the analysis also puts in evidence the existence of terms in our language that work as true metaphor triggers, i.e., the identification of a metaphor occurs much more frequently when a sentence includes a pivot word that is inextricably bound to that specific metaphor. For example, the use of the verb "to steal" in sentence 4.2 b) "The light bulb steals all my happiness and turns it into light" turns on almost unanimously the agent/patient metaphor, as happens in sentence 4.3 c), "I leave the light bulb less charged than when I entered", where the word "less" immediately referred to an adjective brings to mind the idea of a vertical scale, i.e., the level/intensity metaphor. As a matter of fact, a metaphor could be conveyed by several words, some more prompting and some more generic or less tied to that specific metaphor. For example, the two sentences, 2.1 "The current intensity passes through the whole circuit" and 4.2 a) "I would flow very happily because I am positive" mediate the very same metaphor, that of FLUID-LIKE SUBSTANCE, but while this is widely identified in the latter sentence (18 students), only eight students identified it in the former case. The word "flow" triggers the recognition of the fluid-like substance metaphor more directly than the word "current" because we are all used to speaking about "current" when referring to electricity (e.g., in a household context), perhaps without questioning all the aspects implied by the figurative scheme it conveys.

We want now to focus on those metaphors we would call the 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 synonyms). Table 3 synthesizes the metaphors correctly detected by the students specifically regarding these main metaphors for each sample answer. In answer 1.1, due to its formulation, we report the students' analyses if they mention both FLUID-LIKE SUBSTANCE and NUMERABLE SUBSTANCE metaphors, while in the 2.1 and 2.2 answers we report the occurrence of the two metaphors separately.

Table 3. Students' results concerning the FLUID-LIKE SUBSTANCE and NUMERABLE SUBSTANCE metaphors 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%

Table 3. *Cont.*

Answer	Main Metaphors	Metaphors Correctly Detected	Correct Rephrase	Correct Motivation
4.1 a)	numerable substance	24 100%	1 4%	1 4%
4.1 b)	numerable substance	21 88%	17 71%	16 67%
4.1 d)	numerable substance	18 75%	18 75%	18 75%
4.2 a)	fluid-like substance	18 75%	23 96%	11 46%
4.2 c)	fluid-like substance	16 67%	21 * 88%	21 * 88%
4.3 a)	fluid-like substance	19 79%	18 * 75%	18 * 75%

* Includes students who accept the sentence as it is.

The percentages reached by the student teachers are very high, above all expectations, considering the short introduction on metaphor theory and metaphoric analysis the students had. This means that this kind of activity stimulated the students' reflection on the extensive and intensive aspects of electricity and made them able to differentiate electric charge or current from electric potential and tension. The only finding against the trend is the lack of correctness in rephrasing sentence 4.1 a). Here, a large majority of the students reframed the sentence by sticking to the recognized metaphor (NUMERABLE SUBSTANCE) and forgetting to also refer to electron potential using the LEVEL/INTENSITY metaphor. This is, in our opinion, an incompleteness, rather than a conceptual error, because the metaphor works but is just not fully developed.

Table 4 summarizes the average of correctly detected main metaphors by the students, calculated over the sample answers (sample answer 1.1 has been excluded). The percentage of average correctly detected metaphors is high in the three cases, and the standard deviations make them statistically indistinguishable. This means that, at least for the three main metaphors, students became able to make a fairly correct metaphor analysis.

Table 4. Students' results for main metaphors.

Main Metaphor	Average Correctly Detected Metaphors
FLUID-LIKE SUBSTANCE	17.8 (s.d. = 5.6) 74% (s.d. = 23%)
NUMERABLE SUBSTANCE	21 (s.d. = 2.4) 88% (s.d. = 10%)
LEVEL/INTENSITY	20 (s.d. = 1.0) 83% (s.d. = 4%)

6. Summary

For what concerns RQ1, the results presented in this paper show that, with an introduction to metaphor theory and metaphoric analysis very limited in time, student teachers became able to carry out a conceptual metaphor analysis of sentences about electric circuits, applying schemas of FLUID-LIKE SUBSTANCE, NUMERABLE SUBSTANCE, LEVEL/INTENSITY and other secondary schemas such as path/cycle and container. They acquired competence in evaluating the correctness of sentences and in rephrasing both the correct and (in particular) incorrect sentences in a clearer language. Students adequately motivated their choices, showing that their use of metaphors became 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 more meaningful understanding of physics. This is also confirmed by the students' feedback where they pointed out the perception of the usefulness of conceptual metaphors for their professional development and expressed positive attitudes and inclinations. These judgments confirm the benefits of offering a reflection on language to prospective teachers, not only as a general topic per se but in connection with the specific topics included in their science training; they parallel and complement what has already been shown, for example, regarding the recognition of the power of narrative forms of science in understanding nature [52].

A general answer to RQ2 can be deduced from the students' comments on the whole activity, where they declared having strengthened their capacity for critically interpreting the thoughts of children and of other people in general.

Finally, the answer to RQ3 is positive. Not only because formalization will not be the object of teaching by these prospective teachers, but, above all because, as one extrapolates from the students' feedback, they themselves realize that cognitive and linguistic analysis turns out to be for all intents and purposes a deep conceptual analysis, which lacks nothing compared to a formalized study, and which, on the contrary, comes perhaps even closer to the essence of a physical phenomenon and makes the future teachers learn it better and deeper thanks to the use of very well-known linguistic structures. Moreover, this experiment proves that an effective introduction to metaphor theory requires a very limited period of time (2 h over 56), easily integrable in a standard course. This is especially true for student teachers because such content resonates with topics they already address in other curricular areas, such as linguistics, literature, and pedagogy. Hence, metaphor theory introduced in physics education can be seen as good practice, bridging different contexts and contributing to the development of cross-curricular skills.

In conclusion, we have gained evidence that conceptual metaphor is a powerful tool for student teachers, even in the case of abstract topics such as electricity. Student teachers take advantage of conceptual metaphors to analyze their own language and get a deeper and more critical insight into the disciplinary topic. This suggests that student teachers should be trained to perform metaphorical analysis, consciously use the different metaphors of a given subject, and master and differentiate them.

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