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Science Meets Metaphor: Teaching and Communicating about Abstract Concepts in Romanian Science Textbooks

Abstract

Metaphors and analogies are efficient and attractive tools used in science teaching to explain abstract ideas in simpler, familiar terms. Science textbook authors and teachers rely on metaphors and analogies to explain abstract scientific concepts and convey them to young learners. In this paper, we discuss a corpus of metaphorical expressions found in Romanian physics and chemistry textbooks for secondary education (grades 6-8), and classified based on target domains (i.e., the core scientific concepts presented in the unit lessons of the analyzed textbooks) and source domains (i.e., the more concrete, more familiar concepts used to explain scientific concepts from the analyzed textbooks). Furthermore, we explore the way in which the identified and annotated metaphors may provide the basis for understanding core concepts from physics (e.g., electricity in terms of 'water flowing') and chemistry (e.g., electron shells as 'field track lanes'). This study is part of a larger research project which aims is to examine how metaphors and analogies used in Romanian science textbooks are understood and misunderstood by young learners and what (mis-) understanding complex scientific ideas might mean for pupils' preparedness to make sense of the world we live in and, ultimately, for their future engagement with and interest in science.
Keywords: science education and communication, metaphor and science, teaching and communicating abstract concepts, Romanian science textbooks

Introduction

Science education and communication shape young children as future citizens of a modern society. Scientific literacy is crucial to informed citizenship and school textbooks are instrumental for transmitting knowledge and values to the young generation. This paper aims to explore the verbal and visual metaphors used in 11 science textbooks (6 - physics, 5 - chemistry) for young students aged 11 to 14 years. There is widespread recognition of the essential role played by metaphors in education, especially in mediating teaching and learning new abstract concepts. Metaphors help simplify abstract ideas by means of foregrounding analogies

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with concrete, more tangible concepts; at the same time, metaphors facilitate communication of these ideas by enabling students and young learners to make connections between what they already know and unfamiliar concepts.

Assuming that the way in which abstract concepts are represented in textbooks may influence how children understand the world they live in, in this article, we focus on two core concepts from physics and chemistry that are considered crucial to acquiring knowledge of the physical world: electricity and the atomic structure. Drawing on quantitative and qualitative methods of text and image analysis we ask: (1) how these abstractions are made tangible through metaphoric language and visuals in textbooks for children in early years of science education, and (2) what implications the use of metaphors to explain abstract concepts may have for young learners' understanding of abstract concepts from physics and chemistry.

We used Pragglejaz Group's (2007) Metaphor Identification Procedure (MIP) and its refined and extended elaboration MIPVU (Steen et al., 2010) to carry out the identification of linguistic metaphors used to explain and describe core scientific concepts in the analyzed textbooks. By applying MIP(VU) to our corpus we were able to systematically identify and classify the metaphoric potential of linguistic expressions used to explain abstract concepts from physics and chemistry. Furthermore, the identification procedure, which was carried out throughout the entire textbooks, allowed us to make sure that what we identified as metaphor is indeed classified as such. In the case of visual metaphors, we rely on content analysis for visuals to search, code and analyze the visuals in which scientific concepts from physics and chemistry are explicitly part of the image, and the visuals in which such abstract concepts are key discourse topics of the co-text surrounding the image; once identified and coded as visual metaphors, we examine the metaphorical associations in the coded visuals. Our analysis revealed a systematic use of verbal and visual metaphors across the analyzed textbooks and a sensorimotor grounding of metaphorical meaning of scientific concepts.

Communicating science to young students

Science education helps shape young children as future citizens capable of making important life decisions. Scientific literacy is crucial to informed citizenship (Davies, 2004), and school textbooks are instrumental for transmitting knowledge and values to the young generation (Kalmus, 2004). Physics and chemistry are compulsory parts of the 'Mathematics and Natural Sciences' section of the national curriculum for lower secondary education. Scientific subjects are very important for contemporary education reforms in Romania and the European Union. STEM (Science, Technology, Engineering and Mathematics) is a priority area of education throughout all member states (European Commission, 2012) and science education is important to increase young students' interest in science education and careers and to develop their scientific citizenship.

However, despite increasing public concern about the consolidation of scientific literacy, science teachers and communicators have repeatedly warned about the lack of interest of young students in science topics combined with the lack of attractiveness of science instruction (Avraamidou & Osborne, 2009; L'Astorina & Valente, 2011; Raes et al., 2013). To challenge frequent portrayals of science topics in school curricula as "abstracted, disembodied, and decontextualized" knowledge "disconnected from their [students] everyday experiences" (Avraamidou & Osborne, 2009, p. 1684), previous studies have proposed different solutions such as the use of narrative and storytelling (i.e., fictional discourse) in communicating science to make the complex, abstract and, sometimes, opaque scientific information more relevant and accessible (Avraamidou & Osborne, 2009). Other scholars (Raes et al., 2013) have advocated the web-based inquiry science project in teaching and learning science based on empirical findings showing the positive effects this technique has had on narrowing the gender gap in science learning in secondary school classes and on boosting confidence and skills for learning science among low-achievers. In this paper, we explore the potential of metaphors to contribute to both scientific knowledge acquisition and science communication, especially in educational contexts. Metaphors help simplify abstract concepts and make them more accessible to young learners (Cameron, 2003; Low 2005, 2008); simplification of abstract knowledge may facilitate communication of abstract concepts to students (e.g., via visualization, modelling, etc.).

Metaphors have been frequently used in the genetics discourse (Keller, 2002), especially for explaining and describing the nature and the function of genes and DNA. Here is an example of a metaphor used to explain the structure and the role of DNA and genes and communicate this scientific knowledge in a creative and attractive way to appeal to young learners:

> The <u>instructions</u> for <u>building</u> all living things, whether a fish, a bacterium, a tree, an insect, or a person, are found in a molecule called DNA. DNA is made up of 4 tiny <u>building blocks</u>. Each <u>building block</u> has a backbone and a chemical base that is represented by the letter A, C, G, or T. DNA molecules have 2 strands that <u>are joined together</u> through complimentary base pair. A <u>pairs</u> with T and C <u>pairs</u> with G. These <u>building blocks</u> function together in larger units called genes. Each gene is a <u>set of instructions</u> for <u>building</u> a specific protein. A complete set of genes is called a genome. A genome is a <u>set of instructions</u> for <u>building</u> an entire organism. Every person's genome has the same genes arranged in the same order. But small differences in the sequences of the bases in our genes make each person unique.

The excerpt above is a transcript of the text accompanying a video produced by the Genetics Science Learning Center at the University of Utah[1] with the purpose of helping young learners get familiarized with DNA and genes and understand what their role in the development of all living organisms is. The DNA is systematically described here via (LEGO) INSTRUCTIONS metaphor which allows for correspondences to be established between the 4 bases of DNA and LEGO <u>building blocks</u> that are <u>paired</u> two by two and they form 2 strands that are <u>joined together</u> by the pairing of the chemical base. The <u>building blocks</u> of DNA form larger units called genes that are also described as <u>a set of instructions</u> for building proteins. All the genes in an organism form the genome, which can also be thought of as <u>a set on instructions</u> for building an organism. These creative and yet familiar metaphorical correspondences between DNA and 'LEGO instructions' and between the nucleotide bases of DNA and 'LEGO building blocks' help simplify abstract scientific knowledge and make it available to young children. They may feel more motivated to learn about genetics and DNA if they visualize them in more familiar, more concrete terms, such as LEGO building instructions. The metaphor 'DNA/ genes as a set of (LEGO) instructions' is creative and entails vivid correspondences between complex, scientific concepts and a familiar experience to children, i.e., playing with LEGO building blocks. Examining a different material from the same source (i.e., GSLC Utah), Semino (2008) discusses the implications that the systematic uses of the INSTRUCTION metaphor for DNA might have for young learners' understanding and, more importantly, misunderstanding of genetics. She warns about the reliance on a single metaphor that may prevent learners to reach more advanced and more nuanced levels of science understanding and suggests that providing students with alternative metaphors for the same scientific phenomenon may help avoid the risk of oversimplification and mystification of science (Semino, 2008, p. 167).

Metaphor and analogy in science education

Metaphors and analogies are key components of human cognition. They occur in all areas of human experience and imply highly sophisticated cognitive processes in which two conceptual domains (a source and a target) are mapped together so that knowledge from the source domain is transferred to the target domain (Gentner & Gentner, 1983; Gentner et al., 2001) in such a way that inferences can be drawn, and new knowledge arises. It is their capacity to generate new meanings, to evoke new (mental) images allowing us to 'see' things from a different perspective that makes the use of metaphors and analogies indispensable to education, especially to science teaching and learning. Metaphors and analogies are efficient and attractive ways to explain abstract ideas in familiar terms, and they provide the basis for understanding core concepts from physics (e.g., light in terms of 'waves'), chemistry (e.g., links between molecules as chemical 'bonding') and biology (e.g., synaptic receptor as 'key-lock mechanism'). Metaphors and analogies are strongly connected (or arguably equivalent, cf. Glucksberg, 2008), both involving a comparison between two conceptual domains A (target) and B (source). However, in analogy, i.e., A is like B, the comparison is overt and the two ideas (domains) are kept distinct; by contrast, in metaphor, i.e., A is B, the comparison is implicit and the two conceptual domains are blended, certain attributes of B being mapped directly onto A (Steen, 2007).

We rely on metaphors to understand a complex concept (typically abstract) in terms of another (usually more concrete, more familiar) concept. Metaphors are intrinsic to thought (i.e., conceptual dimension) and this is reflected in the everyday use of metaphorical language (i.e., linguistic dimension) to convey our conceptualization and understanding of the world around us (Lakoff & Johnson, 1980). Additionally, a third dimension – communicative – of metaphors explains why we sometimes use metaphors with the intention to prompt a change of perspective in the way the audience conceives an abstract idea by urging a mapping to a totally different, 'alien' domain (Steen, 2008, 2016). All three dimensions are at play when metaphors are used in educational discourse to simplify complex ideas and communicate them to students (Low, 2005; Cameron, 2003).

The important role played by metaphors in the development of scientific knowledge has been largely recognized in previous work on metaphor in discourse and across genres (Deignan et al., 2019; Semino, 2008; Cameron, 2003; Knudsen, 2003; Boyd, 1993). Boyd (1993) even suggests that the use of metaphors in science can be either 'pedagogic' or 'theory-constitutive'. Impossible to paraphrase, theory-constitutive metaphors are unique and original and, arguably, the only way of talking about a particular scientific phenomenon, e.g., computer metaphors used by cognitive psychologists to talk about abstract cognitive processes: 'brain is a computer' and 'thought is information processing' (Boyd, 1993, p. 486). Pedagogical metaphors, on the other side, are neither original, nor argumentative, they are descriptive, can be paraphrased and are only used to explain or illustrate a scientific phenomenon, e.g., the water analogy to explain electricity as 'current' or 'flow' or as 'moving crowds of people' (Gentner & Gentner, 1983). However, subsequent studies have shown that this distinction is rather fluid than fixed and that it captures different *functions* of metaphors better than different *types* of metaphors, as Boyd initially presented it (Knudsen, 2003; Semino, 2008). For example, in the field of biochemical and molecular biology, metaphorical expressions such as ‘translation’, which had initially been used to structure and support the field, became established lexicalized terms used to talk about genetic code and protein synthesis (Knudsen, 2003, 2005). Although such expressions are not used as metaphors by experts, the general public may still explore and extend them, generating alternative metaphors to help them make sense of the abstract scientific concepts.

The extended use of scientific metaphors is a double-edged sword: it can generate either understanding or misunderstanding of scientific concepts, which, in turn, can lead to development of either accurate or inaccurate knowledge about a scientific phenomenon. Cameron (2003) analyzed transcripts of school children discussing science metaphors and found out that some metaphors used by teachers led to inaccurate understandings of scientific phenomena, such as the heart pumps air into the body, based on the metaphor of ‘heart as a bicycle pump’. Similarly, when analyzing metaphors of climate change used by young students from English schools, Deignan and her colleagues discovered that, in addition to using conventionalized metaphors (such as ‘greenhouse’ ‘release’ or ‘trapped’) to discuss climate change-related issues, students came up with their own metaphors. At the expense of scientific accuracy, students used metaphors such as ‘bounce’ (“the sun gives off rays, and then, they bounce off the earth”), and ‘band’ (“…like there’s… like a rubber band around the earth and then we’re in the middle of it […] and the band gets tighter and together”) to extend creatively their understanding of climate change (Deignan et al., 2019).

Metaphors and analogies are important tools used in science teaching and learning to facilitate learners’ understanding of complex scientific concepts (Cameron, 2003; Berger & Jäkel, 2015), to allow them to visualize abstract concepts and to motivate them (Duit, 1991), to promote critical thinking among students (Littlemore, 2004). This paper aims to examine the metaphors and analogies used in Romanian physics and chemistry textbooks for lower secondary education (grades 6-8) to explain abstract scientific ideas and to communicate them to students. After a brief description of the methodology used, we discuss in more detail two established discipline-specific (Goschler, 2019) metaphors of electricity that we identified in the physics textbooks, i.e., electricity as ‘moving crowd’ and electricity as ‘water flowing’ (Gentner & Gentner, 1983) and a creative metaphor identified in one of the chemistry textbooks, i.e., electron shells as ‘field track lanes’. Our analysis explores the implications that the use of these metaphors in science textbooks may have for the understanding of abstract concepts and for the acquisition of scientific knowledge by young students enrolled in secondary education in Romania.

Methodology and findings

Considerable criticism of the Lakoff and Johnson’s (1980) conceptual metaphor theory targeted the idea that recognition and identification of metaphor rely overwhelmingly on analysts’ intuitions (Gibbs, 2007; Steen et al., 2010). To overcome this methodological challenge, a rigorous, bottom-up procedure to identify metaphors in language has been developed by the Pragglejaz Group (2007) and subsequently refined and extended by Steen et al. (2010). The Metaphor Identification Procedure (MIP), and its updated version called MIPVU, is a tool that allows researchers to identify metaphor-related words in texts. Basically, MIP(VU) consists of the following steps (Pragglejaz, 2007, p. 3; Steen et al., 2010, pp. 5-6):

1. Read the entire text/discourse to establish a general understanding of the meaning.

2. Determine the lexical units in the text/discourse.

3. a) For each lexical unit in the text, establish its meaning in context, i.e. how it applies to an entity, relation or attribute in the situation evoked by the text (contextual meaning).
Take into account what comes before and after the lexical unit.

b) For each lexical unit, determine if it has a more basic contemporary meaning in other contexts than the one in the given context. For our purposes, basic meanings tend to be:
– more concrete; what they evoke is easier to imagine, see, hear, feel, smell, and taste;
– related to bodily action;
– more precise (as opposed to vague);
– historically older.
Basic meanings are not necessarily the most frequent meanings of the lexical unit.

c) If the lexical unit has a more basic current/contemporary meaning in other contexts than the given context, decide whether the contextual meaning contrasts with the basic meaning but can be understood in comparison with it.

4. If yes, mark the lexical unit as metaphorical.

For this study, we built up a corpus comprising 11 science textbooks for young students aged 11 to 14 years enrolled in lower secondary education in Romania. We, thus, content analyzed 6 physics textbooks for grades 6, 7 and 8, and 5 chemistry textbooks for grades 7 and 8, which resulted in a corpus of 195,201 words. The physics subcorpus (132,133 words) included 2 textbooks for grade 6 of secondary education, 1 for grade 7 and 3 textbooks for grade 8; the chemistry subcorpus (63,068 words) included 3 textbooks for grade 7 and 2 for grade 8 of secondary education; although all content analyzed textbooks follow the national compulsory physics and chemistry curricula, they had different publishers and, thus, we decided to include in the corpus all Ministry of Education-approved physics and chemistry textbooks for lower secondary education validated by the National Center for Policy and Assessment in Education and available on the dedicated website, manual.edu.ro.

To identify the linguistic metaphors used in the textbooks to describe and explain core concepts from to the two teaching subjects, we applied MIP(VU). However, due to the specificity of the corpus, we decided to make some methodological choices to simplify the analysis and to focus on metaphors used in relation to abstract concepts from physics and chemistry. We did not include in the corpus the sections of the textbooks that were not directly related to introducing, explaining, and describing core concepts and ideas from the two disciplines. Thus, we discarded from the analysis the sections of the textbooks that included descriptions of experiments, exercises, assignments, group work, class activities and revisions. For every metaphor identified using MIP(VU), we checked if it was used indirectly or directly and if its use could be explained by a cross-domain mapping to a topic in the text. Given the scope of our study, another methodological choice was to pre-define the target domains of the metaphors as core concepts from physics and chemistry, respectively, explained in the unit lessons of the textbooks.

Frequency of linguistic metaphors in textbooks

Our analysis revealed a total of 1098 direct and indirect metaphors which were significantly more present in physics textbooks compared to chemistry textbooks for secondary education (see Table 1 below).

Table 1. Linguistic metaphors identified in the analyzed textbooks

	Frequency of metaphors	Percentage	Metaphor density scores (%)*
Physics	997	90.8	7.54
Chemistry	101	9.2	1.60
Total	1098	100.0	

*Metaphor density is calculated as the number of metaphoric expressions per 1000 words.

Given the target domains in our analysis were pre-defined and coincided with the core concepts from physics and chemistry that were the topics of different lesson units in the examined textbooks, we were able to determine which targets were most frequently explained via metaphors, as shown in Table 2 below.

Table 2. Scientific concepts most frequently explained via metaphors

	Grade 6		Grade 7		Grade 8	
	Target domains	# M	Target domains	# M	Target domains	# M
Physics	physical body	37	force	33	electricity	110
	light	28	energy	26	light	76
	electricity	18	pressure	10	heat	67
Chemistry			atom	20	atom	4
			air	5	energy	3
			water	5	substance	3

Based on these findings we have chosen to thoroughly examine here the metaphors ‘electricity as water flowing’ and ‘electron shell as field track lanes’ found in physics textbooks and chemistry textbooks, respectively. Our content analysis has revealed that electricity is the abstract concept most frequently described through metaphors in the examined physics textbooks, while explanations of atoms, atomic structure and electron configuration of an atom tend to contain metaphoric correspondences with more familiar and more tangible concepts in the chemistry textbooks.

Visual metaphors in physics and chemistry textbooks

Multimodality has become one of the highly valuable features of modern education, allowing for information to be displayed in various modes, thus, facilitating encoding and accessibility of content (Weninger, 2020). Textbooks’ multimodal (textual and visual) content may positively impact on both students’ and teachers’ engagement with the topic taught. Arguably, multimodal textbooks convey the information in a more attractive way than monomodal alternatives. The textbooks we have analyzed can be considered multimodal repositories of scientific knowledge since in all the learning units the information is encoded both linguistically and visually. In an attempt to account for the visual representations of metaphors used to explain abstract concepts from physics and chemistry, we coded and analyzed visuals in which the target domains (i.e., core concepts from physics and chemistry) were explicitly part of the image or key discourse topics of the co-text surrounding the image; once identified such visuals, we examined the metaphorical associations. We found 12 visual metaphors used in physics textbooks to convey information about electricity, light, physical bodies, atoms and heat; we also found 5 visual metaphors for atomic structure (including electron configuration) and greenhouse effect in the analyzed chemistry textbooks. Our analysis also revealed a systematic sensorimotor grounding of metaphorical meaning of scientific concepts in visual metaphors. In what follows, we show how electricity and electron shells, respectively, are metaphorically described in physics and chemistry textbooks via linguistic and visual expressions, and we explore the implications that multimodality might have for young learners' understanding of these scientific concepts.

Electricity as 'a fluid'

Electricity is key to physics curricula for secondary education and concepts related to electricity are particularly complex and abstract, therefore they are often explained via metaphors. Gentner and Gentner (1983) discuss two established mental models of electricity based on water-flow and moving-crowd analogies. These models are pervasive in both scientific and commonsensical explanations of electricity and strongly influence how people reason about electricity in terms of flowing water and moving crowds. When they think of electricity as water flowing or as crowds of moving objects, people import elements of the source domains to make inferences within the target domain.

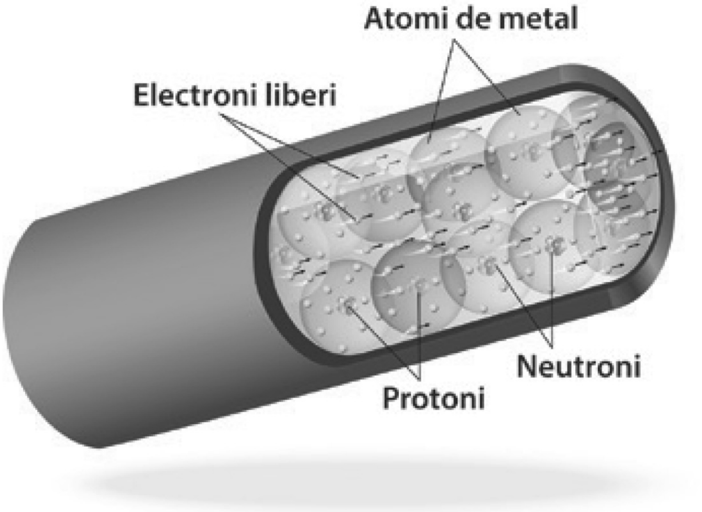
The two metaphorical models for electricity are frequently used in all 6 analyzed physics textbooks to explain this concept. We focus here on the electricity as 'water flowing' metaphor and we focus on one of the visual renderings of this metaphor in the textbooks to show how the image may lead to a misunderstanding of this phenomenon by children.

> There are materials that allow electricity "to flow" through them (because of the movement of free electrons) and they are called electrical conductors (Physics, grade 8, Litera, p. 40).
> The generator is like a pump that raises the water into a high tank from where it will flow freely – like the "flowing" of electrons in the circuit (Physics, grade 8, Litera, p. 56).

In the corpus, the metaphor 'electricity is water flow' is expressed linguistically mainly via the verb "to flow", which describes the process of the electric current traveling in a circuit. Different aspects of electricity and electric current are mapped onto corresponding elements of a hydraulics system, e.g., electric generator > pump. The water pump analogy requires specific knowledge that allows children to map elements of the source – water pump (e.g., water debit) onto the target – voltage of an electric circuit. However, children aged 11-14 may not necessarily be familiar with the functioning of water pumps to be able to map this attribute (water debit) of the source onto the target and, thus, to reason about voltage of an electric circuit in terms of water debit.

An extended water flow metaphor is also visually rendered to explain another aspect of electricity, namely the intensity of the electric current, by means of creating correspondences between water pipes and electric circuits and, possibly, between air bubbles in water pipes and atoms. While the first set of mappings is conducive to show how structural relations from the source domain are reflected in inferences in the target domain (Gentner & Gentner, 1983, p. 119), the second set of correspondences is problematic because it highlights aspects of water flowing in pipes, a feature which electricity does not share with water.

Figure 1. Visual expression of the ‘electricity as a fluid’ metaphor in a physics textbook



(Physics, grade 8, Litera, p. 57)

We have deliberately chosen this example of ‘electricity as a fluid’ metaphor used in the examined physics textbook to show how using metaphors in teaching abstract scientific concepts may lead to misunderstandings and poor conceptualizations of relevant aspects of natural phenomena such as electricity. Studies have shown that the use of conventional metaphor of electricity as water flow has a significant impact on learning about electric current and electric circuits (Gentner & Gentrner, 1983; Cosgrove, 1995; Reiner et al., 2000); however, a questionable visual rendering of the metaphor as in Figure 2 above may activate familiar knowledge about the source domain that is incompatible with the target domain.

Electron shells as ‘field track lanes’

As already shown (see Table 1 above), metaphorical expressions used to explain abstract concepts specific to the subject were scarce in the analyzed chemistry textbooks. Nonetheless, we found that the most metaphorical target domain corresponding to a core concept in chemistry was by far the atom, including atomic structure, electronic configuration and electron shells. In contrast to the example from physics textbooks which consisted of a conventional metaphor of electricity, we have chosen to discuss a novel metaphor used in a chemistry textbook to explain how electrons are distributed in atomic orbitals or shells.

To describe the electron configuration in an atom, we could draw an analogy with a track and field event (running) which takes place on a circular track. Athletes have the tendency to occupy the inside lane of the track because the distance they must run is shorter and therefore the amount of energy they consume is smaller. As the inside lane is occupied, the other athletes must occupy lanes that are more far away from the centre and, therefore, a higher amount of energy is required to run the distance. Only a certain number of athletes are allowed on each lane. Atomic structure contains electron shells similar to lanes on a field track. In an atom, there can be n shells numbered with digits 1, 2, 3, 4, 5, 6, 7, or with letters K, L, M, N, O, P, Q.

Figure 2. Visual expression of the 'electron shells as track field lanes' metaphor in a chemistry textbook

(Chemistry, grade 7, Intuitext, pag. 57)

Previous studies on the use of analogies and modelling in teaching chemistry (Harrison & Treagust, 1996, p. 532) have shown that young students prefer models of atoms that describe them as concrete structures, e.g., atomic structure as solar system and electron shells as complete or semisolid structures. Other studies have shown that many conventional metaphors in chemistry textbooks have become discipline-specific and form explicit models used to structure highly abstract and complex science domains (Goschler, 2019), such as the 'solar system' model of the atom or the electron 'shell'.

Novel metaphors used in chemistry instruction such as the one discussed here simplify abstract knowledge by describing in terms of a familiar and concrete experience, i.e., participating and/ or watching a track field event. But, more importantly, this metaphor has the potential to evoke embodied experience that underlies the metaphorical mapping of electrons orbiting the atomic nucleus onto athletes running, atomic orbit onto circular field track, and electron shells onto field track lanes. Presumably, children aged 10-13 years have experienced field track competitions either directly via participation in athletic events or indirectly by watching such events. The text containing the metaphor and its extended meanings is accompanied by an image of athletes racing on a running track. The lanes are visible, and the athletes run in lanes. Admittedly, the 'electron shells as field track lanes' seems to be an apt metaphor to describe the electron configuration in an atom, judging by the ability of this metaphor to compact complex scientific knowledge, its vividness, and the ease to be expressed linguistically and visually. However, we wonder whether such metaphor evokes vivid sport-related mappings that may be inappropriate to describe electronic configuration. Confronted with invisible abstract concepts of atom structure and electron configuration, young learners motivated by the complementary text-image relationship may push the metaphor to establish correspondences between electrons as 'competing' athletes to occupy the inside lane closest to the nucleus, which does not hold with the rules of occupying shells laid down in chemistry. Finally, this metaphor may not be appropriate to explain the electron configuration of atoms to more experienced learners, university students and chemistry enthusiasts, since the Rutherford-Bohr model in which electrons move around the nucleus in fixed circular shells has been superseded by Schrödinger's electron cloud model.

Discussion and conclusions

Our analysis aimed to examine the metaphors used in Romanian physics and chemistry textbooks to explain abstract concepts to young students enrolled in secondary education. Drawing on previous research supporting the idea that abstract thought is largely based on metaphors and analogies (Gentner & Gentner, 1983; Duit, 1991; Gentner & Jerziorski, 1993; Boyd, 1993; Harrison & Treagust, 2006; Niebert et al., 2012), we content analyzed a sizable corpus of 195, 201 words and applied MIP(VU) to identify and classify metaphoric linguistic expressions used to explain and describe abstract concepts from physics and chemistry in more familiar and more concrete terms. The content analysis revealed that the analyzed physics textbooks were more populated with metaphors compared to chemistry textbooks. This finding might be explained by a number of factors including the slightly difference in size between the physics and the chemistry subcorpora and the difference in degree of metaphor density between the two subcorpora, 7.39 for physics vs. 1.6 for chemistry. Given that we only coded the expressions used to describe abstract scientific concepts from the two subjects, the difference in metaphor density between the two subcorpora might be read at least in two ways: a) as an indication of textbooks authors' inclination to describe the abstract concepts from physics in terms of more concrete terms, and b) as a result of a higher frequency of conventionalized (including discipline-specific) metaphors used to explain abstract concepts from physics compared to the number of conventionalized metaphors for abstract concepts in chemistry. Clearly, these assumptions need to be tested by more extensive future studies, which ultimately might offer valuable insights into the crucial role that metaphors play in the understanding of science by young learners.

Following the identification and classification of metaphors in the textbooks, we were able to account for the target domains, i.e., core concepts from physics and chemistry, that were most frequently explained through metaphors. Two examples of such metaphors, one for each subject, were chosen to be discussed: 'electricity as a fluid' and 'electron shells as field track lanes'. The two metaphors were linguistically and visually rendered in the corpus, which allowed us to inquire into the role that visualization plays in the understanding of abstract scientific concept by young learners. Visualization has been shown to help learners better understand scientific concepts (Liu et al., 1999; Rapp, 2005; Harrison & Treagust, 2006), particularly when metaphors are used to describe abstract knowledge in more concrete terms that evoke more easily mental images. Concreteness is usually associated with imageability (Paivio, 1986; McDonough et al., 2011), which makes the use of metaphors in teaching and learning science more appealing. Integrating visual imagery in physics education (Botzer & Reiner, 2005) has facilitated students' understanding of physical phenomena associated with magnetism, whereas visual representations and animations have proven effective in teaching concepts related to equilibrium, reaction chemistry, electrochemistry, or miscibility in chemistry instruction (Russell & Kozma, 2005). In line with these studies, our analysis of how electricity and electron configuration are linguistically and visually described through metaphors in the physics and chemistry textbooks has highlighted the potential of visual metaphors to evoke mental images and embodied experiences in learners which may facilitate their understanding of these invisible physical and chemical phenomena.

However, not all metaphors and analogies are effective in science education, because not all of them ultimately facilitate conceptual understanding of certain abstract scientific concepts. We warn that this might be the case with the two metaphors examined in this paper. The well-established water-flow analogy may not be understood as intended if students rely on the visual rendition of the mapping between water flowing in a pipe and current flowing in a circuit, since the graphical depiction of atoms as bubbles could evoke knowledge about the circulation of water in pipes that may be incompatible with the target. Undoubtedly, this assumption needs to be accounted for empirically by tapping into students' own explanations of the scientific concepts metaphorically described. Our concern about the possibility that the analyzed metaphors may lead to misunderstandings and inappropriate conceptualizations of electricity and electron configuration in an atom resonates with similar findings from other studies. Gentner and Gentner (1983) found out that being taught about electricity in terms of water-flow may have helped students efficiently solve problems related to serial electric circuits but not when the problems required an understanding of the properties of parallel circuits. Apparently, certain properties of electricity were not recognized because they were hidden by the language used to convey the metaphor 'electricity is a fluid'

Turning to the metaphor used in the chemistry textbook, it could be part of a deliberate teaching strategy to introduce complex, invisible abstract concepts to young students in a creative way to activate their embodied experience with athletes and track field running which to then be associated with the scientific concept. 'Electron shells are field track lanes' may elicit embodied meanings incompatible with the properties of the novel concept to be grasped. Harrison and Treagust (2006) have shown that analogies, as metaphors, can be double-edged swords in teaching and learning science because sometimes they are not understood or not used as intended by students when they explain the abstract concepts they learn about. As already mentioned, a limitation of this study has to do with the need for its findings to be validated by qualitative inquiries into young students' own interpretation of the metaphors and their own explanations of the scientific concepts metaphorically presented in the textbooks. The project that this study is a part of does include qualitative methods designed to account for how young students understand and use metaphors for science concepts.

Finally, by identifying metaphors used in physics and chemistry textbooks for secondary education and, furthermore, by showcasing how metaphors are used to explain core concepts from these two subjects, we hope to have convincingly shown that metaphors are indeed important tools in teaching and learning science. However, at the same time, we hope to have raised awareness of the (genuine) possibility that metaphors used in science education may sometimes lead to unwanted misunderstandings and misconceptionalizations of complex scientific concepts. In the future, comprehensive research might explore ways in which cognitive and communicative aspects of metaphor could be efficiently used in science education to help young learners develop a scientific reasoning and to shape their understanding of the complexity of the physical world.

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Note

[1] The video can be found here: https://learn.genetics.utah.edu/content/basics/dna We recommend readers to access this link and watch the video in which the metaphor DNA as LEGO INSTRUCTIONS is more vivid as it is rendered visually, too.

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