PEL
Pensamiento Educativo. Revista de Investigación Educacional Latinoamericana
2021, 58(1), 1-15
Pontificia Universidad Católica de Chile
Facultad de Educación

A Review of Studies About Conceptual Metaphors in Science and Science Education

Revisión de estudios sobre metáforas conceptuales en ciencia y educación cientí ica

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Abstract

This literature review summarizes research contributions to the study of conceptual metaphors in science education. Given the importance of conceptual metaphors as a phenomenon in the development of scientific concepts, it is necessary to understand how they have influenced the field of studies on science learning and teaching. Based on the theory of conceptual metaphor and the relevance of experientialism and the embodied cognition thesis, this paper presents a hermeneutic review of 31 academic sources, mainly published in the last decade, about conceptual metaphors in science and science education. We identify and discuss spaces for advancing a research agenda with practical and teaching potential, with more consideration of the relationships between the human body, the environment, and language in school science learning.

Keywords: conceptual metaphors, science learning, conceptual understanding.

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Se agradece el apoyo financiero de ANID (Ex-CONICYT), programa FONDECYT 11170880.

ISSN:0719-0409 DDI:203.262, Santiago, Chile doi: 10.7764/PEL.58.1.2021.12

Resumen

Esta revisión de literatura sintetiza los aportes de la investigación al estudio de metáforas conceptuales en educación científica. A propósito de la relevancia del fenómeno lingüístico de las metáforas conceptuales en el desarrollo de conceptos científicos, se hace necesario entender cómo ha influido la metáfora conceptual en el campo de estudios sobre aprendizaje y enseñanza de las ciencias. A partir de la teoría de metáfora conceptual, con la relevancia del *experiencialismo* y la *tesis de la cognición incorporada*, este trabajo presenta una revisión hermenéutica de 31 fuentes académicas publicadas principalmente en la última década sobre metáforas conceptuales en ciencias y educación científica. Se discuten e identifican algunos espacios para avanzar una agenda de investigación con potencialidad práctica y didáctica que involucre una mayor consideración sobre las relaciones entre el cuerpo humano, el ambiente, y el lenguaje en el aprendizaje escolar de las ciencias.

Palabras clave: metáforas conceptuales, aprendizaje de las ciencias, comprensión de conceptos.

The psycholinguist Steven Pinker (2010) suggested two hypotheses to explain why humans engage in abstract tasks such as science. The first is that, through evolution, we have developed a survival mode, which is characterized by manipulation of the environment through causal reasoning and social cooperation. Pinker called this notion of social interdependence and intensive use of knowledge the "cognitive niche". The second is that the psychological faculties that we have evolved to proposer in this cognitive niche can be co-opted to abstract domains through processes of *metaphorization*, with language being its most vivid manifestation. Metaphorical abstraction is key for explaining the capabilities of abstract human reasoning, including scientific reasoning.

If metaphorical abstraction is so important for explaining scientific reasoning, how has this perspective been applied in the science education research community? This paper is based on a literature review that seeks to answer this question and establish the connection between metaphorical abstraction and the development of science education.

Metaphorical abstraction, or rather conceptual metaphor, is a linguistic phenomenon that is well documented in the literature on cognitive science—specifically cognitive linguistics—with George Lakoff and Mark Johnson (Lakoff, 1993, 2008; Lakoff & Johnson, 1980, 1999) being the pioneering exponents of this in the 1980s. Cognitive linguistics is an area of study that focuses on researching cognition by examining language (Croft & Cruse, 2004; Evans & Green, 2006; Geeraerts & Cuyckens, 2007; Ibarretxe-Antuñano & Valenzuela, 2012; Lee, 2001; Ungerer & Schmid, 1996). Cognitive linguistics is grounded on certain basic assumptions. The first is that language reflects fundamental properties of the human mind; the second that grammar itself represents a conceptualization; and third that knowledge of and about language emerges when investigating language in use. According to these assumptions, language in use reflects cognition, or knowing something about language is equivalent to knowing something about processes of meaning, form, and thought.

Conceptual metaphor is a language phenomenon that is studied with the tools of cognitive linguistics. Lakoff and Johnson (1980) contended that metaphorical thinking is ubiquitous and inevitable, and is fundamentally unconscious. From this perspective, the analysis of linguistic evidence, of language in use, can provide clues about the conceptualizations that we have—as humans—about the world and about science, and conceptual metaphor can be part of this evidence. Lakoff and Johnson (1980) emphasized that conceptual metaphors differ from the conventional notion that considers them as rhetorical, aesthetic, or stylistic ornaments of language. This view has permeated other fields of applied research (see Geary, 2011), so this has motivated researchers in science education to explore what these conceptual metaphors are and how they are related to understanding and learning science. This paper seeks to connect the literature that currently exists at this intersection of conceptual metaphors, science, and science education, in order to understand the potentials for research and application in teaching.

To address the question about the link between studies of conceptual metaphor and science education, I refer to conceptual metaphors and their relationship with embodiment as a theoretical framework. Then, I present a review of the literature regarding conceptual metaphors in science and science education, before concluding with a discussion that addresses a research agenda and didactic potentials.

Theoretical Framework

Conceptual metaphors, embodiment, and language

Lakoff and Johnson (1980) described metaphors as conceptual and essential for abstract thinking. A conceptual metaphor is a mapping or pairing between an abstract conceptual domain (*target domain*) and a physical-material conceptual domain or an embodied experience (*source domain*). The target domain is the concept that the metaphor intends to describe, while the source domain serves as the origin to describe the target domain. In a source domain, the emphasis is on specific, perceptual, embodied, and, sometimes, cultural experiences.

Two concepts of cognitive linguistics are related to the idea of embodied experiences: *experientialism* and the *embodied cognition thesis*. Experientialism is the idea that human knowledge about abstract concepts emerges from human experience with other domains of knowledge, specifically embodied experiences with the environment (Lakoff, 1987). Embodiment involves the experiences that result from interactions between the human body and the physical and cultural world. These interactions are prelinguistic in nature, that is to say, they occur before the human body can communicate via language and are intimately linked to the development of cognition (Lakoff & Johnson, 1999). Sensory experiences such as vision, balance, and gravity are examples of embodiment, as are emotional experiences such as anger and happiness. *Embodied cognition thesis* contends that humans' conceptual systems depend on the ways in which the human body interacts with the environment (Evans & Green, 2006). One of the consequences of assuming this theory is that, in practice, the nature of the human body and its perceptual systems limit its ability to interact with the physical environment and thus the access to conceptualizations that arise from such interactions (Lakoff & Johnson, 1999). Therefore, we only have access to think what the human body allows us to perceive and conceive. Although of a prelinguistic in nature, language is able to capture the character of embodied experiences and their influence on the ability to conceptualize.

Considering this, the relations between the body and the environment would be responsible for establishing links for the creation of conceptual *source* domains in conceptual metaphors. One of the characteristics of conceptual metaphors is their unidirectionality in the mapping between domains. This means that a target domain can be understood as a source domain, but a source domain cannot be understood as a target domain. The following expressions, taken and adapted from the Corpus del Español (Davies, 2017), exemplify this unidirectionality (here, translated into their equivalents in English):

- They walked the dog with a steel chain.
- That manipulation of the overall figure led to a chain of errors.
- The double chain of DNA separates.

The first example is a linguistic expression about the direct perception of an entity, the steel *chain*, as a link between a person and a specific, culturally situated and embodied perceptible activity (as depicted in Figure 1(a)). The second expression implies levels of abstraction where a *chain* is not perceptible in the same way, but requires mapping from the conceptual domain of a *chain* in specific terms, as seen in Figure 1(b), to another conceptual domain where certain attributes of the *chain* enable the expression to be understood. Thus, we infer that the physical attribute of the chain, being an entity with links in which each link is joined to another, serves as a concept to assume that an error—an abstraction that is not obviously perceptible—can be linked to another and, in turn, to another, giving meaning to the idea that an act can cause a *chain of errors*. In this case, the chain of errors is not perceptible in terms of embodiment, but it is understood and exists thanks to the mapping or *pairing* of conceptual domains: AN ERROR AS A LINK IN A CHAIN[1]. In the third example, the conceptual domain of the *chain* is paired with a conceptual domain of science, an organic macromolecule—deoxyribonucleic acid or DNA. As in the previous example, there are perceptible attributes of a chain that are mapped or paired with imperceptible attributes of an entity to be conceptualized: DNA (Figure 2). Thus, each structural unit of DNA, the nitrogenous bases, is understood as a link: A NITROGENOUS BASE AS A LINK IN A CHAIN. In these examples, both the *chain of errors* and the *DNA chain* are concepts with a similarity that is created, or which exists, thanks to the understanding of the physically perceptible conceptual domain of the *chain*. This pairing or creation of similarity is called *metaphorical abstraction*.

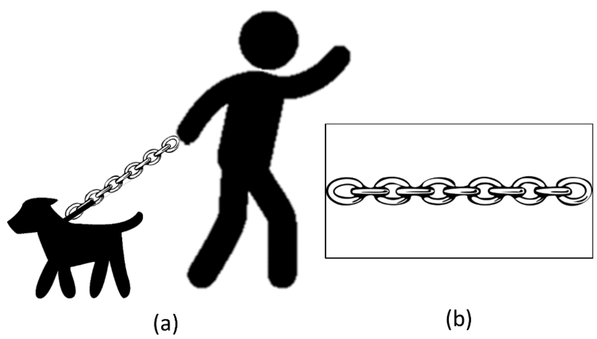

Figure 1 . *Picture (a) is a representation of a culturally and physically perceptible situation: attaching a chain to a dog's collar in order to take it for a walk. The entity of the chain has a material configuration, which is represented in (b).*
Source: Prepared by the author.

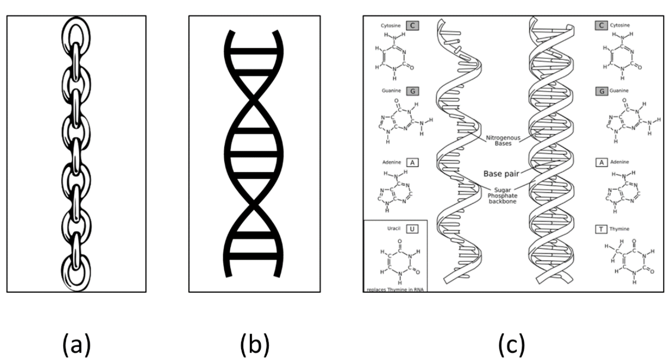

Figure 2. *Representations of the conceptual domain of a chain (a) with the conceptual domains representing the macromolecule deoxyribonucleic acid (DNA) (b) and (c).*
Source: Prepared by the author.

1. Conceptual metaphors have a notation as expressed in this section. The notation is explained in the following paragraphs.

Conceptual metaphors are denoted using capital letters, in the form: TARGET DOMAIN AS SOURCE DOMAIN. In the two examples above, the mapping between conceptual domains is denoted as: AN ERROR AS A LINK IN A CHAIN and DNA AS A CHAIN (with the aforementioned A NITROGENOUS BASE AS A LINK IN A CHAIN). For both metaphors, the source domain is the perceivable entity called a chain, and certain attributes of this construct a similarity in the concept of an *error* and in the concept of *DNA*.

Lakoff and Johnson (1980) argued that conceptual metaphors are also generative, as they provide a framework for the creation of further linguistic expressions that show mapping between conceptual domains. The following expressions, taken from the Corpus del Español (Davies, 2017), enable us to exemplify this (translated into their equivalents in English).

- Evaporation is the change from liquid to gas.
- All of that cognitive surplus is going to evaporate.
- The vapor rises and is transformed into clouds in the atmosphere.
- Unemployment soared into the clouds.

The first example illustrates a physical phenomenon that can be named and conceptualized (evaporation) in terms of a change of location (or state), where one entity (liquid) *moves* to another entity (gas). The metaphor would be denoted as TO EVAPORATE IS TO MOVE BETWEEN TWO LOCATIONS, or LIQUID AS A LOCATION, or SOLID AS A LOCATION. Based on that idea, *evaporation* is then used to conceptualize an abstract entity (a *cognitive surplus*), projecting perceptual properties in context (the idea that something evaporating ceases to be visible); the metaphor COGNITIVE SURPLUS AS LIQUID can thus be proposed. In the third example, a directional transfer process is mentioned, upward (*vapor rises*), locating a specific entity (*clouds*) that would result from this process. The visual perception of the location of the clouds then serves as a reference to indicate the directionality of an abstraction: *unemployment*. In this case, the metaphor is MORE IS UP, and that, therefore, orients the meaning of the statement towards *high* unemployment. This metaphor is generative, since multiple linguistic expressions can be created using the mapping between the quantity domain (MORE) and its topology (UP). Expressions such as *unemployment has gone up*, *inflation has gone down*, or *prices are high* demonstrate the generativity of the conceptual metaphor. The vertical orientation (up-down) also shows that this metaphor depends on the relationships that the body establishes with the environment and with the representations of quantity, as well as the access that the language in use enables for the relationships between embodiment and the creation of concepts and conceptual domains. This generative attribute of metaphor allows us to approach the analysis of language in use in order to identify its conceptual content. Considering the necessary conceptual richness and deployment associated with science learning, the framework of conceptual metaphors enables the creation of a perspective on the conceptual domains present in the construction of scientific knowledge relevant to science education and could, therefore, inform didactic interventions that recognize this analytical element.

Methodology

I conducted a literature review using a hermeneutic approach (Boell & Cecez-Kecmanovic, 2014). This kind of hermeneutic review allows continuous involvement and a gradual development of the corpus of literature, in order to increase the depth of understanding of a theme. This approach involves combined and iterative cycles of searching for and acquiring literature to analyze and interpret. The search and acquisition cycles entailed a search approach based on initial ideas, classification, selection, acquisition, and reading of the material.

The search was started with the concept of conceptual metaphors and the pioneering work of Lakoff and Johnson (1980). In specialized databases (ERIC, Web of Science, Scopus) via the GoogleScholar search engine and journals specialized in science education, I searched for papers that cited the work of Lakoff and Johnson (1980) or which contained the terms conceptual metaphor, *metáfora conceptual*, or *metáforas conceptuales* in titles or abstracts up to July 2018. Similarly, in another search cycle, the same terms were used to conduct searches in the Scielo database. The first search cycle produced a total of 1192 matches. The list was processed, eliminating duplicates and the search was refined to focus on studies related to science learning and teaching, or which were directly related to the topic of conceptual metaphors in science.

Following the cycle of the hermeneutic approach, the material was mapped and classified, and I conducted a critical analysis to understand the position from which each work was written, before developing an argument and, based on that, formulating initial research problems or questions. These questions gave rise to new search and acquisition cycles, making it possible to identify and refine the searches, as well as to group the literature into emerging categories (e.g., themes, actors involved in the studies). In terms of time, the searches were carried out in stages after 1980, with one exception; literature focused on analogies was excluded. This review thus includes a total of 31 papers, books and other works, five of which address the discussion of metaphors in science, while the remainder involve metaphors in learning and teaching. Most of these papers have been published in English-language journals or sources. This corpus included two books, 24 papers in indexed journals, and five works from other sources.

Results

Two main categories emerged from mapping and classifying the literature: texts that give metaphors and conceptual metaphors a role in scientific ideas, and literature that researches or addresses the concept of conceptual metaphors in science education. The results of the review are organized according to these two categories: conceptual metaphor in science and conceptual metaphor in science education.

Conceptual metaphor in science

The notion of metaphor in the sciences is not new. The texts placed in this category are focused on discussing the sciences and their relationship with conceptual metaphors. One reference prior to 1980 is included, since its content could be related to the subject. This review provides an account of the shift of the discussion in the sciences regarding the incorporation of the concept of the conceptual metaphor, so the order of presentation is chronological.

In the early 20th century, Harris (1912) stated that the history of science involved examples in which an idea was first represented by a metaphorical expression before coming into concrete existence over time. Harris argued that the principle of the embodiment of ideas was a process that occurred in the sciences, such as that in which a vague idea was anticipated in the mind before acquiring a concrete expression in the future. Decades later, Hoffman (1980) examined the role of metaphors in scientific theories, noting that scientists tend to demonstrate a favorable attitude towards them due to their abundance in science and their apparent availability in any problem that they face. Hoffman contended that scientists were aware that scientific metaphors and theories need to change on the basis of evidence, as they are used to explore nature but cannot be confused with nature itself. The usefulness of metaphors in science would thus reside in not perpetuating such a drastic distinction between the literal and the figurative.

Bradie (1999) contended that metaphors are indispensable for scientific thinking, and that there is no possibility of describing science without them. He pointed to the existence of three functions of metaphors in science. The first is rhetorical, or their use in teaching and communications. The second is heuristic, as a guide to orient new discoveries (e.g., talking about the particles of a gas as billiard balls). The third is cognitive (or theoretical), contributing to the validation and justification of theories.

The chemist Theodore L. Brown (2003) linked conceptual metaphor with science in the book *Making Truth: Metaphor in Science*. Brown argued about the nature of the sciences based on two fundamental ideas: i) that scientists understand science primarily in terms of metaphorical concepts that are based on an embodied understanding of how nature works, and ii) the models and theories that scientists use to explain observations of the world are metaphorical constructs. Brown explained that the understanding of nature and science derives from very basic interactions with the physical world, and that these are tacit and widely shared by humankind. Understanding the sciences and understanding their success entails accounting for the fact that there is an access to reality that is always mediated and that the implication of truth is always the result of human reasoning (as opposed to an objective truth that is independent of the mind).

Tajer (2012), a cardiologist, conducted a review of the most relevant conceptual metaphors in medicine, carrying out an analysis that highlighted the importance of finding metaphors that change the meanings attributed to existing metaphors and their relationship with patients' suffering. In another paper, Sá, Nagem, Almeida, and Marcelos (2014) studied conceptual metaphors regarding concepts of evolution in two books: *The Origin of Species* by Charles Darwin and *Early Man* by Francis Clark Howell. They found that, in texts discussing evolutionary theory, the conceptual metaphor EVOLUTION AS PROGRESS was contained in several examples. Although this was not found in Darwin's text, it was observed in Howell's book, with expressions such as *path* and *march*. Finally, Palma (2008, 2015) stated that metaphors in the sciences primarily fulfill an epistemic and cognitive function. That is, they are a constitutive part of scientific knowledge, and are also part of its teaching.

This part of the review enables us to observe a transition in the understanding of metaphors and their role in scientific knowledge, increasingly highlighting them to understand the history of science and their practical application in contexts such as medicine. The arguments in the literature are to pay heed to the cognitive and epistemic dimension of metaphor, as opposed to its traditional (ornamental) conception of language.

Conceptual metaphors in science education

This category includes published works with a direct focus on science education. It begins with a review conducted in 2012 and then gives an account of the temporal evolution of the studies in which references to Lakoff and Johnson (1980) are informative. This enables us to show how this reference to conceptual metaphors has permeated the literature on science education and demonstrates that attention to the conceptual metaphor as a phenomenon in science education is a recent trend.

In the paper *Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science*, Niebert, Marsch, and Treagust (2012) pointed to the importance of conceptual metaphors for science teaching and learning. The paper analytically examined conceptual metaphors based on the language in use in science teaching and learning, using records in science education publications. They found 199 conceptual metaphors used for the construction of various scientific concepts. The authors contended that there is a need to expand the idea of what is considered *prior knowledge*, clearly recognizing the prevalence of embodied experiences in order to facilitate the understanding of scientific concepts.

Brookes and Etnika (2015) studied the language in use of scientists teaching and discussing quantum mechanics and students learning about the same subject. They concluded that physicists naturally used conceptual metaphors when talking about quantum mechanics, but their students had difficulty understanding them because they interpreted them literally. Meanwhile, in a series of essays, Fuchs (2007, 2009, 2010) developed an analytical rationale for considering embodied experiences for teaching physics and chemistry, arguing that cognitive linguistics provides tools to analyze the scientific concepts of students. Fuchs emphasized the study of linguistic phenomena such as conceptual metaphors, force dynamics, and image schemas[2], since they are interrelated with respect to the relationship of the body with the environment, which would be a source of key conceptualizations for physics and fluid dynamics. Using a computer survey system, Nehm, Rector, and Ha (2010) analyzed the frequency with which university biology students used words associated with force dynamics terms to explore the accuracy or inaccuracy of their explanations of evolutionary biology. Their findings call for science teachers to pay attention to the use of *force-talk* to explain models of biological evolution, since it leads to incorrect explanations. Force dynamics is considered a primary discourse of students learning science, which serves to position their performances on a line of progression toward more sophisticated models of scientific reasoning (Gunckel, Covitt, Salinas, & Anderson, 2012; Gunckel, Mohan, Covitt, & Anderson, 2012; Mohan, Chen, & Anderson, 2009).

Dreyfus et al. (2014) studied *ontological metaphors* for the concept of energy in physics learning, identifying two metaphors for energy: one for location and one for substance. They highlighted the problematic nature of the substance metaphor when discussing *negative energy* in chemical reactions, and argued that an interdisciplinary approach to understanding energy, in which the two metaphors are blended, can be useful for reasoning about phenomena such as negative energy in chemical bonds. For his part, Lancor (2014) conducted a study of the concept of energy in chemistry, physics, and biology using conceptual metaphors. He focused on what he called *pedagogical discourse*, or what is contained in textbooks and the science education literature. He managed to identify six metaphors of substance to refer to the concept of energy: energy as a substance that can be quantified, that can flow, that can change form, that can be lost, that can be an ingredient, a product, or which can be stored in some form. For each metaphor there are aspects that are highlighted, while others are concealed. For example, the metaphor of energy as a substance that can flow highlights the idea of an energy source, but conceals that of energy transformation. On the other hand, the metaphor of energy as a substance that can be quantified highlights the idea of energy conservation, while concealing the notion of its source of transformation. Lancor stated that there is no single conceptual metaphor that fully explains the complex and abstract concept of energy.

Niebert and Gropengießer (2014) carried out a metaphorical analysis of the content of 35 interviews with secondary school students considering their understandings of the greenhouse effect, and also analyzed research reports and textbooks on the same subject. They contended that the conceptions of scientists and students are based on the same schemas, with three of them being fundamental: warming by more input, warming by less output, and warming by a new equilibrium. This interrelation between the conceptions of students and scientists allows them to describe some of the students' learning demands about the topic, outlining certain principles for the design of learning experiences about the greenhouse effect, where students can explore the interactions of electromagnetic radiation and carbon dioxide, and reflect on the experiences they use as source domains for metaphorical comprehension of the greenhouse effect.

In another text, Salinas (2014) used conceptual metaphor analysis to explore the embodied and perceptual experiences that secondary school students use to conceptualize the idea of *systems*. He stated that it can be inferred that perceptions about the boundaries of physical entities and perceptual dynamics about changes in position (locomotion) are starting points, or source domains, for the development of systems thinking as a target domain.

The 2015 special issue of the *International Journal of Science Education*, entitled Conceptual Metaphor and Embodied Cognition in Science Learning, included seven papers—some of the authors of which were already making publications on this topic—and three commentaries, confirming the growing focus on the study of conceptual metaphors in research on science education in English-speaking contexts. Amin,

2. Both force dynamics and image schemas are linguistic phenomena that are also highly relevant in the field of cognitive linguistics. They are important in the formulation of domains that constitute conceptual metaphors. While they are related in significant ways to conceptual metaphor, they are addressed briefly in this paper. For references on force dynamics see Alarcón (2010) and on image schemas see Ibarretxe-Antuñano and Valenzuela (2012).

Jeppsson, and Haglund (2015) presented the special issue, considering the emphasis on conceptual metaphor as a useful category in the study of science learning phenomena. Brookes and Etnika (2015) reported that they interviewed university-level physics students to study their reasoning regarding heat in thermodynamic processes. The study revealed certain relationships between how students understood heat and their approach to solving heat problems, contributing to describe the effects of considering the metaphor of *heat as a substance* in understanding thermodynamic phenomena.

Jeppsson, Haglund, and Amin (2015) reported that the use of conceptual metaphors in the interpretation of both linguistic and mathematical propositional knowledge is learning that underlies the development of scientific expertise applied to problem solving. Meanwhile, Dreyfus, Gupta, and Redish (2015) discussed conceptual metaphors regarding the conceptual productivity of using different metaphors for the concept of energy. In their paper, commonly used ontological metaphors such as ENERGY AS A SUBSTANCE and ENERGY AS A VERTICAL LOCATION can be *blended* by both experts and novices to create a coherent mental model for reasoning about the concept of energy. Close and Scherr (2015) examined the effect of using these blends, illustrating the creation of a learning environment to comprehend the phenomena of energy transfers and transformations. The learning environment involves learner interactions with each other, such as body movement, gesture, and metaphorical speech with the metaphor ENERGY AS A SUBSTANCE. The authors demonstrated that the *blended* aspects of the learning environment promote active intellectual engagement with the understanding of the concept of energy. They therefore estimate that there are specific conceptual metaphors that can be blended with a specific human activity and can be used to benefit science teaching. Lancor (2015) expanded his study of energy metaphors into the discourse of university-level students, conducting a qualitative analysis to study the metaphors that emerged when 49 undergraduate students taking an interdisciplinary, general science course were asked to explain the concept of energy in five contexts: radiation, transportation, generating electricity, earthquakes, and the big bang theory. Most of the students used multiple, coherent conceptual metaphors to explain the role of energy in various different contexts, not just traditionally scientific ones.

Niebert and Gropengiesser (2015) expanded the notion of the experiential grounding of scientific thought—using conceptual metaphors—in order to understand the embodied basis of certain scientific concepts. They studied which embodied concepts students and scientists use to understand phenomena represented in the microcosm and macrocosm, and how these concepts enable the design of external representations of microcosmic and macrocosmic phenomena. The authors argue that human perception is adapted to a medium-scale dimension and our embodied conceptions originate from this mesocosmic scale. In this study, Niebert and Gropengiesser identified various conceptual metaphors for understanding microcosmic phenomena, such as microbial growth and signal conduction in neurons, and macrocosmic phenomena, such as the greenhouse effect and the carbon cycle.

Fuchs (2015) discussed conceptual metaphors and their link to the field of narrative studies in science learning. In this study, he proposed the idea of the narrative structure for natural and technical scenarios, in order to represent the enlisting of narrative intelligence in the perception of phenomena, and stories containing conceptual elements used to model scientific phenomena. Fuchs used the analytical study of simple stories of natural phenomena and products associated with thermodynamics. In the study, he recognizes what he calls figurative structures, demonstrating that the perceptual gestalt called FORCE OF NATURE (emphasis in original) is based on a narrative structure, where natural agents act and suffer storyworlds. Fuchs argued that scientific thinking and its formal models are profoundly related to these storyworlds, which contain and must be formed by agents, tensions, events and processes, causality and power relations, and a connection to emotional understanding. He considered that if the narrated world is to contribute to scientific thought, it must also have a certain degree of conceptual structure, provided by metaphoric projections, which makes formal scientific reasoning possible.

Celik (2016) studied 226 students' perceptions of heat, temperature, and energy phenomena at four secondary schools in Turkey, using assessment tools or instruments to elicit 176 metaphors generated by the participating students. The metaphors generated by the students were classified as formal/scientific metaphors, abstract metaphors, environmental/daily life metaphors, and metaphors including misconception. He organized the metaphors and their classifications in terms of their increasing prevalence at each of the educational levels, suggesting the existence of differences or stages of metaphors. Celik discusses the possibility of progressing with the construction of models of metaphor analysis based on what the students state, in order to create models for teaching key scientific concepts.

Kersting and Steier (2018) conducted a thematic and metaphorical analysis to study written online accounts of small groups of university students in their physics classes in Norway. The topic was the abstract nature of spacetime. The researchers found that students generated conceptual metaphors that were reported in the literature, as well as novel ones that led to different conceptions of gravity than those held by experts in the field. The authors identified a conflict between the students' embodied understanding of gravity and the abstract description of general relativity. Based on these findings, the researchers offered some guidelines for teaching general relativity, also assuming the epistemological implications of employing specific scientific metaphors in school classrooms.

The review of this literature provides an overview of the influence that the study of conceptual metaphors has had on the understanding of scientific phenomena, as well as on science learning and teaching. With a general summary of the results of the review, it can be stated that:

- There is a clear and growing interest in addressing the phenomenon of conceptual metaphors in science and in processes of science education
- Conceptual metaphors can be identified in various areas of science education and concerning various concepts, which means that there is still a non-systematic repository of metaphors in use in science education.
- Researchers tend to recognize metaphors at different levels of education, at different levels of scientific expertise, and in different subjects and contexts of use of scientific language, which may or may not be consistent for the same concept.
- There are limited examples of the use of conceptual metaphors for the design of science teaching experiences, located almost entirely in English-speaking contexts.

The review shows that, in some international contexts, there is research that tends to agree on the importance of embodiment and the study of conceptual metaphors in the understanding of scientific concepts. It also demonstrates that this is a nascent field, with recent studies. The results of this review are discussed below in terms of a contribution to a basic and applied research agenda for science education in Spanish-speaking contexts.

Discussion and Conclusions

The growing interest in the study of conceptual metaphors, their identification in contexts of communication and science education, and the recognition of their differentiated use in various contexts and at different levels enables us to organize their potential. Likewise, development of the field of cognitive linguistics in Spanish-speaking countries is also an opportunity to advance on a perspective regarding the role of metaphors in science education in Latin America. This discussion refers to the proposal of basic research—the epistemic potential—and applied research—the didactic potential—of the study of conceptual metaphors for science education.

In a way, the review indicates that there is a field of studies in which systematic research on conceptual metaphors, understood as language phenomena that allow access to patterns of embodiment and conceptual understanding, can be conducted in contexts of science education.

Basic research agenda

The interest of the international community in the study of conceptual metaphors in science education can be explained by the transition that certain perspectives on language have undergone in recent decades and the way in which they have been linked to studies on learning, specifically with the development of the field of cognitive linguistics (Evans & Green, 2006; Geeraerts & Cuyckens, 2007; Lee, 2001; Ungerer & Schmid, 1996). Although this has reached the English-speaking science education community, development of cognitive linguistics in Spanish-speaking contexts has been more recent (Ibarretxe-Antuñano & Valenzuela, 2012), which partly explains why this interest has developed later. This represents an opportunity to think about language studies in science education based on conceptual metaphors, projecting the study of language in science beyond approaches that are focused on finding the distinctions in scientific language in relation to other discourses (Gee, 2005). By fostering a view of language as a faculty that is inseparable from cognition, and which is therefore a *window* on thought (Pinker, 2007), it is possible to stimulate research that identifies patterns of thought in scientific language linked to other experiences, which may be significant in the construction of scientific concepts. Conceptual metaphors allow scientific thought to look through these windows, seeking to identify the *source domains*, or basic experiences of scientific concepts.

The review gives an account of the research efforts associated with the search for *source domains* regarding different scientific concepts. In order to continue identifying these source domains and their link with scientific concepts, agreements are needed on the use of methods, forms of analysis, and data sources that can allow this work to be systematized and developed. This implies a methodological dialogue in the field of studies of science education, to specify and identify what the relevant conceptual domains are and how they could be denoted and exemplified for future research. In addition to this, there must be deeper interdisciplinary dialogue on the phenomenon of metaphors from the linguistic perspective, as proposed by Steen (2011) in the revised proposal of the contemporary theory of metaphor, which emphasizes its communicative dimension.

The distinction of conceptual metaphors based on levels and contexts of use can also enable productive discussion in the field of studies on science learning. One of the scopes of this line of research could mean new epistemological discussions regarding the ways in which science didactics can understand concepts that are currently included in the pursuit of learning experiences, such as conceptual change. Niebert et al. (Niebert & Gropengiesser, 2015; Niebert & Gropengießer, 2014; Niebert et al., 2012) have called for consideration of *experientialism* as a theoretical framework to reexamine our conceptions of how learning take place in the sciences. They also propose moving from the exemplification of students' prior ideas toward explanations that primarily indicate the reasons for those prior ideas. For his part, Amin (2009, 2015) has argued that conceptual metaphors can be positioned as additional sources in the study of conceptual change. Meanwhile, Palma (2008, 2015) contended that metaphor has a fundamental cognitive and epistemic role, both for the production of scientific knowledge and in the acquisition of this knowledge by those who learn science. He proposed "analyzing the nature and function of metaphors in order to understand the type of conceptual, intellectual, and epistemological commitments that are assumed when they are enunciated and to take advantage of their potential" (Palma, 2008, p. 17). This view could promote other perspectives on the progress of learning in the sciences, and thus energize the curricular debate.

The results of this review point to the potential to develop a line of research in science education with the aim at linking the study of language in use in scientific contexts and learning and teaching based on the understanding of conceptual metaphors.

Didactic potential

The growing interest in the study of conceptual metaphors in science education is marked by certain interventions in pedagogical or didactic aspects. In most of the literature reviewed, there is an intention to describe the conceptual metaphors associated with scientific concepts and to understand their use in school or university contexts. For example, Niebert et al. suggested that an "analysis of the experiential background of everyday and scientific conceptions can provide a fruitful basis for the development of learning environments" (p. 23). However, this interest has been expressed more frequently in English-speaking contexts, while the epistemic value of metaphors in science, and thus their value for science teaching, has been recognized in Spanish-speaking contexts (Palma 2008, 2015). This is a challenge for the field, to create and understand the pedagogical and didactic potential of the study of conceptual metaphors in science education. From that perspective, conceptual metaphors have been used to propose didactic applications in second language learning (Hijazo-Gascón, 2011), and in relation to communicative perspectives (Steen, 2011) and considerations of science as a *second language* (Lemke, 1990; Darian, 2003; Roth, 2005; Reeves, 2005; Bruna & Gómez, 2009) elements of experience could be proposed to develop didactic proposals that are associated with conceptual metaphors.

The identification of conceptual metaphors in scientific concepts could be a great contribution to the design of science learning experiences. In this paper, we have, for example, presented several metaphors to refer to the concept of energy. These already constitute a resource or repository of conceptual *source* domains, which construct and give existence to the scientific concept of energy, or the conceptual *target* domain. By identifying more of these conceptual source domains, tools will be made available to help design experiences that are easily linked to the comprehension of the target domain. This exploration is open-ended.

Several of the texts presented here have examined the metaphors that are present in different contexts and at different levels, and which are used in the language of various actors with different roles in the context of science education. This finding combines the possibility of understanding a *developmental* or *progressive* aspect of the conceptual metaphor, or one in which context influences comprehension. By enabling metaphors to be understood in different contexts, the usefulness of curricular materials for different actors and roles can be established. Questions such as, what metaphors underlie the scientific concepts to be taught? or what might be the most relevant metaphor to use in the context or at the level at which it is taught? could spur innovations that have only been reported to a limited extent in the literature reviewed thus far.

This review shows some examples of research that have applied what has been learned about conceptual metaphors to the design of these learning experiences (Lancor, 2014; Niebert & Gropengießer, 2014; Close & Scherr, 2015). Therefore, interesting elements for advances in this direction in the field of science didactics could involve the experimental or quasi-experimental study of didactic interventions based on these investigations of conceptual metaphors. That is, metaphorically understanding some of the key scientific concepts that partly organize the curriculum, based on experientialism, could promote didactic innovations whose impact can also be understood from the way in which the *source domains* are linked to the *target domains*. The possible scope of these studies could provide the field with new organizational frameworks, or resituate certain elements of constructivism in science teaching, such as the notion of prior ideas to the learning of scientific concepts. The systematic study of conceptual metaphors could drive the interest of the Spanish-speaking community to experiment with them in order to design didactic experiences. Some of this innovation has been discussed by Salinas, González, and Fernández (2017).

The review I present here calls for a reexamination of the language of science from the perspective of *experientialism*, which understands abstract human knowledge as a result of experience with conceptual source domains, particularly embodiment experience with the environment. The conceptual metaphor as a linguistic phenomenon captures the link between conceptual domains of experience. There are those who argue that metaphor is not only about thought, but also about communication, which paves the way for debate on how to approach the metaphorical phenomenon from a social perspective (Steen, 2011). This paper has been limited to reviewing the research associated with the concept of conceptual metaphors in science education, which has fundamentally resonated with research in English, and which supports the idea that understanding scientific concepts requires embodiment. Considering this, it is proposed that the field of science education should pay heed to this concept, stimulating its potential to understand conditions to inform and study innovations in the area.

The original paper was received on December 19th, 2019
The reviewed paper was received on September 20th, 2020
The paper was accepted on September 29th, 2020

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