Categorical Information Improves the Effectiveness of Refutation Texts

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Abstract

We present the results of an empirical study, which investigated the effects of the amount of information and the type of information refuted in refutation texts. The study compared the effects of three refutation texts on elementary school children's understanding of the scientific concept of the Earth. One text refuted only the belief that the Earth is flat, the second refuted in addition the belief that people cannot live at the 'bottom' of the spherical Earth because they would fall down, and the third added the categorical information that the Earth is an astronomical object. The term 'categorical information' is used to refer to information about the category to which a concept belongs. We hypothesized that the text refuting more information as well as the one that included the categorical information that the Earth is an astronomical object would be more effective in improving students' scientific knowledge about the Earth. The refutation of categorical information is important because it is generic and carries a great deal of implicit information that can guide new learning. The findings showed that the text that included more information as well as the categorical information facilitated scientific understanding most. The results support the hypothesis that both the amount of information and the kind of information being refuted need to be taken into consideration when deciding what to refute in a refutation text.

Keywords: refutation texts; categorical information; learning; conceptual change

Introduction

Refutation texts

Science texts are difficult to understand, especially for young, elementary school children (Goldman & Bisanz, 2002; Graesser, Leon, & Otero, 2002; Vosniadou & Skopeliti, in preparation). One possible reason for these difficulties is that science texts do not take into consideration children's incompatible prior knowledge and their possible misconceptions (Mikkila-Erdmann, 2002; O'Reilly & McNamara, 2007). In situations where an expository text presents counter-intuitive scientific information which may not be supported by readers background knowledge, the use of refutation texts - the texts that acknowledge students' alternative conceptions and then explicitly refute them- produces better understanding results than non-refutation texts (Broughton & Sinatra, 2010; Diakidoy, Kendeou, & Ioannides, 2003; Dole, 2000; Guzzetti, Williams, Skeels, & Wu, 1997; Kendeou & van den Broek, 2005, 2007). However, refutation text studies have not adequately addressed the question of **how much** information as well as **what kind** of information should be refuted.

In the present study we investigated the effects of refuting more information as well as of adding categorical information. More specifically, the texts used refuted prior knowledge representing the belief that the Earth is flat, and the belief that people cannot live at the bottom of the Earth because they will fall down. In addition, we investigated the effect of adding in the text information about the scientific category to which the Earth belongs. Conceptual change research has shown that learning science often requires re-assignment of the category to which a concept belongs (Chi, 2013; Vosniadou & Skopeliti, 2005).

Categorical Information and Conceptual Change

Categorization is one of the most powerful learning mechanisms (Chi, 2013; Medin & Rips, 2005; Vosniadou, 2008). When an object is assigned to a given category, all the characteristics of the category are transferred to this object. For example, if the 'Earth' is assigned to the category of physical objects, then the characteristics of physical objects, known to the learner, are assigned to it. Prior research has shown that young children do indeed assign the Earth to the category of physical objects and transfer to it characteristics of physical objects, such as stability, support and the belief in an 'up/down' gravity (Vosniadou & Skopeliti, 2005).

Categorization is a dynamic rather than a static process.. During development many concepts may change category, i.e. plants are considered to belong to the category of non-living things at first but later change category and are considered to belong to the category of living things (Carey, 1985). This process of re-categorization is an important part of the conceptual change process that takes place, particularly in learning science. The re-categorization of plants from the category of "non-living" to the category of "living" things is accompanied by important changes in the characteristics applied to pants.

Many of the misconceptions children form are the result of assimilating scientific information into their background knowledge without changing their initial categorizations (Vosniadou & Skopeliti, 2013). When conceptual change is achieved, a new scientific concept has been formed which has either been re-assigned to a different existing category, or an altogether new category has been formed (Chi, 2013). In most cases (i.e., concepts like heat, energy, force, matter, etc.) the new, scientific category does not exist and needs to be constructed with the help of specific instruction.

The concept of the Earth

Previous research has shown that children have considerable difficulty understanding that the Earth is a sphere that rotates around its axis and revolves around the Sun (Vosniadou & Brewer, 1992). It has been argued that this is the case because children categorize the Earth as a physical object and apply to it the characteristics of physical objects, which are found on the Earth, such as solidity, stability and up/down gravity. These in turn constrain children's understanding of the scientific information about the earth and become the cause for children to form various kinds of misrepresentations of the Earth.

A substantial body of cross-cultural research supports the conclusion that during the preschool years children construct an initial concept of the earth based on interpretations of everyday experience in the context of lay culture. According to this initial concept, the Earth is a flat, stable, stationary, and supported physical object. Objects located on the earth obey the laws of up/down gravity, and space is organised in terms of the dimensions of up and down. The sky and solar objects are located above the top of this flat earth, which is thought to occupy a geocentric universe (Nussbaum, 1985; Vosniadou & Brewer, 1992, 1994).

The scientific concept of the Earth, to which children are exposed at least as soon as they enter elementary school, violates practically all of the characteristics that apply to children's initial Earth concept. According to the scientific concept, the Earth is a planet, i.e., an unsupported, spherical, astronomical object, which rotates around its axis and revolves around the sun, in a heliocentric solar system. People live all around the spherical Earth and gravity operates towards the centre of the earth. Understanding the scientific concept of the Earth requires that children re-categorize the earth to a new ontological category, that of an astronomical object.

Vosniadou & Skopeliti (2005) examined in detail this hypothesis and showed that indeed there is a shift in children's categorizations of the Earth from a physical object to an astronomical object, and that this shift is related to children's understanding of the scientific model of the Earth. In this study 62 1st and 5th grade children were shown 10 cards with the words 'SUN', 'MOON', 'STAR', 'EARTH', 'PLANET', 'HOUSE', 'CAT', 'ROCK', 'TREE', and 'CAR' and were asked three categorization questions. The results showed that the great majority of the children were able to distinguish physical from astronomical objects and that there was a developmental shift in their categorizations of the Earth. Many of the younger children thought that the Earth belongs with the physical objects, while practically all of the 5th graders categorized the Earth with the astronomical objects. Furthermore, significant correlations were obtained between children's categorizations and their Earth shape models. In conclusion, the results supported the hypothesis that there is a change in the categorization of the Earth from a physical to an astronomical object, and that the re-categorization of the Earth as an astronomical object may precede children's full understanding of the Earth as a spherical planet that rotates around its axis and revolves around the sun.

Previous studies have shown that when children's initial beliefs about the Earth are addressed, their understanding of the spherical shape of the Earth is improved. A study comparing a control group that received traditional instruction with an experimental group that received additional information about the spherical shape of the Earth and gravity based on simulations, showed much improved understanding of the scientific concept of the Earth for the experimental group (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). In another study, Hayes, Goodhew, Heit, and Gillan (2003) based on the findings of Vosniadou and Brewer (1992) used non-refutational texts and videos to explain the beliefs of flatness and up/down gravity that constrain the scientific understanding about the earth. The results again showed significant differences between the experimental and the control group. In the present study, we investigated the effects of the refutation of the same two beliefs as well as of the categorical information that the Earth is an astronomical object..

Three refutation texts were compared. The first dealt with the belief that the Earth is flat (Text 1), the second also refuted the belief that people cannot live at the bottom of the Earth because they will fall down (Text 2), and the third added to the above the information that the Earth is an astronomical object rather than a physical object (Text 3), i.e., a spherical planet in a heliocentric solar system. More specifically, Text 1 explicitly stated "*the Earth is not flat but spherical, like a very big ball*" and explained that "*the Earth looks flat to us who live on a very small piece of it, like Greece*". Text 2 added to this the information that "*gravity is the force that holds us on the Earth so that we do not fall down. It pulls everything that is found on the Earth's surface towards the center of the Earth. Because of gravity people can live on all the parts of the spherical Earth without falling*". Finally, Text 3 also stated "the *Earth is one of the planets of our solar system. Today we know that our solar system is heliocentric. All planets revolve around the sun. The sun is located in the middle of the solar system. The Earth is also a planet with all the characteristics of planets. All planets are spherical, round like very large balls*".

We hypothesized that Texts 2 and 3 that refuted more information would be better in improving children's understanding compared to Text 1. However, it was also hypothesized that Text 3, which contained the categorical information that the Earth is an astronomical object, would be more effective than the other two.This is the case because categorical information is generic and allows inferences about the characteristics of astronomical objects while it prevents inferences of the sort that the Earth is stable and in need of support, and of 'up/down' gravity.

Method

Participants

Eighty-one 3rd grade students (mean age 8 years and 4 months) from a middle-class school in Athens, Greece, participated in the study. 3rd graders were selected because previous studies have shown that although they are exposed to scientific information about the Earth they do not yet fully understand the Earth concept. Furthermore, this is the youngest age at which we expected the children to be able to read and understand a simple science text.

Materials

The materials used were: (a) three different refutation texts which referred to the Earth, and (b) a questionnaire consisting of 14 open-ended questions. As mentioned earlier, Text 1 refuted the belief that the Earth is flat and explained that it is spherical (310 words). Text 2 included all the information found in Text 1 and also refuted the belief that people can fall off the Earth and explained that there is force called gravity that holds people on to the surface of the spherical Earth (410 words). Text 3 included all the information found in Texts 1 and 2 and also added the information that the Earth is an astronomical object (510 words). All texts were of comparable readability level (Flesch index: 57.84 for text 1, 61,32 for text 2 and 73,24 for text 3).

The questionnaire was used both as a pre-test and as a post-test. The questions were divided in two groups: (1) explicit questions, some of which arose directly from all the texts (common explicit), and some only from Text 3; and (2) inferential questions, the answers to which were not explicitly stated in the texts but could be inferred from it. Again, some inferential questions could be inferred from all texts (common inferential), while others could be inferred only from Text 3.

Procedure

Children were randomly assigned to one of the experimental conditions. More specifically, each classroom was randomly given one of the three texts to read. The pre-test was administered first. When all children finished answering the pretest, the answer sheets were collected and a written copy of one of the refutation texts was distributed. They had 15 minutes to read it on their own. At the end of the reading period, the experimenter read the text aloud in order to make sure that the children could decode all the words. Then the written texts were withdrawn and the posttest was administered..

Results

Scoring. Two judges agreed on a scoring key, which they used to score independently children's responses in all the questions. The judges' agreement was calculated at 95% [*Kendall's tau* $\tau=0.939$; $N=81$; $p<.001$]. All disagreements were discussed until a common score had been achieved on all the items. Children's responses to each of the 14 questions received a score of 3 if they were scientific, of 1 if they were "initial" (if they were consistent with the flat Earth model), and of 2 if they revealed exposure to scientific information, which was however not fully understood. No responses were scored as 0. Thus, for each student the total score could range from 0 to 42.

A group type (text1*text2*text3) ANOVA was used to test whether there were any significant pretest differences between the two experimental groups assigned to the different text conditions.. The results showed no statistically significant differences between the three experimental groups in the pretest [$F(1,78)=.710$, *n.s.*; $\eta^2=.004$].

Children's total scores in all the common (explicit and inferential) questions in the pretest and posttest were subjected to a mixed two-way ANOVA with text type as a between subjects variable and pre-post test performance as a within subjects variable. The results showed that all refutation texts improved significantly children's responses in the posttest [$F(1,78)=49.742$, $p<.001$] (see Table 1) and the size effect for this analysis [$\eta^2=.387$] exceeded the convention for a large effect ($\eta^2=.025$).

Table 1: Mean Score and Mean Score Difference in Children's Responses in All the Common Questions in the Pretest and the Posttest as a Function of Text Type

Text		Mean	Std. Error	Mean Difference
1	Pretest	18.950	.586	.500
	Posttest	19.450	.529	
2	Pretest	19.457	.443	.743
	Posttest	20.200	.400	
3	Pretest	19.038	.514	2.347
	Posttest	21.385	.464	

The analysis also showed a statistically significant interaction between text type and students difference in performance from pretest to posttest [$F(2,78)=7.438$, $p<.001$]. The effect size for this analysis [$\eta^2=.160$] was found to exceed the convention for a large effect ($\eta^2=.025$). The students who read Text 3 showed greater improvement in their responses in the posttest compared to the pretest, as opposed to the students who read Text 1 and Text 2 (Figure 1).

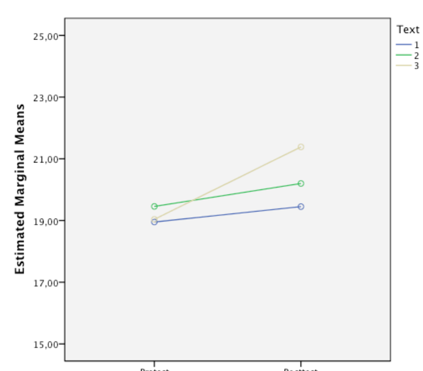

Figure 1: Mean Scores of Children's Responses in all Common Questions as a Function of Text Type

Post hoc comparisons using the LSD test indicated that the mean score difference from pretest to posttest for Text 3 was statistically significant only when Text 3 was compared to Text 1. The mean score difference between Text 2 and Text 3 was in the expected direction but not statistically different (see Table 2). Similarly, the mean score difference between Text 1 and Text 2 was not statistically different. Taken together, these results suggest that Text 3, improved children's responses in the posttest more than the other two texts, but the difference was statistically significant only between Text 1 and Text 3..

Table 2: Mean Score Difference in Children's Responses in all the Common Questions Using the LSD post-hoc Analysis

Texts		Mean Difference	Std. Error	Significance
1	2	-0.629	.662	n.s.
	3	**-1.012***	**.703**	**p<.05**
2	1	0.629	.662	n.s.
	3	-0.383	.612	n.s.
3	1	**1.012***	**.703**	**p<.05**
	2	0.383	.662	n.s.

A similar mixed ANOVA was conducted separately for the common explicit and the common inferential questions only. In the case of the common explicit questions the analysis showed statistically significant improvement in children's responses from pretest to posttest in all three texts [$F(1,78)=20.058; p<.001; \eta^2=0.205$]. No statistical significant interactions were obtained [$F(2,78)=.637$; *n.s.*; $\eta^2=0.006$], despite the fact that Text 3 had a greater effect in children's responses in the posttest compared to the other two texts (see Table 3).

Table 3: Mean score and Mean Score Difference in Children's Responses in the Common Explicit Questions in the Pretest and the Posttest as a Function of Text Type

Text		Mean	Std. Error	Mean Difference
1	Pretest	10.300	.383	.450
	Posttest	10.750	.324	
2	Pretest	10.143	.290	.514
	Posttest	10.657	.245	
3	Pretest	9.500	.336	1.154
	Posttest	10.654	.284	

In the case of the common inferential questions a statistically significant improvement in children's responses from pretest to posttest in all three texts was obtained [$F(1,78)=20.058; p<.001; \eta^2=0.205$] (see Table 4).

Table 4: Mean score and Mean Score Difference in Children's Responses in the Common Inferential Questions in the Pretest and the Posttest as a Function of Text Type

Text		Mean	Std. Error	Mean Difference
1	Pretest	8.650	.366	.050
	Posttest	8.700	.345	
2	Pretest	9.314	.277	.229
	Posttest	9.543	.261	
3	Pretest	9.885	.321	.846
	Posttest	10.731	.303	

Significant interactions were obtained only in the case of the inferential questions [$F(2,78)=6.410; p<.005$]. The η^2 effect size value for this analysis [$\eta^2=.141$] was high. Figure 2 is a pictorial representation of these results.

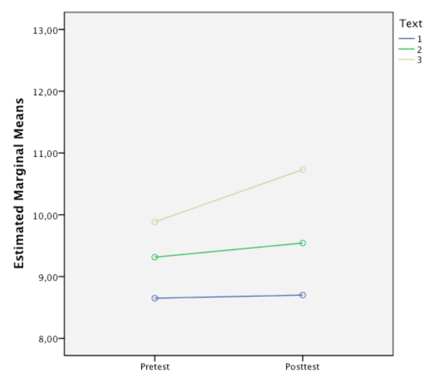

Figure 2: Mean Scores of Children's Responses in the Common Inferential Questions as a Function of Refutation Text Type

It appears that Texts 1 and 2 slightly improved children's responses in the posttest, while Text 3 had a greater impact on children's posttetst explanations compared to the other two texts. Additional post-hoc analyses using the LSD test showed that this difference was in favor of Text 3 compared to the other two texts (Table 5).

Table 5: Mean difference of children's responses in the inferential questions in the posttest using the LSD post-hoc analysis

Texts		Mean Difference	Std. Error	Significance
1	2	-0.754	.431	n.s.
	3	**-1.633***	**.457**	**p<.001**
2	1	-0.754	.431	n.s.
	3	**-0.879***	**.398**	**p<.05**
3	1	**1.633***	**.457**	**p<.001**
	2	**.879**	**.398**	**p<.05**

It seems that, once again Text 3, which included the categorical information, improved children's responses in the inferential questions more than the other two texts.

Discussion

Science texts are difficult to understand, especially for young elementary school children (Goldman & Bisanz, 2002; Graesser, Leon, & Otero, 2002; Vosniadou & Skopeliti, in preparation). Refutation texts that take into consideration children's incompatible prior knowledge and possible misconceptions and explicitly refute them are a good means to promote text understanding in these cases (Dole, 2000; Diakidoy, Kendeou, & Ioannides, 2003; Guzzeti, et al., 1997; Mikkila-Erdmann, 2002; O'Reilly & McNamara, 2007). The results of the present study are consistent with the results of previous research in view of the fact all the refutation texts improved children's responses in the posttest.

In addition, the results of the present study indicate that the refutation text that included the categorical information was more effective than the other texts in improving children's understanding of the scientific information about the Earth. The children who read Text 3, which included the information about the categorization of the Earth, improved their responses in the inferential questions in the posttest more compared to their peers who read the other two texts. This finding is consistent with our hypothesis that categorical information is more important than other types of information, because it is generic and carries with it a great deal of implicit information that can be used by the learner to guide new learning (Vosniadou & Skopeliti, 2005). However, since Text 3 also included more information than the other two Texts, more experiments are need in order to further test the power of presenting categorical information alone.

Overall, the present results support the conclusion that when using refutation text, it is important to consider what kind of information is being refuted as well as how much information is refuted. It appears that texts are more effective when more information is refuted as well as when the refutation includes categorical information (Skopeliti & Vosniadou, 2006, 2009). This finding has important practical implications and needs to be considered by curriculum designers, authors of science text, and of course teachers.

Learning science very often requires changes in the ontological category to which an object belongs. These changes are considered to be the most difficult conceptual changes to achieve (Chi, 2013; Chi & Roscoe, 2002; Thagard, 2013; Vosniadou & Skopeliti, 2013). In the case of the Earth concept it was not too difficult to add the information that the Earth is an astronomical object in the present texts, because the children already had formed a category of astronomical objects. However, it might be more difficult to refer to the scientific category when this category does not exist in the conceptual repertoire of the student. For example, reference to the category 'interactions' for concepts like force, or heat, which are initially categorized as substances or properties of objects might not carry much meaning or explanatory power for a student. Taking this into consideration, it has to be clear that caution needs to be exercised as to how categorical information can be best included in science texts, particularly in situations where there are reasons to believe that the scientific category does not already exist in the conceptual repertoire of the student.

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