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Children's Use of Metaphors in Relation to their Mental Models: The Case of the Ozone Layer and its Depletion

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Abstract

This paper examines the relationship between children's use of metaphors and their mental models concerning the ozone layer and the ozone layer depletion. Our study was based on semi-structured, individual interviews with primary school Greek pupils. The analysis of data pointed to the construction of a limited number of models concerning the role of the ozone layer and the process of its depletion. A parallel analysis of the transcripts focused on the metaphorical statements pupils used while discussing the same issues. These statements were classified in categories such as persons, substances, and objects (containers, dividing surfaces, absorbing or reflecting surfaces, or holes). The results of the two dimensions of the analysis were correlated. It is found that there exist correlations between the ontological basis of metaphors and the particular models children use in order to understand and explain the role and depletion of the ozone layer. Thus, metaphors can be used as educational tools, so as to enhance understanding in the case of the ozone layer and its depletion.

The general public is becoming more and more aware of, and concerned about, environmental issues with global dimensions such as the problem of ozone depletion. Thus, there exists a growing need for teaching strategies and resources if future citizens are to develop an adequate understanding of this environmental problem.

Moreover, since the role of stratospheric ozone and its depletion involves complex processes which are not included in the children's perceptual experience, we require tools which can help in the transformation of unfamiliar entities into familiar ones (Black, 1979; Lakoff & Johnson, 1980; Mac Cormac, 1985; Cornell Way, 1991). Metaphors could play this role by attributing similar functions and relationships to completely different things (Ogborn, Mariani, & Martins, 1994a; Duit & Glynn, 1995), and suggesting a partial relationship between parts of the structures of two different conceptual domains. The unfamiliar conceptual domain is referred to as the target domain, while the familiar conceptual domain is called the source domain (Lakoff, 1987).

Metaphorical thinking is activated when the attempts to represent mentally a target domain fail to explain a new situation (Mac Cormac, 1985). To accomplish the explanation a source domain is selected, which is structurally similar to the target domain and is accompanied by an explanation of how it functions and on what grounds it is similar to the target domain (Halford, 1993; Vosniadou, 1989). Subsequently, a model is constructed for the target domain by mapping the structure of the source domain on it (Black, 1979; MacCormac 1985; Vosniadou, 1989). The model is evaluated and if it provides a satisfying explanation, it is adopted, the target domain is understood and ceases to be problematic. This last stage involves the transfer of knowledge to the target domain through the establishment of new rules and the final connection of the target domain to the existing conceptual structures (Halford, 1993; Vosniadou & Ortony, 1989). Thus, metaphorical thinking:

1. can function as a mechanism for the enrichment, the modification, or even the radical restructuring of the knowledge base, by facilitating the construction of new models (Vosniadou, 1989; Vosniadou & Ortony, 1989).
2. plays an important role in understanding, and it can be utilised in science education in order to help pupils construct adequate models of different phenomena and then to evaluate them (Nersessian, 1984, 1994).

However, research in science education should first determine if pupils can handle thinking tools, such as metaphor, easily and spontaneously and then search for correlations between the metaphors they use in order to explain a phenomenon and the model(s) they construct for this phenomenon.

Children's models of the ozone layer and ozone depletion have already been documented (Christidou, 1997; Christidou & Koulaidis, 1996) along with a first attempt to draw educational implications relative to these models and to determine what still needs to be learnt if pupils are to develop more complete models.

The present paper concerns the study of correlations between the metaphors primary pupils use and the mental models they construct in order to understand and explain the role of the ozone layer, and the process of its depletion. If metaphorical thinking proves to be consistently used in the representation of complex scientific phenomena, important educational implications can emerge, which may open new perspectives for the application of the explanatory power of metaphors in science education.

Method

Data were collected through individual semi-structured interviews with 40 primary school pupils in three state schools in the area of Thessaloniki (Greece). Pupils were in Year 5 and Year 6 (aged 11 and 12 years old respectively) and the sample involved 22 boys and 18 girls. No particular criterion was used for the selection of the sample in terms of pupils' performance. Interviews were recorded and transcribed. The parts of each transcript in which the role and distribution of ozone and the ozone depletion process were discussed were isolated. These statements reflected children's views on

1. where ozone is and how it is distributed in the atmosphere,
2. how ozone prevents ultraviolet radiation from reaching the earth,
3. how ozone is depleted, and
4. the meaning of the term "ozone hole."

Based on these views we inferred two detailed personal models for each pupil: the first model referred to the role and distribution of ozone in the atmosphere, while the second model concerned the process of ozone depletion.

Our next step was the formulation of generalised models. We found five generalised models of the role and distribution of ozone (shown in Table 1) and three generalised models of the ozone depletion process (shown in Table 2). The formulation of these generalised models was based on the identification of the common characteristics of the detailed personal models of the students. These common characteristics involve:

1. For the generalised models of the role and distribution of ozone
   - the thickness of the ozone layer (thick versus thin)
   - the position of the ozone layer with respect to the earth and sun (surrounding the earth versus surrounding the sun)

- the process of prevention of the ultraviolet radiation (blocking versus reflecting)

2. For the generalised models of the ozone depletion process
   - the thickness of the ozone layer (thick versus thin)
   - the locality of ozone depletion (local versus general)
   - the degree of ozone depletion (total destruction versus thinning down)

The data analysis proceeded with the examination of the interview transcripts in order to identify all the metaphors introduced by pupils which referred to ozone and its depletion. For each of all the generalised models found, a set of all the relevant original statements made by the pupils was formed. Thus, we ended up with eight sets of original statements (five sets corresponding to the generalised models of the role and distribution of ozone and three sets corresponding to the generalised models of ozone depletion) in which metaphors were included. These metaphors were studied in order to identify the types of concepts used as the source domain in order to approach unfamiliar target domains such as the ozone layer, the ozone hole, or the action of harmful gases.

The last step of the analysis was the study of correlations between the generalised models and the categories of metaphors used by the pupils. The existence of correlations was checked by a χ^2 test, while the interpretation of the correlation was based on the size of the standardised residuals. As Blalock (1979) argues, the sum of the squares of the standardised residuals provides a good approximation of the chi square statistic for a contingency table. That is, cells with large standardised residuals contributed most to the size of the chi square statistic, thus being responsible (that is to say the sources) for the existence of the correlation between the variables represented by the dimensions of the table. Therefore, if one establishes the existence of the correlations on the basis of the chi square statistic, a very meaningful way to interpret these correlations is to look at the size of standardised residuals for each cell.

Results

The presentation of the results is structured in three different parts. The first part concerns the presentation of the metaphor categories used by pupils during the interviews. The second part studies the correlation between children's models of the role and distribution of ozone and the metaphors children introduced concerning this topic. The third part introduces the results of the analysis with respect to the correlation between pupils' models of ozone depletion and the relevant metaphors they used during the discussion.

Categories of Metaphors

The concepts introduced as source domains in metaphors involved three general categories which are illustrated in Figure 1 (for an extended presentation of the scheme of metaphor analysis the reader should refer to Koulaidis & Christidou, 1993).

These concepts include:

1. Objects. For example:

   Ozone is in the atmosphere. It is a cover over the earth, which holds the sun's harmful rays. (Pupil 18)

The general category of objects is further divided for the purposes of the analysis to five subcategories, including containers, dividing surfaces (screens, covers, layers, and so on), absorbing or reflecting surfaces, air or atmosphere, and holes (see Figure 1).

2. Substances. For example:

> Ozone is like an umbrella made of gases that we can't sense of, and CFCs are gases... [they are] like an acid which makes holes on the umbrella. (Pupil 8)

3. Persons. For example:

> . . . [CFCs] fight ozone, like chasing it and killing it. They make a big hole in it, like the one over Australia, and ultraviolet rays come in. (Pupil 14)

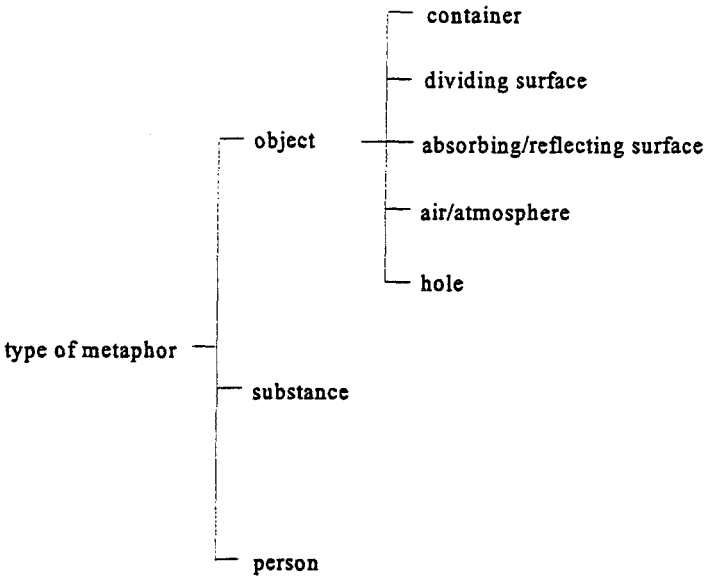


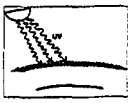
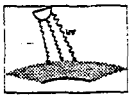
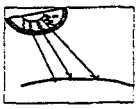
Figure 1. The categories of metaphors used by pupils to explain the role and depletion of ozone in the ozone layer.

Having categorised all the metaphors in each model, the two dimensions of the analysis described above, namely children's models and the categories of metaphors used, were correlated.

Metaphors and Models of the Role and Distribution of Ozone

Table 1 shows the frequencies of use of the types of metaphors for each of the models of the role and distribution of ozone. It should be noted that when pupils refer to the role and distribution of ozone, they rely on the metaphorical categories of person (28 instances), container (17 instances), dividing surface (91 instances), absorbing or reflecting surface (21 instances), and air/atmosphere (16 instances). In Table 1 the following values are shown, (a) the observed values, (b) the standardised residuals (in brackets), and (c) a sign showing whether the observed value is greater or less than the expected value.

Table 1
Frequencies (and the Corresponding Standardised Residuals) of the Types of Metaphors Used for the Models of the Role and Distribution of Ozone

Models	Frequencies (and standardised residuals) of metaphorical categories					
	person	container	dividing surface	absorbing/ reflecting surface	air/atmosphere	Total
Category 1						
	22	8	74	13	4	
Model R1: Thin O_3 layer around the earth blocking UV	[0.29] +	[1.27] -	[1.68] +	[0.19] -	[4.62] -	121
Category 2						
						
Model R2: Thin O_3 layer around the earth reflecting UV						
						
Model R3: Uniformly distributed O_3 around the earth blocking UV	6	9	17	8	12	
	[0.69] -	[2.96] +	[3.92] -	[0.45] +	[10.75] +	52
						
Model R5: Thin O_3 layer around the sun, blocking UV						
						
Model R4: Uniformly distributed O_3 around the earth reflecting UV						
Total	28	17	91	21	16	173

The models are divided into two general categories. The first category consists of model R1 (where R stands as an indicator for all the models concerning the role and distribution of ozone), according to which ozone forms a relatively thin layer at a large altitude in the atmosphere. This layer blocks ultraviolet radiation, preventing it from reaching the ground. The second category comprises model R2 describing ozone as a thin layer around the earth reflecting UV rays, models R3 and R4 which consider ozone as uniformly distributed in the atmosphere stopping or reflecting UV radiation respectively, and model R5, according to which ozone forms a thin layer around the sun, stopping its harmful ultraviolet rays and preventing them from reaching the earth. (For a detailed presentation of the models, the reader should refer to Christidou & Koulaidis, 1996). The basis for this categorisation was the fact that model R1 is a better approximation of the scientifically accepted view of the role and distribution of ozone, while the four models constituting the second category involve important alternative conceptions.

Statistical analysis shows that there exists a correlation ($\chi^2(4) = 26.83$, $p < .05$) between the categories of the metaphors and the models pupils construct for the role and distribution of ozone in the atmosphere.

The interpretation of this correlation will be based on the size of the standardised residuals. Specifically:

1. Children who represent ozone as forming a thin layer surrounding the earth at a high altitude and stopping harmful solar radiation (model R1) prefer the metaphor of a dividing surface (layer, shield, umbrella, or cover) in order to describe or explain its position and role metaphorically. This is based on the size of the corresponding standardised residual which is 1.68. An example of such a use of metaphorical thinking is illustrated in the following extract:

   > [Ozone] is like a big sheet, but extremely thin, which is something like an umbrella over the earth. Very thin. (Pupil 7)

2. Children who have model R1 tend not to consider the metaphors of air/atmosphere to be valuable in order to explain or describe ozone metaphorically (standardised residual = 4.62).

3. Children who have model R1 tend not to use the category of container to describe the role and position of ozone, as indicated by the size of the corresponding standardised residual which is 1.27.

4. Children who have the less adequate models R2, R3, R4, or R5 use significantly more frequently than expected by chance above, the air/atmosphere category in order to conceptualise the role and distribution of ozone, as indicated by the corresponding standardised residual equal to 10.75 and illustrated by the following example:

   > Ozone is like air... it's the atmosphere around us. [...] Ozone is the atmosphere. (Pupil 19)

5. The pupils who prefer models R2, R3, R4, or R5 for the role and distribution of ozone also tend to use the category of containers (standardised residual = 2.96), for instance:

   > Ozone is found 25 kilometres above the earth and it surrounds the sun. It contains the sun and stops the ultraviolet sun rays from coming and burning us. (Pupil 11)

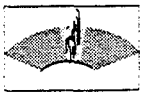
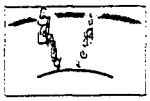
6. Last, the children who have the less adequate models R2, R3, R4, or R5 introduce the metaphor of a dividing surface significantly less than expected by chance (standardised residual = 3.92).

Metaphors and Models of Ozone Depletion

The frequencies of the types of metaphors used for the models of ozone depletion are shown in Table 2, along with the corresponding standardised residuals, which are shown in brackets accompanied by a sign showing whether the observed value is greater or less than the expected value.

Three categories of models are included in this part of the analysis. The first category involves model D1 (where D stands as an indicator for all the models concerning ozone depletion), which represents the depletion of the thin ozone layer as a complete local destruction of ozone, caused by gaseous pollutants (especially CFCs). The second category corresponds to model D2 in which the depletion of the uniformly diffused atmospheric ozone by CFCs is seen as an alteration of the composition of the atmosphere. Model D3, constituting the third category, considers the depletion of the thin ozone layer by CFCs (or other man-made gases) as a "thinning down," be it a decrease in the concentration of ozone or a decrease in the layer's thickness. In order to explain the ozone depletion process metaphorically, pupils rely on the categories of person (196 instances), substance (61 instances), container (80 instances), hole (201 instances), and dividing surface (55 instances) as source domains.

Table 2
Frequencies (and the Corresponding Standardised Residuals) of the Types of Metaphors Used for the Models of Ozone Depletion

	person	substance	container	hole	dividing surface	Total
Category 1						
 Model D1: Local but total destruction of the thin O_3 layer	150 [0.36] +	31 [4.06] -	56 [0.1] -	151 [0.14] +	44 [0.39] +	432
Category 2						
 Model D2: Local decrease of O_3 alters atmosphere	23 [0.3] -	12 [1.97] +	14 [1.15] +	28 [0.09] +	1 [5.37] -	78
Category 3						
 Model D3: Local thinning down of the O_3 layer	23 [0.72] -	18 [10.49] +	10 [0.13] -	22 [1.34] -	10 [0.69] +	83
Total	196	61	80	201	55	593

The statistical analysis shows that there exists a correlation between the models of ozone depletion and the types of metaphors they introduced ($\chi^2(8) = 27.29$, $p < .05$). Thus, the selection of the appropriate metaphor seems to play a decisive role in the formation of their models regarding the ozone depletion process.
Moreover, the examination of the standardised residuals in Table 2 suggests that:

1. The pupils who view the depletion of the thin ozone layer as a local but total destruction of ozone (model D1) tend to use the category of substances as a source domain in their metaphors rarely. This is indicated by the size of the corresponding standardised residual which is 4.06.

2. The children who prefer model D2 tend to explain ozone depletion in terms of substances. This is based on the size of the corresponding standardised residual which is 1.97, and is illustrated by the following extract:

   > CFCs are gases, they are substances that... eh... "dilute" ozone and then penetrate it. So, the methane and carbon dioxide that the ozone contains are not very concentrated and they can't weaken the sun's rays. (Pupil 20)

3. The metaphorical category of containers also seems to help pupils who prefer model D2 explain the ozone depletion process. This is indicated by the size of the corresponding standardised residual, which is 1.15, while an example of the use of containers as a source domain is illustrated in the following extract:

   > Ozone contains carbon dioxide, methane, and oxygen. But the CFCs destroy ozone and go into it and then the methane and carbon dioxide that the ozone contains are not dense enough to stop the sun's rays. (Pupil 21)

4. The pupils who introduced model D2 view the depletion of the (uniformly distributed) ozone in the atmosphere as a local decrease in the ozone's concentration altering the atmospheric composition. The uniform diffusion of ozone in the atmosphere seems to discourage pupils strongly from using dividing surfaces as a metaphorical source (standardised residual = 5.37).

5. The category of substances has proved overwhelmingly useful (standardised residual = 10.49) for the pupils who view ozone as localised in a thin layer high in the atmosphere and its depletion as a decrease in the concentration of ozone, or as a thinning of its layer (model D3). The following extract illustrates this tendency:

   > CFCs are gases found in sprays and in fridges. They are substances made up of little, drastic molecules [...] which go up in the ozone layer and there they alter it, [...] they melt the ozone layer at some places, they reduce the substances it consists of. (Pupil 33)

6. Lastly, the pupils who have model D3 tend not to use the concept of holes as a source domain when referring to the ozone depletion process (standardised residual = 1.34).

Discussion

Pupils introduced an abundance of metaphors while discussing the role and the depletion of ozone. Metaphors function as tools for thinking when pupils attempt to understand different aspects such as the nature of ozone, its position and distribution in the atmosphere, the mechanism through

which ozone prevents ultraviolet radiation from reaching the earth, the upward movement of pollutants in the atmosphere, the process through which these pollutants destroy ozone, or the meaning of the term "ozone hole" (being also a metaphor itself).

Our analysis departs from the hypothesis that the familiar metaphorical source used for the explanation of an abstract, complex and unfamiliar phenomenon should present important morphological, structural, and/or functional similarities with the crucial aspects of the model each pupil adopts. Such an hypothesis is justified and supported by the views of other researchers in the field of analogical and metaphorical thinking, who view analogy and metaphor as closely related to the representational mechanism (Black, 1979; Cornell Way, 1991; Gentner & Gentner, 1983; Rumelhart & Norman, 1981; Ogborn, Mariani, & Martins, 1994b). This view also suggests that metaphorical thinking constitutes a mechanism of construction, selection and use of mental models, through the abstraction of the common aspects of two conceptually distant knowledge domains. Moreover, metaphors themselves can also serve as models, relating different conceptual domains. However, despite the explicit character of these positions, some researchers suggest that the validity of this position has not been adequately confirmed or supported by research data (Paivio, 1979; MacCormac 1985; Goswami, 1992). They expect that the empirical study of metaphorical thinking should provide a different perspective to the mechanisms involved in understanding and representing knowledge.

Analysis of correlations of the categories used as source domains in metaphorical thinking and the models pupils adopt for the role and distribution of ozone and the process of its depletion leads to one central conclusion: the way children represent the role and depletion of ozone is strongly correlated with the types of metaphors they use while constructing and/or articulating their models.

Thus, metaphorical thinking is consistently and systematically utilised in the models with the familiar basic concepts introduced in metaphors selected for those of their attributes which help the pupils structure their mental representations. Children use metaphors systematically. When a pupil conceptualises ozone as a thin atmospheric stratum, (s)he uses the category of a dividing surface to process and describe it metaphorically. Specific examples of this type of metaphor, that were frequently used during the interviews, include the concepts of a layer, a shield, an umbrella, or a cover protecting the earth from the harmful ultraviolet radiation.

Similarly, when a pupil understands the depletion of the thin ozone layer as a local decrease in its concentration, or as a decrease in its thickness caused by gaseous pollutants released on earth, (s)he prefers the category of a substance rather than that of a hole (which could imply the local but total destruction or the complete absence of ozone) to explain it.

Educational Implications

The results indicate that pupils use metaphors in a consistent and systematic way to understand, explain, and represent the role and distribution of ozone in the atmosphere and the depletion of ozone. Thus, metaphors can be a valuable educational tool in order to enhance the representation of these abstract and complex processes.

On the other hand use of inappropriate metaphors can enhance the construction of incomplete models which involve important alternative conceptions. These incomplete models are closely related to certain target obstacles. Target obstacles are central components missing from children's thinking, thus preventing pupils from developing an adequate understanding (Martinand, 1982). Thus, target obstacles, if appropriately identified and used in teaching, can be valuable educational tools, since they could provide guidelines to teachers so as to help pupils detach their thinking from

their alternative conceptions (for a more detailed discussion of target obstacles in the case of the ozone role and its depletion, see Christidou & Koulaidis, 1996).

The central, established and widely used metaphors connected to the issue under discussion, namely the ozone layer and the ozone hole, seem to be valuable and helpful for children in order to understand and conceptualise ozone and its depletion. The use of the term "layer" enhances and encourages an understanding of the localisation of ozone in a relatively thin atmospheric stratum, which corresponds sufficiently to ozone's distribution in the atmosphere. Pupils who introduced the layer metaphor constructed adequate models as far as the distribution of ozone was concerned. On the other hand, pupils who used the categories of air/atmosphere, or container failed to represent the distribution and role of ozone sufficiently. Thus, the layer metaphor can be educationally valuable in order to enhance an appropriate representation of stratospheric ozone.

More importantly, on the basis of our evidence we could argue that the air/atmosphere metaphor should be strictly avoided in explanations concerning the distribution and role of ozone, since it encourages the construction of inadequate models (see Table 1). The air/atmosphere metaphor also seems to be closely related with the conceptualisation of the atmosphere as an entirely homogenous mixture, which constitutes an important target obstacle characterising models R3 and R4.

Children's thinking about the role and distribution of ozone is also constrained by another critical target obstacle that teaching about ozone should aim at overcoming: the lack of the absorption mechanism of UV radiation (Christidou & Koulaidis, 1996). Even the pupils who adopted the most accurate model concerning the role of ozone (model R1) did not use metaphors that could explain or specify how ozone stopped ultraviolet radiation from reaching the earth (e.g., compare the frequencies of the absorbing/reflecting surface and dividing surface metaphors in Table 1). Thus, the introduction of an absorbing surface as a metaphor could help pupils to overcome the related target obstacle and at the same time could lead to construction of more complete models regarding the role and distribution of ozone.

The metaphor of the ozone hole can lead to inappropriate explanations of ozone depletion. This is made apparent by the fact that this metaphor is strongly preferred by the pupils who interpret ozone depletion as complete local destruction of ozone; these pupils use model D1. Their understanding of ozone depletion is constrained by the fact that ozone depletion is not interpreted as a decrease in concentration. This target obstacle, central in many pupils' thinking (Christidou & Koulaidis, 1996) seems to be closely related to the use of the hole metaphor, which children tend to interpret as complete lack of ozone. On the basis of our results we argue that more adequate models which view ozone depletion as a decrease in ozone concentration can be supported by metaphors using the category of substance as a source domain. Thus, substance metaphors can be an educationally helpful and valuable tool in order to teach ozone depletion, while the ozone hole metaphor should be avoided, or used by teachers with great caution so as not to lead to misinterpretations.

Consequently, we argue that the analysis in this paper looks at children's models of the role and depletion of ozone from a new perspective, taking advantage of the explanatory potential of metaphorical thinking. The study of pupils' alternative conceptions in relation to the specific metaphors they use can be extremely valuable in determining what the origins of these conceptions are and where teaching should focus in order to overcome them. It is therefore necessary to design teaching materials that will take full advantage of the explanatory potential of educationally appropriate metaphors. Such pedagogical means could discourage the formation of alternative conceptions and inadequate representations by helping pupils' thinking overcome important target obstacles. At the same time, such teaching material could facilitate the construction of more appropriate models in terms of the position and distribution of ozone in the atmosphere, its role, the mechanisms and consequences of its depletion.

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