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Towards an Effective Use of Language to Explain Light in the Museum

Abstract

Museum educators play a key role in explaining science in a museum. Verbal language is primarily used to communicate scientific concepts, but the way language shapes the explanations provided has not been investigated. This qualitative study focuses on the explanations about light provided by three museum educators to 8th grade students (13-14 years old), during unstructured visits to a science museum. The visits were audio-recorded and field notes taken. The museum educators' language was analyzed at a micro-level, through the perspective of Cognitive Linguistics and Conceptual Metaphor theory. The results of this analysis coupled with a multidimensional framework for analysing explanations allowed an understanding on what is explained and how it is explained in the museum by museum educators. Findings show that explanations were descriptive and causal, structured by the use of hybrid lexicon and by conceptual metaphors, whose quality depends on the structural similarity between domains. Furthermore, the explanations based on geometric optics were qualitative and with low level of precision, complexity and abstractness.

Keywords

Conceptual metaphor theory, frontline museum educators, explanations, science museums

Introduction

Science museums not only preserve and study objects of scientific interest, but also contribute to science education (Stocklmayer, Rennie, & Gilbert, 2010). By embracing science education, science museums support an appreciation of the meanings of currently agreed explanations and to the ways in which they were arrived at (Yeo, & Gilbert, 2014). Teachers value the contribution of museums to enhance students' learning of scientific ideas that are part of the curriculum or that complement it in ways that are not possible in schools (Kisiel, 2005). While learning scientific content is one of the main reasons for taking students on school visits to museums, teachers often do not support learning in these institutions (Faria, & Chagas, 2013). They often rely on front-line museum educators (museum educators, henceforth) for facilitating students' meaning making. This entails discussing new ideas which, in turn, requires some explaining (Baram-Tsabari, & Lewenstein, 2017). Because these professionals act between unseen or hidden science of the curatorial department and the visitors (Anderson, Cosson, & McIntoshosh, 2015), what is explained is, to some extent, restricted by the institutions' missions and rules (Clark, 1996). The content and style of those explanations vary widely, as museum educators need to embrace the diversity of visitors (Vlach, & Noll, 2016), who differ not only in terms of how they understand the message, but also in terms of what they consider worth knowing (Callanan, & Jipson, 2001). Indeed, even for children in school groups, learning in museums is inevitably driven by their choice, that may or may not be aligned with the teachers' or with the museums' learning agendas (Falk, & Dierking, 2000; Mujtaba, Lawrence, Oliver, & Reiss, 2018). This learning context puts pressure on museum educators as they need to understand the audience well to explain science in a way that is relevant, interesting, and engaging for the learner (Rennie, 2013).

Explaining science in the museum is, therefore, neither straightforward nor intuitive. Research on parent-child explanations in science museums reveals that overall parents' explanations are often brief, fragmented, do not fully explain the scientific idea, and focus on a particular event, rather than on big ideas (Crowley, & Galco, 2001). Explanations were sometimes presented through ad hoc analogies, with low level of structural similarity between analogue and target (Crowley, Callanan, Tenenbaum, & Allen, 2001; Valle, & Callanan, 2006), but the created comparisons often attended to children's interests and background knowledge (Valle, & Callanan, 2006). Despite parents' limitations in explaining new situations, conceptual gains for children, who engaged deeply with the situations presented to them, were observed (Crowley, Callanan, & Tenenbaum, et al., 2001).

Museum educators, in their role as science communicators (Stocklmayer, 2013), are asked to develop a body of knowledge and skills (see Tran, & King, 2007) that support learning at multiple dimensions (see the six learning strands approach by Bell, Lewenstein, Shouse, & Feder (2009)), being conceptual learning an important component of the museum visit. Hence, museum educators would be expected to engage in successful explanatory practices with an intended audience. However, little is known about museum educators' actual explanatory practices, in part because their professional development has attracted little attention (Patrick, 2017).

Some of the known studies show that museum educators, during guided school visits, often deliver fact-based information, using undigested scientific jargon and disregarding students' background knowledge (Cox-Peterson, Marsh, Kiesel, & Melber, 2003; Tal, & Morag, 2007). In contrast, Tran (2007) found that museum educators adjusted the depth and details of content discussed to students' interests and needs and employed a diversity of strategies to enhance learning. In line with Tran (2007), Pattison and Dierking, (2012, 2013), in a study with families in science museums during non-guided visits, revealed that museum educators discussed the science behind the exhibits by connecting it with the audience's prior knowledge and experience with the phenomena.

What these studies do not provide, however, are insights on how and to what extent the language used by museum educators (i.e. verbal and discourse strategies) shapes the explanations provided and may contribute to enhancing science learning. In all known studies in science museums, data were collected by observing and/or interviewing museum educators about their practice rather than recording their interaction with the audience and analyzing the language used to explain scientific phenomena. Recording and analyzing museum educators' speech during interaction with museum visitors is of paramount importance, because spontaneous speech is an ephemeral phenomenon. Unless it is recorded as it is being produced, museum educators will not be able, upon reflection, to reproduce it exactly in the same way.

As verbal language is the main and often only tool used by museum educators (King, & Tran, 2017), a linguistic analysis of the explanations provided, particularly from the perspective of Cognitive Linguistics and Conceptual Metaphor Theory (Lakoff, & Johnson, 1980 and followers) used in the present study, can provide an insight into how particular scientific concepts are mentally structured (and transmitted) by museum educators. This analysis, in turn, will enable the identification of the perspective of the "official science" that museum educators offer to a given audience (i.e. the explanations selected) and an assessment of the quality of the explanations, which could inform their future practice in view of enhancing learning.

Language, from the perspective of Cognitive Linguistics and Conceptual Metaphor theory, is an embodied cognitive ability, i.e. it arises from and is a reflection of the basic bodily experience of the external world (Lakoff, & Johnson, 1980). It furthermore construes our experience. Language is therefore a window to our conceptual system made up of concrete and abstract concepts, which emerge through conceptual metaphor, i.e. mappings between a concrete source domain to an abstract target domain. Research has shown (e.g. Gibbs, 1994) that metaphors have a psychological reality, and, as such, metaphors play a role in, among other processes, organizing human thought (Kovecses, 2009).

Through the analysis of museum educators' language, in particular the use of metaphors, this study aims at analyzing the explanations about light provided by museum educators during school visits. The empirical analysis of the museum educators' language will address the following questions:

1. What type of explanations on light did museum educators convey (i.e. function of explanation)?
2. Which verbal resources, including conceptual metaphors, did the museum educators deploy in order to explain light phenomena (i.e. form of the explanation)?
3. What are the museum educators' conceptualization of light conveyed through language (including conceptual metaphors) and to what extent do these conceptualizations concur with the scientific ideas of light phenomena?
4. What was the quality of the explanations provided (i.e. level of explanation)?

Looking at explanations in science education through a multidimensional framework

Scientific explanations are a major goal of science education (e.g. Bell et al., 2009; Treagust, & Harrison, 2000). Gilbert and collaborators (Gilbert, Boulter, & Rutherford, 2000; Gilbert, Taber, & Watts, 2001; Yeo, & Gilbert, 2014) developed over the years a framework to look at explanations in science education from different angles, i.e. function (i.e. the purpose of explanation); level (i.e. quality of explanation); and form (i.e. the structure of the discourse) (Yeo, & Gilbert, 2014). These components are important to consider when scientific explanations are communicated by museum educators, as will be discussed in turn.

Function

The lack of agreement on what a scientific explanation is (Harré, 1983) has resulted in the coexistence of different philosophical models of explanations, each performing different functions (e.g. the Covering law model, or the causal model) (Braaten, & Windschitl, 2011). These models need to be considered in science education (Braaten, & Windschitl, 2011) so that science can be as "authentic" as possible (Gilbert, Boulter, & Rutherford, 2000). However, a useful way of studying science is to imagine it as answering certain questions about phenomena (e.g. "What happened?"; or "How did it happen?"), perspectivized from different angles (Harré, 1983). The responses to those questions are statements of knowledge (termed explanations) with specific purposes (Gilbert, Boulter, & Rutherford, 2000). The explanations can be of different types, according to the different functions explanations may perform (see Table 1).

[INSERT TABLE 1 ABOUT HERE]

Successful explanatory practices should be grounded on conscious decisions on the types of explanations which are relevant for a given audience. For example, for primary school students, causal explanations might not be relevant, but descriptive explanations seem appropriate.

Level

The level of a scientific explanation (i.e. its quality) can be assessed by considering to what extent it fulfils the purpose for which it was generated. It can be assessed in terms of precision, abstraction, and complexity (Yeo, & Gilbert, 2014). Precision is a property of model descriptors, whose function is to represent models on which explanations are based, e.g. equations, graphs, and axiomatic statements built on general abstract terms (e.g. "energy" or "light ray") (Weisberg, 2006). Precision is concerned with the fineness of specification of the model descriptors (Weisberg, 2006), i.e. in terms of the detail in representing aspects of a phenomenon. For example, the level of precision of a front-wave diagram is higher than the level of precision of a ray diagram, as the latter does not represent entities such as the speed of light. The precision of an explanation is influenced by the context in which the explanation is required (Treagust, & Harrison, 2000; Yeo, & Gilbert, 2014). In the domain of very short wavelengths compared with the dimensions of the equipment available for their study, for example, geometrical optics is appropriate to describe the phenomena, using model descriptors such as light ray and refractive index. In this situation, there is no need to use more precise model descriptors, as Maxwell equations, because the electromagnetic field behaves locally as a plane wave.

Abstraction of a scientific explanation arises from its representation through model descriptors, which are far removed from reality (Weisberg, 2007). Model descriptors emphasize aspects of the world that are important to be considered in its representation, omit others, and add fabricated entities (Weisberg, 2007; Yeo, & Gilbert, 2014). Their meaning is set up according to the conventions defined by the scientific community, and often do not resemble the part of the world they represent (Weisberg, 2007). Nevertheless, there are relations of similarity between the scientific explanation and the world, or parts of it (Yeo, & Gilbert, 2014), allowing the latter to be conceptualized. In geometric optics, for example, ray light indicates the direction of the motion of light, but does not provide any information about its nature.

Complexity of a scientific explanation refers to its completeness and coherence. The former includes an assessment of how well an explanation describes the structure and processes of a phenomenon (Matthewson, & Weisberg, 2009), and the reasons to support the claims made. The latter refers to the consistency of the explanations provided with the accepted scientific knowledge (Yeo, & Gilbert, 2014). In the museum, museum educators need to select the appropriate model descriptors to represent an explanation for a given situation. However, they also need to be aware that the audience is often unfamiliar with those model descriptors, because they are part of the scientific language. Hence, model descriptors need to be comprehensible to the audience without compromising the complexity of the explanation.

Form

The form refers to the features of language used to provide scientific explanations. Scientific texts are considered to be a genre with which specific linguistic characteristics are associated, not only at the micro-level, e.g. lexical innovations to create specialized terminology (Halliday, & Martin, 1993), but also at the macro-level, i.e. the organization of the text itself[1].

Yeo and Gilbert (2014) propose a three-level analysis of the explanation narrative produced by a Grade 12 student: macro-level (organization of the narrative), meso-level (the speaker's vantage viewpoint in producing the explanation) and micro-level (how abstract meaning is conveyed in each turn). The analysis of the narrative at the micro-level shows the importance of pictorial resources as everyday semiotic tools of meaning-making along with the expected use of scientific representation schemes (Yeo, & Gilbert, 2014). However, the use of verbal language to construct abstractness of explanation, and in particular the use of everyday language and metaphors along with scientific terminology, was not addressed.

Language, regardless of the context of its use, construes human experience with the world. Just like the everyday use of language, the use of language in science also construes human experience. However, the conventionalized, and to some extent ritualized, way in which language is used in science has been recognized by scientists themselves as "creat[ing] a massive disjunction between everyday commonsense knowledge and the systematized knowledge of the disciplines" (Halliday, & Martin, 1993, p. 53).

In instructional settings, both in formal and particularly in informal settings, such as in a science museum, the use of language can shed light on how scientific phenomena are conceptualized by museum educators. Museum educators interact with a variety of audiences whose social and intellectual expectations are projected on to the demand of an explanation. These expectations, which must be perceived by the museum educator, will have an impact on the way scientific concepts are verbally explained. For example, when explaining light to secondary students, museum educators need to decide on whether it is enough to use the geometric optics (Raftopoulos, Kalyfommatou, & Constantinou, 2015) or to extend the explanation so as to include the link between particle and wave model of light (Rutherford, 2000). Providing scientific explanations in informal contexts does not always follow the same level of structured interaction as in formal education settings. However, the final goal in both contexts is the same: communication and acquisition of a scientific concept.

Because the three dimensions (function, level and form) are correlated, Yeo and Gilbert's (2014) framework allows us to assess how successful museum educators are in communicating scientific explanations. In this framework, particular attention needs to be given to the language used as a tool to "translate" scientific explanations in a way that the audience can understand. Many authors (e.g. Alexander, 2006; DeWitt, & Osborne, 2007; Mercer & Littleton, 2007) have pointed out that language is the most important tool for learning, as it is central to learners in knowledge (re)construction. Indeed, studies in formal and informal education have discussed the explanatory power of analogies (e.g. Dagher, 1995; Rennie, Stocklmayer, & Gilbert, 2019; Zhai, & Dillon, 2014). However, if one truly wishes to assess the success of a scientific explanation, and its communication, the analysis of the use of language cannot be limited to the production of analogies, but must necessarily encompass the vastness of language in its full range of resources. An explanation may be well structured but fails to be communicated effectively; on the other hand, it may be less well structured but the way in which it is communicated is effective. Cognitive Linguistics in general, and metaphor theory in particular, is a linguistic framework that argues convincingly for the association between language and mental structures so that, through language, it is possible to unveil how the world is conceptualized. The combination of the two theoretical frameworks is crucial and presents itself as a very robust way to assess the success of a scientific explanation, both in terms of its structure as well as in terms of how it is communicated.

Metaphor as the underlying mechanism of human conceptual structure

Historically, metaphors have been considered to be primarily "a kind of decorative addition to the ordinary plain language – a rhetorical device to be used at certain times to gain certain effects" (Saeed, 2016, p. 370). It was only in the early 20th century that metaphors were recognized to be omnipresent in everyday language. Richards (1936, p. 92) described metaphors as the "omnipresent principle of language" and, most importantly, concluded that metaphor is a structuring element of thought: "*Thought* is metaphorical (…) and the metaphors of language derive therefrom" (Richards, 1936, p. 94; emphasis in original).

In the same light, Lakoff and Johnson (1980) (see also Sweetser, 1990 and Kövecses, 2010) argued that human's conceptual system is metaphorical, i.e. metaphors are the organizing principle of concepts which structure what and "how people think, reason and imagine in everyday life" (Gibbs, 1997, p. 145). Human's conceptual system is therefore metaphorical in nature (Lakoff, & Johnson, 1980; Kövecses, 2010). One evidence for the metaphorical nature of thought is the ubiquity of metaphorical expressions in everyday language. Many of these are not used consciously by speakers; they have become conventionalized (conventional metaphors) due to its high frequency of use (e.g. “we *construct* a theory”, “*attack* an idea” (Lakoff, & Johnson, 1980, p. 54)).

The conceptual structure is organized according to cross-mappings between conceptual domains. These mappings are unidirectional and operate between a source and a target domain. Basic physical experiences, i.e. interaction between human sensorimotor system with the surrounding environment, underlie basic conceptual knowledge (substance, travel, etc.) and image schemas, which, in turn, structure abstract concepts metaphorically. An image schema, such as container, path, etc. is a “recurrent pattern, shape, and regularity in, or of (...) ongoing ordering activities [such as actions, perceptions, and conceptions]. These patterns emerge as meaningful structures for us chiefly at the level of our bodily movements through space, our manipulation of objects, and our perceptual interactions” (Lakoff, & Johnson, 1980, p. 29). For instance, ‘to be in love’ is a conventional metaphor which structures a state by means of a mapping between conceptual domains; the source or concrete domain incorporates the embodied or bodily-based knowledge of a container.

There is cross-linguistic evidence that source domains are generally based on embodied experience (e.g. human body, animals, plants, food, forces) whereas target domains are more abstract in nature (e.g. emotion, morality, thought, human relationships, time).

Metaphors, therefore, play an important role in understanding because they are capable of attributing new meanings to abstract experiences which can only be fully comprehended through familiar entities and experiences (e.g. AN ARGUMENT IS A BUILDING) (Lakoff, & Johnson, 1980), i.e. “the embodied conceptions in the source domain provide an inference pattern to reason about the target domain” (Nierbert, & Gropengiesser, 2015, p. 905).

Mappings are, however, not arbitrary. What is mapped must not conflict with the schematic structure of the target (see for example Hesse, 1970; Kövecses, 2010; Lakoff, &

Johnson, 1980). When a target is structured in terms of a particular source, certain aspects of the target are highlighted (metaphor highlighting) while simultaneously other aspects are hidden (metaphor hiding) (Kövecses, 2010; Lakoff, & Johnson, 1980).

Metaphor in science discourse and science education

Richards (1936) early on noted the presence of metaphors in scientific discourse and technical language, even though, in theory, philosophers of science objected to metaphors in scientific discourse as they are not concomitant of the intended objectivity of the scientific language. But many scientists do use metaphors in scientific writing. They perform several crucial roles, such as coining new terminology (e.g. 'wormwholes' in general relativity and 'electron clouds') as well as theory-building (e.g. Bohr's appearance of the atom based on the solar system) (Boyd, 1979).

More recently, Lakoff and Nuñez (2000) proposed that scientific discourse, in particular Mahematics, is very much metaphorical and embodied, contrary to the well-entrenched myth that Mathematics is abstract and desembodied. Metaphor, in particular, plays a defining role in mathematical ideas, i.e. "conceptual metaphor structures mathematics as human beings conceptualize it" (Lakoff, & Nuñez, 2000, p. 4). For instance, numbers are conceptualized as wholes made up of parts. The metaphor ARITHMETIC IS OBJECT CONSTRUCTION (Lakoff, & Nuñez, 2000, pp. 65-66) underlies expressions such as "Five is *made up* of two plus three", "You can *factor* 28 *into* 7 times 4", and "If you *put* 2 and 2 *together*, you get 4". The source domain is composed of the embodied concept of object and related notions (e.g. properties such as size) which are mapped on to a target domain composed of abstract concepts such as number, subtraction, etc. Conceptual metaphors have been identified in scientific discourse for other topics as well, e.g. quantum mechanics (Brookes, & Etkina, 2007), biochemistry (Semino, 2008).

Conceptual metaphors, in particular analogies, i.e. novel metaphors, deliberately constructed to convey complex concepts, are considered to be central in explaining science in both formal and informal educational settings (Gilbert, & Justi, 2016; Zhai, & Dillon, 2014). However, most of the known benefits of analogies come from research in science classroom. Analogies can provide visualization of invisible and abstract entities and processes; enhance the understanding of abstract entities; increase students' interest in the target; and make students' ideas clear to teachers (Duit, 1991; Harrison, & Treagust, 2000). Understanding analogies generated by others is not an easy task (Dagher, 1995; Harrison, & De Jong, 2005), because learners may develop or reinforce misconceptions when they attempt to make sense of them. Increasing the potentialities of an analogy and decreasing its limitations require~~s~~: 1) familiarity with the source, enhanced when it is embodied in the addressee's experience (Niebert, Marsch, & Treagust 2012); 2) discussion of the mappings between the source and the target, so that high order relations (often cause) can be established in constructing the target (Gentner, 2003); and 3) evaluation of the deductions about the target, by reflecting on its structural soundness (e.g. what is highlighting and hidden) and relevance (Markman, 1997).

More recently, studies suggested that conventional metaphors can also have value in school science. Conventional metaphors, unlike analogies, are commonly used in everyday language. Amin (2009) suggests that alongside analogies, conventional metaphors can be an additional tool to enhance conceptual change. The main argument that supports this claim emerges from the analysis of the term energy in everyday discourse and in the book "The Feynman Lectures on Physics". The analysis showed that the scientific discourse uses multiple conventional metaphors to convey different aspects of energy; that different conceptual metaphors are used in different contexts; and that some of the metaphors employed in scientific and everyday discourse overlap. Hence, moving from naïve understanding of energy to a scientific one may be facilitated when the conventional metaphors used in scientific discourse are recognized. However, while many of the image schemas that structure scientific discourse are familiar to the learner, they often exhibit difficulties in establishing the mapping underlying the conventional metaphors presented in scientific discourse (Amin, 2009). Studies that compare conceptual metaphors in students' discourse with scientific textbook (e.g. on the theme glaciers (Felzmann, 2014) or climate change (Niebert, & Gropengiesser, 2013)) show that both discourses rely on similar image schemas, but students and scientists conceptualize the target differently. Making sense of a given target is, according to Kövecses (2010) enhanced when several conceptual metaphors are employed (see also the concept of integrated multiple analogies by Brown and Clement, 1989 and Spiro, Feltovich, Coulson, and Anderson, 1989). Hence, Niebert and Gropengiesser (2015) suggest that learning can be enhanced through the use of external representations that uncover the image-schematic structure of concepts. More recently, Daane, Haglund, Robertson, Close, and Scherr (2018) found that teachers use conventional metaphors to express ideas about energy, although they are unaware of their use. The study showed that engaging teachers with conventional metaphors allowed them to perceive their value in teaching abstract concepts and in providing insights into their students' thinking.

Methodology

The focus of the study (i.e. how museum educators explain light to students during school visits); the nature of the inquiry, which generated context-dependent and empirical linguistic data (i.e. naturally occurring language); and the type of product expected (i.e. description and interpretation of a phenomenon, as a result of an interpretative approach), justify the option for a qualitative approach for this study (Creswell, 2008; Denzin, & Lincoln, 1994).

Data collection

Participants in this study were three paid museum educators (20-30 years old), who voluntarily accepted to participate in the study. Two of them hold a first degree in Chemistry, and the other in Biology. These museum educators often played a central role during the interaction with students (7th to 9th grade), controlling the interaction, the direction of talk, and offering explanations. Occasionally, and when students were receptive, museum educators also engaged in a dialogic model of communication, in which questions were generated to support students' meaning-making. For students attending the 7th to 9th grade, museum educators were expected to start the school visit by providing an overview of the museum and of its mission. After this initial stage, museum educators were expected to stay in the exhibition areas, observing and supporting students while they were interacting with the exhibits, rather than providing a guided visit.

For this study, students attending the 8th grade (13-14) were selected. They were identified from the list of scheduled school visits. This audience was chosen because optics is introduced in Portugal at this level and because these students represent one of the main audiences visiting the museum, being familiar to museum educators.

The physics teachers were interviewed at the entrance of museum, enabling an identification of the type of visit and, in case the visits were unstructured (i.e. students did not receive pre-guidance for the visit by their teachers, nor was it integrated in the classroom-based learning unit), to collect data about the students (Appendix 1). The students were from six schools and their achievement in physics was heterogeneous with non-extensive knowledge in optics. They were not familiar with the museum.

Data were collected at three interactive exhibits, which were part of a science museum exhibition about light. The selected exhibits were: 'Internal reflection', showing the efficacy of light propagation in optical fiber; ‘Light decomposed does not decompose further’, a model of Newton’s crucial experiment in order to show that once white light is decomposed it does not decompose further; and ‘Light refraction’ aimed at comparing light propagation through a lens immersed in media with different index of refraction. A description of the exhibits is provided in Table 2.

[INSERT TABLE 2 ABOUT HERE]

These exhibits were the ones selected because they were identified by museum educators as those which triggered conversations between them and the students. Two audio-recorders were situated near the exhibits in places suggested by museum educators. In addition, the third author took field notes as a non-participant observer. The field notes aimed at facilitating transcriptions. They included aspects such the participation of a teacher in the interaction between the museum educators and the students, the location of a teacher in relation to the group of students and to the museum educators, the use of electronic devices or worksheets, the use of other resources by museum educators to represent ideas (e.g. visual representations), and the number of students engaged in interaction with museum educators.

Similarly to Allen’s (2002) study, a notice board was placed at the entrance of the museum in a visible location advising that audio-recordings were taking place in the museum near some of the exhibits in order to collect data for the study, whose aims were also stated. Furthermore, teachers were approached at the entrance of the museum and the aims of the study and procedures for data collection explained. The teachers and one of the authors of this paper informed the students about the study and asked for their permission. Students were not aware of the position of the recorders, so that the social dynamics of participants could be as spontaneous as possible. At the end of the visit, the position of the recorders was disclosed to students who authorized the use of the recordings.

Conversations in front of the exhibits were continuously recorded during a school visit. A total of 158 conversations in Portuguese were transcribed and then translated into English. Of these 158 conversations, 20% (n=32) were chosen because they were the ones in which the museum educator interacted with students without the participation or observation of a teacher. In none of these interactions, museum educators used electronic devices, worksheets, or produced visual representations.

Data analysis

The analysis of 32 conversations revealed that museum educators engaged in some explanatory activity (as defined by Gilbert, Boulter, & Rutherford, 2000) in 28 conversations. These 28 conversations were analyzed by focusing on the museum educators' speech turns. Assuming that in a conversation the participants involved take alternative turns to speak, museum educators' speech turns correspond to the speech allocated to a museum educator in a conversation. A turn may range from a single world (e.g. 'certainly') to syntactic constructions with varying degrees of structural complexity. Each turn ends at a "transition-relevance place" (Clark, 1996, p. 321), i.e. when the listeners project the end of an allocated turn from a combination of facial expressions, syntax, intonation and eye gaze (Clark, 1996). The speech turns for each museum educator were read entirely in order to determine whether explanations, as defined by Gilbert, Boulter and Rutherford (2000), were produced. A museum educators' speech turn could include a single explanation, multiple explanations or no explanations at all. The different segments of the text which included explanations were analyzed in terms of content, based on the categories "types of explanation" defined in advance by Gilbert, Boulter and Rutherford (2000) (see Table 1). Two authors, initially separately and then by agreement, coded the explanations included in each museum educators’ speech turn. As a result, we identified 75 explanations included in 104 museum educators’ speech turns.

The analysis of the form of the museum educators’ speech turn at the micro-level was carried out on the original Portuguese data (not the corresponding English translation) and encompassed an identification and classification of the lexicon used in the explanations (i.e. terminological, common or hybrid) as well as all the metaphors, including analogies, which emerged in museum educators’ speech turns. We took an inductive approach following Cameron (2007) and followed similar steps to the ones in metaphor analysis employed by Niebert and Gropengiesser (2015) and Pragglejaz Group (2017). In order to identify the metaphors, we located key words related to the scientific concepts in each exhibition, e.g. light, prism, optical fiber, etc., and the immediate linguistic context in which they occurred, e.g. existence of prepositions co-occurring with the lexical item which could shed light on image schemas (e.g. container, path), existence of quantifiers or other nouns (such as mirror, water, etc.) which entered an ‘X is Y’ identification structure. Next, we assessed whether the located lexical units belonged to a more concrete (i.e. bodily, sensorimotor based) or abstract domain in the specific context they occurred. Finally, if the “contextual meaning constrast[ed] with the basic meaning [of the located lexical items] but could be understood in comparison with it” (Pragglejaz Group, 2007, p. 3), the meaning of the lexical unit was considered to be metaphorical. Once this was done, we identified metaphors which were relevant to build explanations about the phenomena and grouped those with the same target and source domain. The nature of the conceptual metaphor was interpreted with reference to image schemas, which ground metaphors in embodied cognition. The metaphors are presented in capital letters, and in the format TARGET IS SOURCE (Lakoff, & Johnson, 1980).

In addition, the analysis of the language used for explaining light allowed an identification of model descriptors employed (both explicitly or through conceptual metaphors), and, consequently, on the models in which explanations of the phenomena are based. This procedure is justified because what can be explained as well as the quality of an explanation (i.e. level of explanation) are constrained by he selected model(s). The quality of explanations was analyzed, using as a reference the model(s) in which they are based. Two authors, initially separately and then by agreement, identified the models employed and coded the quality of explanations.

Illustrative excerpts from the transcripts are included, and identified by two codes: one attributed to a museum educator (ME1, ME2, or ME3), and the other to the transcript in which the explanations were identified (Tr1….Tr28).

Results

In this section, we present the findings of our analysis. In the first subsection, the models used for explaining light are summarized. In the subsequent subsections, we present the results organized by function, form and level of explanations for each exhibit.

The models used by museum educators for explaining light

An overview of the data suggests that explanations of light were based on geometric optics or on a hybrid model. The geometric model was described by a limited number of model descriptors, namely: ray of light, beam of light. They were defined as having position, direction, and speed. The hybrid model combined the model descriptors of the geometric model and represented light as matter.

The use of the geometric model was inferred from the museum educators' discourse, as it employed model descriptors and their attributes, either provided explicitly (i.e. *beam of light*, *ray of light ray, propagation, speed*), or through the use of the conceptual metaphor LIGHT PROPAGATION IS TRAVELING. This metaphor enhances the creation of an image in the students' mind, as the source domain is grounded on image schemas. As light is conceptualized as an entity that propagates in space, the source domain includes image schemas pertaining to partial orientation (i.e. as shown on Table 3 a source (*comes*, *comes from* in (b) and (e), an intended destination (*arrives at*, *arrives* in (a), (c), (d) and (e)) and a path or track (*passes/ go through*, *changes direction, deviation from the path* in (a), (b), (d), and (e)). In addition, speed as an attribute of light ray is communicated through the vocabulary *slows down* (see (b), Table 3), which complements the source-path-goal schema, in the metaphor LIGHT PROPAGATION IS TRAVELING. The elaboration of the schema is possible as speed can be part of the embodied experience of the concept of traveling which constitute the source domain. The materialization of light in the hybrid model was expressed through the metaphor LIGHT IS A SUBSTANCE (Table 3). As a result, light is conceptualized as a substance which can be quantified, as the following examples on Table 3 show: *the quantity of light* (f), *all go, or almost entirely* (g), *more light* (h) and *less light* (i), and itemized[2].

The robustness of the geometric model, per se, is low as it is very difficult to approach optics by thinking "purely geometrically". Hence, geometric optics is often combined with the wave model (for example in the context of the dependence of refractive index on wavelength). However, to explain a given part of a phenomenon, e.g. qualitative explanation of reflection, the geometrical model may be solid enough (Fredlund, Airey, & Linder, 2012; Raftopoulos, Kalyfommatou, & Constantinou, 2005). On the other hand, the robustness of the hybrid model is compromised as it is not coherent with scientific models of light.

[INSERT TABLE 3 ABOUT HERE]

The exhibit 'Internal reflection': Function, form, and level of explanations

Data suggest that museum educators approached the exhibit 'Internal reflection' by focusing on two phenomena: 'internal reflection' in optical fiber, and 'transmission loss' in non-crystalline media (oil and air). In both cases, the explanations performed the functions of contextualizing the phenomena, describing the effects of light propagation in each medium, and explaining their causes.

In museum educators' discourse, the use of specific lexicon was necessary to give the phenomena a name, i.e. to provide contextualizing explanations, as (1) shows:

(1) "Here, what we have are optical fiber, and in optical fiber happens a phenomenon that we call total reflection or integral reflection" (…) (ME3, Tr6)

On the other hand, descriptive and causal explanations were communicated using hybrid lexicon (i.e. a mixture of specific lexicon and non-specific everyday language, such as *greater intensity of light* in (2)) and were structured through conceptual metaphors.

(2) "If we take a look, there is a greater intensity of light that arrives here [optical fiber], isn't there? (…)" (ME3, Tr5)

Causal explanations for explaining light propagation in different media were based on geometric optics and, sometimes, on the hybrid model, with the support of the conceptual metaphors LIGHT

PROPAGATION IS TRAVELING and LIGHT IS A SUBSTANCE. In addition, other conceptual metaphors were identified, namely: MEDIUM OF PROPAGATION IS A CONTAINER OF LIGHT; OPTICAL FIBER IS A CONDUIT OF LIGHT; OPTICAL FIBER IS AN ACCELERATOR OF LIGHT; OPTICAL FIBER IS A MIRROR; and TRANSMISSION LOSS IN A PIPE IS WATER-FILLED PIPE LEAKING (Table 4).

[INSERT TABLE 4 ABOUT HERE]

The analysis of the structure of the conceptual metaphor shows that each metaphor provides a different contribution to the causal explanations of light propagation in different media. Hence, in the metaphor MEDIUM OF PROPAGATION IS A CONTAINER OF LIGHT, the source domain is grounded on the embodied conceptualization of the media in which light is propagated (optical fiber, oil, and air) as a well-delimited entity and capable of holding something (*inside of the fiber optic* (m), *in optical fiber* (k), *light gets out* (l), *passing through the optical fiber* (o)). In this particular case, the medium is an instance of a container substance (Lakoff, & Johnson, 1980). The conceptualization of oil as a container is based primarily on our bodily experience. The fact that human bodies are metaphorically conceptualized as containers allows for artificial boundaries to be imposed on otherwise unbounded entities such as substances. Unlike oil, air is here not conceptualized as being a container, but rather as not having a physical existence at all (AIR IS NOTHING), as (n) shows. The source domain is based on the embodied experience of substances with physical properties which can be perceived with the senses and manipulated. Air, unlike optical fiber or oil, is invisible to the senses, hence conceptualized as not having a corporeal existence.

In the conventional metaphors OPTICAL FIBER IS A CONDUIT OF LIGHT and OPTICAL FIBER IS AN ACCELERATOR OF LIGHT, light is assumed to travel along a conduit becoming more intense, as (p) illustrates. The metaphorical mapping between intensity of a process and speed is a conventional one: INTENSITY IS SPEED (Kovecses, 2009, p. 292). Cameron (2008, p. 197) pointed out that "metaphor in talk is dynamic", i.e. metaphors occur dynamically in discourse as the speaker "adjusts and adapts to what the other say". After the student observed that light becomes more intense in optical fiber, the guide reinforces this observation by using the INTENSITY IS SPEED metaphor. At the generic level, this metaphor is usually employed in a relatively conventional way with reference to processes. However, the metaphor in its current use refers not the intensity of a process but of a substance, in line with the identified metaphor LIGHT IS A SUBSTANCE.

In the analogies OPTICAL FIBER IS A MIRROR[3] and TRANSMISSION LOSS IN A PIPE IS WATER-FILLED PIPE LEAKING, the source analogues are part of an experiential interaction with the observed world, i.e. experience with light in mirrors (see (q) and (r)) and water pipes or hoses leaking (see (s)).

Metaphors employed by museum educators often co-occur in the same speech turn, as (3) and (4), examples of causal explanations for light propagation in optical fiber, illustrate.

(3) "Here, what we have is optical fiber, and in optical fiber a phenomenon that we call total reflection or integral reflection takes place, in which we have the **fibers functioning as mirrors** and always reflecting light **to the inside**. As the light is completely reflected **to the inside** of the optical fiber, there are **no deviations** responsible for seeing it from here. Light **will all go**, or almost entirely, to **the other side**. So, the most effective way to **conduct** light is… (ME3, Tr6)

(4) “**Light is going through it**…the optical fiber is composed by mirrors, while these are not. When light is incident in mirrors it is reflected. This does not happen down here. Why? Because this has oil and **this has nothing** [air]. So, they allow light to **get out here**. This is because light is more intense there. […] **in optical fiber** light **gets faster** [than in other media]” (ME 2, Tr8)

Expressions such as *light will all go, to the other side,* and *there are no deviations* in (3) offer the conceptualization of light as a traveling entity, and prepositional phrases *to the inside of the optical fiber* offer the conceptualization of the medium as a container. The inside surface of this container is compared to mirrors that reflect light, which hold and guide light (*conduct light*) along the optical fiber until the destination through a process of multiple reflection.

In (4), the conceptualization of light as a traveling entity (*light is going through* and *get out*), of the medium as a container (*in optical fiber*), and of the optical fiber as a mirror are again expressed. The conceptualization of optical fiber as being an accelerator and conduit of light (*gets faster*) is also present in (4), as well as the conceptualization of the medium air as not having a corporeal existence.

The quality of the explanations (i.e. their level of explanation) is affected by the consistency of the selected conceptual metaphors employed with the scientific domain. For example, in (4), the use of the metaphor OPTICAL FIBER IS AN ACCELERATOR OF LIGHT results in an invalid scientific explanation. Causal explanations for transmission loss in non-crystalline media are another example in which the selected conceptual metaphors resulted in explanations incoherent with scientific knowledge (see (5) below). Transmission loss in non-crystalline media is often explained through the analogy TRANSMISSION LOSS IN A PIPE IS WATER-FILLED PIPE LEAKING (which also encompasses another analogy, namely LIGHT IS WATER). In this analogy, the loss of water in the source domain is mapped on to the transmission of light in the target domain, hence light is conceptualized as water. This is problematic, because no other elements in the source domain with reference to water can be efficiently mapped on to the target domain of light, as scattering and refraction have no structural similarity with a leaking water pipe.

(5) "(…) if we see light like this, from here [side of the pipe], light will not reach there, of course. Imagine that these are hoses with water. If water comes out here, it will not reach there." (ME3, Tr3)

There are some explanations for light propagation in optical fiber which are acceptable within geometric optics (e.g. (3)). This is because the explanations provided are structured through multiple conceptual metaphors (ranging from conduit to mirror metaphors) that maintain higher-order relations between the sources and targets. These explanations, qualitative in nature, are less abstract, precise and complex than those produced by geometric optics. In terms of precision, the low detail in representing aspect of internal reflection emerges from the use of hybrid lexicon, and from the lack of explicit reference to disciplinary parameters (e.g. direction of light inside the optical fiber). The use of hybrid lexicon is a source of imprecision reducing the consistency of the explanation, and hence its complexity. Finally, abstraction is low not only because explanations are qualitative and described with few parameters, but also because the use of the analogy provides a visualization of the structure of internal reflection.

The exhibit 'Light decomposed does not decompose further': Function, form and level of explanations

In the exhibit ‘Light decomposed does not decompose further’, the explanations were of the descriptive type and comprised two parts: one focusing on the visible spectrum of light produced, and the other focusing on the fact that each monochromatic light is not decomposed at the second prism. These explanations were communicated mainly through the use of hybrid lexicon. Specific lexicon was used less frequently in each explanation (i.e. *monochromatic light* (y), *incident beam* (y), *beam of light* (y), *white light* (w)) (see Table 5).

These explanations were structured by a combination of two or more conceptual metaphors: THE VISIBLE SPECTRUM OF LIGHT IS THE RAINBOW, VISIBLE LIGHT SPECTRUM IS COLORED BANDS, LIGHT IS COLOR, PRISM IS A SPREADER OF COLORS, PRISM IS A WHITE-COLOR-BREAKER, LIGHT IS A SUBSTANCE (Table 5).

[INSERT TABLE 5 ABOUT HERE]

Each metaphor structures different aspects of the Newton’s crucial experiment, selecting particular angles from which the phenomena underlying the exhibit can be explained, but at times missing relevant aspects. Hence, the conventional metaphors THE VISIBLE SPECTRUM OF LIGHT IS THE RAINBOW, THE VISIBLE LIGHT SPECTRUM IS COLORED BANDS, LIGHT IS COLOR result from the identification of the observations with the familiar embodied experience of the rainbow and of color, which is inherent in things (Lakoff, & Johnson, 1980). THE VISIBLE SPECTRUM OF LIGHT IS THE RAINBOW and THE VISIBLE LIGHT SPECTRUM IS COLORED BANDS are sometimes complemented by referring to the seven colors (see (u) - (y)), which seems to perpetuate Newton’s analogy THE VISIBLE LIGHT SPECTRUM IS MUSICAL CHORDS.

With regard to LIGHT IS COLOR, color is conceptualized as a property of light, white light is a blending of colors, and each color a kind of light, as (v) and (w) show. The role of the prism in light dispersion is provided through the metaphors PRISM IS A SPREADER OF COLORS and PRISM IS A WHITE-COLOR-BREAKER. The former metaphor reflects the observable angular divergence of rays that emerge from the prism. The latter expressed through the terms *decompose* and *divide* does not emerge from direct observation, as the color production is not attributed to the prism but seen as existing in light (see (y)). The embodied source domain in these metaphors is based on very basic experience of spatial orientation, such as up and down, center and periphery, etc.

In the explanations, the metaphor LIGHT IS A SUBSTANCE is also present. As a substance, light hits a prism (see (j) Table 3) and as a result is itemized into parts, in this case, into different colors (see (j) and (k) (Table 3). The source domain of this metaphor is grounded on the experience of countable and uncountable substances and on the cultural experience of light as a commodity (in industrialized societies, at least) in which light is divided into units, which are recorded in a meter[2], that we use and pay for.

The descriptive explanations that emerge through the use of these conceptual metaphors neglect important aspects of Newton's crucial experiment (e.g. monochromatic light is only deviated in the second prism), and introduce some misrepresentations (e.g. visible spectrum of light is discontinuous).

The exhibit 'Light refraction': function, form and level of explanations

In the exhibit 'Light refraction', the explanations were mainly provided for the lens immersed in water, being the vessel with glycerin often neglected (see (6)). Some everyday vocabulary (e.g. *amplified*) is used to describe the observed changes of the image of the stripes (i.e. displacement of the stripes), when the lens is immersed in one and in the other medium (see (7)). However, most of the time the nature of the changes is omitted in the descriptions (*we see the stripes this* *way* (6); *they* [the stripes] *are seen different* [in air and water]). Specific vocabulary, namely *reflection*, is sometimes employed (see (6)), and supports the audience to identify the source of light propagation in the selected system.

As the examples (6) and (7) illustrate, causal explanations for the phenomenon is built through the use of the metaphor LIGHT PROPAGATION IS TRAVELING, and by employing scientific terms (e.g. *reflected*, *refraction* in (6)) and INTENSITY IS SPEED (e.g. *slows down* in (7)). Indeed, *reflected* and *refraction* were the only specific lexical items employed when explanations were generated.

(6) "In this specific situation, we see the stripes this way because there is light that is *reflected* on the stripes. Whenever this light appears in a different medium, it is *refracted*, i.e. it **changes direction** (…). When we observe the stripes we are bringing to our eyes **light that passes through different media**. Hence, it has a different refraction and the direction in which **it arrives** at our eyes is different." (ME3, Tr28)

(7) "When you take them [the lenses] out, you see the lenses. What happens when you immerse the lenses in the liquids and look at the stripes? On this side [water vessel] they are amplified, and there [glycerin vessel] they are not amplified. So, what happened? Here (in water), **light that comes from the back** (air) **slows down** in the water and **changes its direction**." (ME3, Tr25)

The metaphor provides a qualitative explanation for light refraction, as it includes relevant parameters, namely speed of light, optical path, media and direction (Fredlund, Airey, & Linder, 2012). While this qualitative description of Snell's law provides the base for describing and comparing the path of light rays through the lens when it is immersed in media with different index refraction, this was not included in museum educators' explanations. Hence, while the conventional metaphor is relevant in structuring the causal explanation, it is per se, insufficient to accurately explain what happened in the system. For that, other model descriptors are required, such the indexes of refraction of the media and the relation between them. As a result, precision and complexity of the explanations are, therefore, low.

Discussion

In the results section, we showed that in all types of explanations produced (descriptive, causal), conceptual metaphors (both conventional and analogical) as well as hybrid lexicon were used. Some conventional metaphors (LIGHT PROPAGATION IS TRAVELING and LIGHT IS SUBSTANCE) were pervasive, recurring in museum educators' speech turns in all exhibits, whereas others were specific to certain exhibits (MEDIUM OF PROPAGATION IS A CONTAINER). Often, an explanation (descriptive or causal) was structured through the use of multiple conceptual metaphors, each highlighting different aspects of the target and hiding others. Explanations were qualitative in nature and their quality was, in part, constrained by the type of inferences allowed by the conceptual metaphor. Those consistent with the scientific target domain were less precise, less abstract and less complex than those based on geometric optics. The characteristics of the museum educators' explanations (function, form, and level) are discussed in turn.

Function of explanations

Descriptive and causal explanations were, not surprisingly, the most prevalent type of explanations. This may reflect an awareness of these professionals of the teachers' main reason for implementing school visits (i.e. expecting students to learn content (Kisiel, 2005) and a will to contribute to it). Not only the audience but also the type of exhibits might have constrained the type of explanations generated. Indeed, the exhibits under analysis focus on fundamental optics, rather than on processes or on twenty-first-century wicked problems (Dillon et al., 2016), which are more likely to generate other types of explanations. It is important to note that only descriptive explanations were generated in the exhibit ‘Light decomposed does not decompose further’. The fact that the exhibit represents Newton’s crucial experiment might have restricted the explanations to the context of its creation, i.e. to Newton’s study of properties of white light. However, because the experiment did not provide evidence of the attributes of white light (Martins, & Silva, 2001) and because several historical models coexisted in the interpretation of the observations, this exhibit was a missed opportunity to discuss the processes of science (Rutherford, 2000).

Intentional and predictive explanations were not valued by museum educators. Intentional explanations are important, as they provide reasons for engaging with the science underlying an exhibit. Hence, they contribute to provide a clear vision of the purpose of the communication, which, in turn, will have a positive impact on learning (Gilbert, 2013). They can also provide an opportunity for creating links between the exhibits, the exhibition, and the mission of the museum. Intentional explanations can also contribute to trigger an emotional response towards the exhibits, which may lead to an engagement with them. Predictive explanations, on the other hand, are likely to support inquiry-based discussions, which may lead to visitors’ emotional involvement with the exhibits, as visitors develop learning and build their own narratives (Gutwill, & Allen, 2010; Reiss, & Tunnicliffe, 2011).

The generation of predictive explanations, however, seems to be constrained by the design of the exhibits. For example, the degree of freedom for what can be observed is high for the exhibit ‘Light decomposed does not decompose further’, but low for the other two exhibits.

Form of explanations

The use of everyday language, rather than language from the specific domain of optics, is inescapable when science is communicated to an audience with a non-extensive knowledge in science (Laszlo, 2006). The same could be said for the use of conventional metaphors.
The efficacy of these metaphors in communicating science results from the fact that many image schemas (e.g. container and conduit image schemas) that structure scientific discourse are familiar to learners, because they are embodied (Amin, 2009). However, when museum educators use certain metaphors without the nature of light being explicitly mentioned, the metaphors, deeply embodied in their experiences, could be literally understood. For example, in the metaphor MEDIUM OF PROPAGATION IS A CONTAINER (of light), the implicit conceptualization of light as a substance (which is contained) is present. This is further reinforced by the use of LIGHT IS A SUBSTANCE. Embodiment is important to explain science but it is also important that the source domain grounded on embodied conceptualizations is mapped on to valid scientific conceptualizations, an operation that is not a simple matter for students (Felzmann, 2014, Niebert, & Gropengiesser, 2013).

In other conventional metaphors, e.g. in LIGHT IS COLOR, the source and target domains are not successfully mapped. Color is, in the scientific domain, defined as "a manifestation of the electrochemical sensing system, eye, nerved, brain" (Hecht, 2002, p. 78). This explanation would not be appropriate to engage many science museum visitors, but other accurate conceptualizations are available, e.g. "light that is seen with a certain colour" (Hecht, 2002, p.78). However, this level of accuracy of expression requires an awareness of the language used, which, in the case of conceptual metaphors, might be difficult or even unrealistic (Jeppsson, Haglund, Amin, & Strömdahl, 2013). Developing science teachers' ability to recognize conventional metaphors cannot be achieved with short interventions, according to Daane et al.

(2018). Teachers also pointed out that “to attend to metaphorical language is almost to learn a new language, […] a new kind of listening” (p. 17).

Grounding scientific explanations on embodied experiences has a very important function, namely to engage museum visitors with the phenomena being shown by connecting them with the visitors’experiences (Niebert, Marsch, &Treagust, 2012). The scientific validity of such explanations is not always preserved when explanations are solely based on embodied experiences; they must necessarily make use of other resources. Hence, inappropriate analogies such as TRANSMISSION LOSS IN A PIPE IS WATER-FILLED PIPE LEAKING may constitute a source of students’ misconceptions about transmission loss in light guide. It is also the case, nevertheless, that good analogies (i.e. analogies with higher-order relations within and between souce and target) may not necessarily lead to learning (Dagher, 1995; Niebert, Marsch, &Treagust, 2012). For example, the success in understanding the analogy OPTICAL FIBER IS A MIRROR is constrained by students’ familiarity with the source analogue, namely the behavior of light in mirrors, and by the operationalization of the analogy. For those not familiar with the source analogue, the explanation may not be completely understood because museum educators rarely ensured that the source analogue is embodied in the addressee’s experiences; while reflection is familiar to students’ embodied experiences (e.g. Tiberghien, Delacote, Ghiglione, & Metalon, 1980), multiple reflections may not be as familiar. Indeed, students have difficulties in conceptualizing light in geometric optics, i.e. as an entity consisting of rays that propagate in straight lines (Raftopoulos, Kalyfommatou, & Constantinou, 2005). Furthermore, the absence of an explicit mapping between the source and target analogue does not allow an assessment on how well it describes the behavior of light, e.g. it is unknown whether the mirror is mapped to the cladding of the optical fiber.

Multiple conceptual metaphors are often employed to structure an explanation, by highlighting different aspects of the scientific target, in a coherent way (i.e. in the sense that correspondences in different metaphors overlap, providing a sense that they "fit together" (Lakoff, & Johnson, 1980, p. 94). For example, the container and conduit metaphor hold similar correspondences, being the latter metaphor more specific than the former. Amin (2009) also identified multiple coherent metaphors for structuring the concept of energy. As Jeppsson et al. (2013) suggested, these multiple metaphors, that "fit together", provide an experiential narrative, which constitutes an important aspect for science communication. Indeed, some authors (see Ogborn, Kress, Martins, & McGillicuddy, 1996; Turney, 2004) argue that explanations similar to stories (e.g. in which there are protagonists (entities) responsible for events) support students understanding (Ogborn, Kress, Martins, & McGillicuddy, 1996) and the communication of science to lay audience (Turney, 2004).

Level of explanation

The quality of explanation (in terms of precision, abstractness and complexity) can be seen using the museum educators' selected model as a reference. The use of a hybrid model, in which light is conceptualized, generated explanations incoherent with the scientific target domain. As a result, misconceptions may be induced or reinforced. Misrepresentations of scientific ideas are problematic, not only because they mask the understanding of optical phenomena but also because they negatively interfere with the flow of students' developing understanding (Gilbert, Boulter, & Rutherford, 2000). Consequently, students will need an additional effort to recommence learning, leading to a decrease in motivation (Gilbert, Boulter, & Rutherford, 2000).

Other explanations were based on geometric optics. This is an adequate model for framing the explanations, due to the type of phenomenon underlying the exhibits (Hecht, 2002) and the audience's knowledge in optics. In addition, it does not require learners to hold complex models of light, giving to a lay audience the opportunity to engage with basic features and regularities of optical phenomena (Raftopoulos, Kalyfommatou, & Constantinou, 2005).

The quality of museum educators' explanations is low, using as a reference geometric optics. These explanations use a restricted number of model descriptors in their explanation, which are often translated to the audience through the use of metaphors and imprecise everyday vocabulary. The structure of explanations (i.e. through multiple conceptual metaphors) leads to explanations that are qualitative in nature. Consequently, their level of abstraction is reduced when compared to those generated in science. In the latter context, formal codes of representation are employed.

Finally, regarding complexity, while these explanations are coherent, many of them are incomplete, e.g. those provided in the exhibit 'Light refraction', which sometimes were dissociated from the observations. More complex explanations may be difficult to communicate, particularly when language is the main means of communication. The communication of these explanations about light requires a flexible use of multimodal representations (Kuo, Won, Zadnik, Siddiqui, & Treagust, 2017).

Implications for science communication and learning

From the findings of this small scale study emerge some implications for science communication and for science education of school-age children. Museum educators often communicate scientific content (i.e. describing and explaining phenomena) to students. Although this communication is important, museums have more to offer than just extending or complementing school content; they can support the intrinsic desire to learn in a free choice environment (Bell et al, 2009; Falk, & Dierking, 2000). Hence, what is communicated needs to widen to include other statements of knowledge, including intentional and predictive explanations.

The detailed analysis of the language employed by museum educators using a Cognitive Linguistic theoretical framework suggests that the conventional metaphors need to be brought to light, so that museum educators become aware of how they are used in their explanatory practice; reflect on their potentialities and limitations in explaining science to school students; and transform the language used to explain science. In addition, although good analogies are used to explain scientific ideas, museum educators need to use as a reference the good practices of teaching with analogies in school science contexts (e.g. Harrison, & Treagust, 1993) so that they can lead to the learning intent. Finally, museum educators need to ensure that the quality of the explanations is appropriate to the audience. This can be successfully achieved if museum educators are aware of the models they employ to base their explanations, identify the necessary model descriptors needed for a given explanation, analyze to what extent students (and other visitors) are familiar with them, and, if necessary and possible, translate them into an understandable language.

Another crucial element in enhancing learning science is the use of visual representations. Visual representations have the ability to put in evidence the image schemas that structure the explanations (Niebert, & Gropengiesser, 2015). However, visual representations are not widely used by museum educators who rely primarily on verbal language to produce explanations, restricting, to some extent, what can be learned. One way forward is to pay attention to the use of gestures or body actions in conversation to produce meaning (vom Lehn, 2006). These non-verbal elements can enhance science communication by calling attention to an exhibition element; draw a physical analogy; or indicate patterns (Gilbert, 2013). In the specific case of student visitors, the learning that took place in the museum could be followed up after the visit by the teacher, who would need to pay attention to the conceptual metaphors employed by students to reflect on what they learned in the museum and introduce the formal language of science.

Conclusion

This study focused on the importance of analyzing language of science communicators in informal contexts, in particular in a science museum. The analysis of the museum educators' language at the lexical level using Cognitive Linguistics and Conceptual Metaphor Theory as the theoretical framework proved to be a very important avenue for further investigation, as it showed how language structured the explanations in a very significant way. Taking into consideration Yeo and Gilbert's (2014) multidimensional framework, the study has shown how language conditioned the precision, complexity and abstraction of explanations.

The explanations about light phenomena by museum educators to 8th grade students were mainly descriptive and causal, due to the characteristics of the audience and to the exhibit which focused on fundamental optics. These explanations were verbalized using particular linguistic resources, such as hybrid lexicon and metaphors – both conventional and novel metaphors (or analogies). While some of the metaphors used were in line with the scientific knowledge (e.g. LIGHT PROPAGATION IS TRAVELING), others were at odds with scientific knowledge (e.g. LIGHT S A SUBSTANCE). Furthermore, it was observed that the target concept was explained using several different metaphors which highlighted particular aspects of the phenomena. The level and precision of the explanations varied according to the metaphors which underlay the model used as reference to explain the phenomenon. The use of a hybrid model generated explanations which displayed lower levels of precision, complexity and abstraction, reinforcing, on the other hand, misconceptions about light phenomena.

The results of this study show that enhancing learning of science in museums is largely dependent on the type of language used in the explanations, given that verbal language is museum educators' primary, if not exclusive, tool to explain science. As such, museum educators, and science communicators more generally, must become aware not only of the language used but also of the models that structure the explanations.

The research on the way that scientific phenomena in informal contexts is verbalized needs to continue, expanding the research to a larger sample, which could comprise an audience other than school students. This would allow to assess how the characteristics of the audience may play a role in the choice of the type of explanations and on the choice of language. Furthermore, although the present study only focused on the lexical strategies and metaphors used by the museum educators, researching language in interaction should also encompass the analysis of the language (as well as gestures) used by the other participants. This would allow a better understanding of how metaphors flow in discourse.

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Endnotes

[1] These studies focus on English. The question arises as to whether these characteristics are observed in scientific texts and explanations written in other languages. See, for example, Halliday (1993) for a discussion on the similarities and differences between scientific writing in English and Chinese.

[2] In Portuguese the word is *contador*, literally a counter (a machine that counts).

[3] In some other explanations, the optical fiber is alternatively conceptualized as being composed by mirrors, as (i) illustrates. This misrepresentation of the optical fiber reduces the quality of the explanation.

> (i) "The optical fiber is composed by mirrors, while these are not. When light is incident in mirrors it is reflected" (ME2, Tr8)

Table 1 - Types of explanations and their characterization (Gilbert, Boulter, & Rutherford, 2000)

Type	Characterization
Contextualizing	Answers the question: “What exactly is being investigated?”, by giving a name, an identity to the phenomenon, allowing it to be treated linguistically as a noun.
Intentional	Answers the question: “Why should a particular phenomenon be investigated?”. It gives some ideas of the importance of the phenomenon addressed. It includes, e.g. statements about the historical and/or contemporary value of the phenomenon; or its relevance to everyday life.
Descriptive	Answers the question: “What are the properties of a phenomenon?” by providing a description of its properties. It focuses on the concrete/observable entities of the phenomenon rather than on its abstract entities.
Interpretative	Answers the question: “What models can be used to think about the phenomenon?”, by invoking models and their descriptors that can be used to think about the properties of the phenomenon.
Causal	Answers the question: “Why does the phenomenon behave as it does?”, by stating how a model accounts for the phenomenon through “causal-and-effect” mechanism.
Predictive	It is a subset of descriptive explanation, which aims at convincing others of the degree of validity of the models used for explaining a phenomenon or ability to produce predictions. It answers the question “How will the phenomenon behave (or might behave) under other, specified, circumstances?”.

Table 2 – Description of the selected exhibits

Description
Internal reflection – The exhibit aims at showing how light is transmitted in three different media (air, oil, and optical fiber). The exhibit is composed by three light sources, each one connected to a different pipe. The pipes terminate in a front panel. The pipes, composed by the same material, are vertically aligned. Inside each pipe is a different medium. In the lower pipe the medium is air; in the middle pipe the medium is oil; and in the top pipe the medium is optical fiber. The pipes are transparent, allowing the media to be seen. When each light source is switched on, it is possible to observe the intensity of light that emerges from that pipe in the front panel. The intensity of light that emerges from the pipes can be compared by switching on more than one light source at a given time.
Light decomposed does not decompose further – This exhibit is allusive to Newton’s optical crucial experiment. The exhibit is composed by a source of white light, which illuminates a prism. The light that emerges from the prism is projected onto a screen, where a spectrum of visible light can be perceived. The screen has a slit, which can be moved vertically by means of a lever, so that a small part of the spectrum (perceived as a band of a single color) proceeds to a second prism. The emergent beam of the secondary prism is projected onto a target and the emergent beam is perceived as having the same color as the incident beam.
Light refraction – Inside a transparent box, there is a system composed by a front panel with vertical black and white stripes; two converging biconcave lenses with the same characteristics; and two vessels, each containing a different liquid (water and glycerin). The lenses are placed in front of the striped panel and are connected by a wire to a horizontal metallic bar, in such a way that they are horizontally aligned. At the bottom of the panel there are two transparent vessels (one with water, the other with glycerin). By activating a lever, the horizontal bar moves

vertically, so that each lens can be immersed in each of the liquids contained by vessels. Hence, the striped panel can be seen through the lenses when they are in air, and when they are inside each liquid. The index of refraction of the glycerin is similar to the index of refraction of the medium of the lenses. Consequently, when a lens is immersed in the glycerin, an observer can only see a very minor displacement of the stripes of the front panel, when s/he is at right angles to the lens, and looking through it. In the same position, but looking through a lens immersed in water, the stripes are perceived as being evidently displaced to the side.

Table 3 - Metaphors underlying the models employed for explaining light

Metaphors	Exhibit	Examples
LIGHT PROPAGATION IS TRAVELING	Internal reflection	(a) (…) to make it [light] **arrive** in a **proper time**, we have to ensure that in that time interval, the quantity of light must be much greater. (ME3, Tr5) (b) When we have light propagating in the air or oil, what happens is that there is **deviation in the path of light** (…) **Light will** all **go**, or almost entirely, **to the other side.** So, the most effective way to conduct light is… (ME3, Tr6)
	Light decomposed does not decompose further	(c) In brief, white **light comes**, all colors **arrive** there [prism] and spread out. Then, when they **go through** the second prism, for example red, of course they will not decompose (…) (ME2, Tr23)
	Light refraction	(d) In this specific situation, we see the stripes this way because there is light that is reflected on the stripes. Whenever this light appears in a different medium, it is refracted, i.e**. it changes direction** (…). When we observe the stripes we are bringing to our eyes **light that passes through different media**, hence it has a different refraction and **the direction in which it arrives** at our eyes is different. (ME3, Tr28) (e) Here (in water), **light that comes from the back** (from air) **slows down** in the water and **changes its direction**. (ME3, Tr26)

Table 3 - Metaphors underlying the models employed for explaining light (continuation)

Metaphors	Exhibit	Examples

LIGHT IS A SUBSTANCE	Internal reflection	(f) (…) to make it [light] arrive in a proper time, we have to ensure that in that time interval, the **quantity** of light must be much **greater**. (ME3, Tr5) (g) The light that we see leaving here, **these pieces of light**, if we call them like that, are pieces that will not reach that side anymore (…) **Light will all** go, or **almost entirely**, to the other side. So, the most effective way to conduct light is… (ME3, Tr6) (h) In other materials, light gets out from the pipe. In the optical fiber, **more light** arrives here, doesn't it? (ME1, Tr9) (i) By observation, light that arrives here is more intense, isn't it? What does it mean? On its way, **less light** is lost" (ME3, Tr5)
	Light decomposed does not decompose further	(j) White light **hits that prim** and decomposes in the colors of the rainbow! (ME1, Tr24) (k) If you look here on this side, (…) all the little colors are there. He [Newton] wanted to make each little piece of light, of color, pass through the hole in order to see whether it would decompose again, but, no, that didn't happen (ME1, Tr22)

Note: The expressions in bold show which parts of the museum educators' speech turn have led to the identification of the conceptual metaphor.

Table 4 - Metaphors used by museum educators in the exhibit 'Internal reflection' only

Metaphor	Examples
MEDIUM OF PROPAGATION IS A CONTAINER OF LIGHT	(l) **In other materials,** light gets out from the pipe. **In optical fiber**, more light arrives here (ME1, Tr9) (m) As the light is completely reflected to the **inside of the fiber optic**, there are no deviations responsible for seeing it from here. (ME3, Tr6)
AIR IS NOTHIING	(n) this does not happen down here. Why? Because this has oil and **this has nothing** [air]. (ME2, Tr8)
OPTICAL FIBER IS A CONDUIT OF LIGHT	(o) When **passing through** the optical fiber, [light] suffers internal reflection (ME3, Tr1)
OPTICAL FIBER IS AN ACCELERATOR OF LIGHT INTENSITY IS SPEED	(p) Student – So, light becomes more intense in optical fiber Museum Educator – Exactly, in optical fiber light **gets faster** [than in other media] (ME2, Tr8)

Note: The expressions in bold show which parts of the museum educators' speech turn have led to the identification of the conceptual metaphor

Table 4 - Metaphors used by museum educators in the exhibit ‘Internal reflection’ only (continuation)

Metaphor	Examples
OPTICAL FIBER IS A MIRROR	(q) **Inside**, the optical fiber **is composed by mirrors**. This is optical fiber. (ME2, Tr10) (r) **The optical fiber is composed by mirrors**, while these are not. When light is incident in mirrors it is reflected. (ME2, Tr8)
TRANSMISSION LOSS IN A PIPE IS WATER-FILLED PIPE LEAKING LIGHT IS WATER	(s) (…) if we see light like this, from here [side of the pipe], **light will not reach there**, of course. **Imagine that these are hoses with water. If water comes out here, it will not reach there**. (ME3, Tr3)

Note: The expressions in bold show which parts of the museum educators’ speech turn have led to the identification of the conceptual metaphor

Table 5 – Metaphors used by museum educators in the exhibit ‘Light decomposed does not decompose further’ only

Metaphor	Examples
THE VISIBLE SPECTRUM OF LIGHT IS THE RAINBOW	(t) Look! **Look at the rainbow** there (ME3, Tr21)
THE VISIBLE LIGHT SPECTRUM IS COLORED BANDS	(u) There is a **decomposition of light in the seven colors of the rainbow** (ME3, Tr20)
LIGHT IS COLOR	(v) Although light goes through that prism, nothing else is decomposed because **it is only light of one color**” (ME2, Tr23) (w) In brief, **white light** comes, **all colors arrive** there [prism] and spread out. (ME2, Tr23)
A PRISM IS A SPREADER OF COLORS	(x) In brief, white light comes, **all colors arrive there [prism] and spread out**. (ME2, Tr23)
A PRISM IS A WHITE-COLOUR BREAKER	(y) Here we have an incident beam of light in a prism, **there is decomposition of light** in the seven colors of the rainbow. Then, it (light) comes here, **we try to divide the beam of light again in this prism** but it does not **decompose** further…so we have monochromatic light. (ME3, Tr20)

Note: The expressions in bold show which parts of the educators’ speech turn have led to the identification of the conceptual metaphor

Appendix 1

Questions used during the interviews to teachers

- What is the grade level of the students?
- What is the nationality of the students?
- Overall, what is the students' level of achievement in physics?
- How familiar are the students with the museum?
- What were the aims for the school visit?
- Is the visit integrated in the content you are teaching at the moment? If so, how?
- How familiar are students with optics?
- How was the visit prepared in the classroom?
- Do students bring any activity to engage in the museum? If so, which one?
- Did you plan any activity to be developed by students after the visit?
- Is there anything else that I did not ask and that you would like to say?