Routledge
Taylor & Francis Group

International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

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INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
https://doi.org/10.1080/09500693.2017.1361557

Is it the Earth that turns or the Sun that goes behind the mountains? Students' misconceptions about the day/night cycle after reading a science text

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ABSTRACT

The present research tested the hypothesis that the reading of science text can create new misconceptions in students with incongruent prior knowledge, and that these new misconceptions will be similar to the fragmented and synthetic conceptions obtained in prior developmental research. Ninety-nine third- and fifth-grade children read and recalled one of two texts that provided scientific or phenomenal explanations of the day/night cycle. All the participants gave explanations of the phenomenon in question prior to reading one of the texts and after they read it. The results showed that the participants who provided explanations of the day/night cycle at pretest incongruent with the scientific explanation recalled less information and generated more invalid inferences. An analysis of the participants' posttest explanations indicated that these readers formed new misconceptions similar to the fragmented and synthetic conceptions obtained in developmental research. The implications of the above for text comprehension and science education research are discussed.

ARTICLE HISTORY
Received 20 December 2016
Accepted 26 July 2017

KEYWORDS
Conceptual change; misconceptions; text comprehension; science text

Introduction

Since the seminal work of Driver and Easley (1978), a great deal of evidence has accumulated showing that students hold deeply rooted conceptions and ideas which stand in the way of learning science (Duit & Treagust, 2003). The terms alternative conceptions, preconceptions or misconceptions have been used interchangeably to refer to students' ideas that are incongruent with scientific theories and explanations. The purpose of the present research is to use a text comprehension experiment to directly test the hypothesis that many such misconceptions are not just erroneous ideas but hybrid constructions that bridge scientific explanations with incongruent initial conceptions.

This research is relevant for the learning and teaching of science because it shows that misconceptions are not accidental errors but constructive attempts of learners to relate counter-intuitive scientific information with initial conceptions based on everyday

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experience. The learning of science, we claim, is not produced from sudden insights but is a long and gradual affair. The formation of synthetic and fragmented conceptions that attempt to bridge people's intuitive explanations of phenomena with scientific theories is a natural outcome of this process and should be understood and addressed as such by science education programmes.

Prior research on misconceptions

The dominant view on misconceptions in the science education literature has been that they are erroneous ideas produced by students either prior to instruction or because of faulty instruction. In what is known as the classical conceptual change approach (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985, 1992), science learning is achieved when students become aware and dissatisfied with their prior conceptions and also understand the fruitfulness and intelligibility of the scientific view. It is only then that a radical process of conceptual change or conceptual replacement can take place.

This view has shown not to be consistent with the results of science education research. As Duit and Treagust (2003, p. 5) argue, 'there appears to be no study which found that a particular student's conception could be completely extinguished and then replaced by the science view'. It is also not consistent with the findings of more recent cognitive science research that show that initial (or otherwise, intuitive, naive, folk, etc.) conceptions coexist with scientific theories, sometimes even in the minds of experts (Babai, Sekal, & Stavy, 2010; Legare, Evans, Rosengren, & Harris, 2012; Potvin, Masson, Lafortune, & Cyr, 2015; Shtulman & Valcarcel, 2012).

What is proposed here, is that the term 'misconceptions' is too broad to be useful and that a fundamental distinction needs to be made between initial conceptions formed before exposure to science and erroneous conceptions formed after exposure to science. Research has shown that long before they are exposed to systematic science instruction, young children develop initial (intuitive, naive) conceptual knowledge about the world, which is very different from scientific theories and explanations (see Carey, 1985; Gelman, 1991; Hatano & Inagaki, 1987; Vosniadou & Brewer, 1992; Wiser & Smith, 2008). Initial conceptual knowledge in turn influences children's interpretations of scientific information resulting in the creation of hybrids. Hybrid conceptions are an amalgamation of initial understandings and scientific information.

The idea that students create hybrid conceptions during the processes of assimilation and accommodation of new information to prior knowledge is not new. It can be found in the early work of Piaget (1929) as well as in recent cognitive science research (Chinn & Brewer, 1993; Legare et al., 2012; Wiser & Smith, 2008). Legare et al. (2012) describe three different ways in which individuals might combine different explanatory frameworks, i.e. integrative thinking, synthetic thinking and target-dependent thinking, while Chinn and Brewer (1993) use historical data and examples from interviews to argue that people rarely accept anomalous data that contradict their prior knowledge but respond by ignoring, rejecting, excluding, hold in abeyance or reinterpreting it.

Vosniadou and Brewer (1992, 1994) have provided many examples of hybrid conceptions (Vosniadou, 2013). They distinguish between fragmented conceptions consisting of a combination of initial beliefs and scientific information put together without concern for explanatory power and coherence, and synthetic conceptions, which are also scientifically incorrect but nevertheless exhibit concern for internal consistency and have some explanatory power. For example, children might say that night is caused because the Sun disappears (initial conception) and also because the Earth moves (information coming from instruction). This is a fragmented conception because it makes simultaneous reference to two incongruent explanations of the day/night cycle without any justification. On the other hand, the explanation that night is caused because the Sun revolves around the Earth every 24 hours synthesises initial beliefs (Sun's movement causes day/night cycle) with scientific information (revolutionary movement) creating a hybrid model that has some explanatory power despite the fact that it is scientifically incorrect.

The presence of fragmented and synthetic conceptions has been interpreted to suggest that individuals use constructive learning mechanisms to assimilate scientific information into their initial belief systems distorting the scientific information in the process. This happens because scientific concepts are counter-intuitive and require many conceptual changes over our initial belief systems, changes that are difficult to achieve in a short period of time. Fragmented and synthetic conceptions are thus intermediate, and one could argue natural steps in the long and gradual process of learning science.

Despite the wealth of descriptive evidence that attests to the presence of such hybrid conceptions, the proposal that misconceptions are produced by constructive learning mechanisms that integrate initial conceptions with counter-intuitive scientific information has not been subjected to experimental test. The purpose of the present study is to test this hypothesis directly in a text comprehension study in which students' explanations of a phenomenon are elicited before and after reading a science text. In such a study, it is possible to examine the specific ways in which scientific information alters children's pretest explanations. We argue that if students use constructive learning mechanisms to bridge scientific information with their initial conceptions, then we should be able to observe that students with initial conceptions at pretest create fragmented and synthetic conceptions after reading a science text.

The purpose of the present research is not to suggest that reading a science text is a good instructional method to produce conceptual change. Our purpose is to test the hypothesis that new, fragmented and/or synthetic conceptions can emerge when readers with initial conceptions are exposed to a counter-intuitive scientific explanation. We argue that this research is important for the fields of both science education and text comprehension. Despite the high quality of text comprehension and science education research, many researchers treat students' misconceptions as unitary erroneous beliefs that need to be extinguished and replaced by the correct scientific concepts, failing to understand their complex and constructive nature.

Text comprehension research

Science texts are difficult to understand, their most severe limitation being their failure to affect knowledge revision and conceptual change (Goldman & Bisanz, 2002; Graesser, Leon, & Otero, 2002; Snow, 2010). One important reason for readers' difficulties is the mismatch between prior knowledge and the information presented in the text. Research has shown that when there is a conflict between prior knowledge and text information, readers may fail to draw the necessary inferences to connect the ideas in the text (Mikkilä-Erdmann, 2002; O'Reilly & McNamara, 2007), or understand the inconsistencies between their background knowledge and text information (Chi & Roscoe, 2002). Research has also shown that readers who have science misconceptions produce more invalid inferences and lower recall when they read a science text compared to students who do not have misconceptions (Diakidoy, Kendeou, & Ioannides, 2003; Guzzetti, Snyder, Glass, & Gamas, 1993; Kendeou & van den Broek, 2005, 2007).

As Van den Broek (2010) argues, in most text comprehension tasks 'the readers' background knowledge supports the process of interpreting and representing the text'. Text comprehension becomes difficult when the readers' background knowledge does not support the creation of a situation model of the text. In this case, background knowledge itself 'becomes the object of change' (Van den Broek, 2010, p. 453). The crucial question then is to find out if it is possible for the readers' background knowledge to be modified by text information, and if so under what circumstances.

Text comprehension research has addressed this question by focusing mostly on the *processes* involved in the modification of the reader's background knowledge during the reading process. A class of text comprehension models have been proposed which provide a basis for possible associations between text comprehension research and conceptual change learning (Sinatra, Broughton, & van den Broek, 2011). All of these models assume that the reader is actively processing information from the text in order to create a coherent situation model (Kintsch, 1998). In this process, background knowledge discrepant from text information may be activated, preventing the reader from creating a coherent representation.

According to the Constructionist Model (Graesser, Singer, & Trabasso, 1994), noticing the discrepancy between background knowledge and text information is crucial, because only if they notice the discrepancy, readers are likely to generate the necessary inferences to restore coherence. The Landscape Model (Van den Broek, Young, Tzeng, & Linderholm, 1999) claims that only concepts that are co-activated can be compared and contrasted, while according to the Resonance Model (O'Brien & Myers, 1999), change happens when background knowledge resonates with text information creating a coherence break. This motivates the reader to rebuild coherence, particularly when an explanation of the phenomenon is presented in the text.

A major reason for the emphasis on processes in text comprehension research has to do with the differences observed in the comprehension of refutation vs. non-refutation expository texts. Refutation texts – texts that acknowledge students' misconceptions and then explicitly refute them – have often been found to have a positive effect on conceptual change learning (Diakidoy, Mouskounti, Fella, & Ioannides, 2016), and are associated with increases in the use of conceptual change strategies such as noticing discrepancies and attempting to revise erroneous knowledge (Kendeou & van den Broek, 2007). These results have been interpreted to indicate that refutation text leads readers to pay greater attention to the discrepancy between their misconceptions and text information and to engage in processes to repair it, such as those described by the models mentioned above.

Despite its sophistication, text comprehension research usually treats misconceptions as unitary erroneous beliefs that need to be replaced with the correct scientific concepts and explanations. Rather, we argue, misconceptions should be treated as hybrid conceptions, representing attempts to bridge initial (naive, intuitive) beliefs with scientific information. Such hybrid conceptions are usually transitory, malleable and likely to change.

The treatment of misconceptions we propose has implications, among others, for the analysis of the results of text comprehension experiments and for the writing of refutation or non-refutation science text. Sometimes, what is considered to be an invalid inference might actually represent an improvement over the particular individual's previous beliefs. For example, if a student with the misconception that day/night happens because 'the Sun revolves around the Earth every 24 hours' reads a science text where this misconception is negated and the scientific explanation is presented, and then forms the invalid inference that 'the Earth revolves around the Sun every 24 hours', this invalid inference in fact represents an improvement over his/her previous conception despite the fact that it is scientifically incorrect. This is something that current text comprehension research does not take into consideration.

With respect to the writing of refutation text, one implication is that instead of negating the misconception and presenting the correct scientific explanation, one should consider explicitly mentioning all the steps that are required in order to move from one's present state of understanding to the scientific explanation, otherwise the reading of the text is likely to lead to generation of invalid inferences. In the example given earlier, the negation of the misconception 'the Sun revolves around the Earth every 24 hour' and the presentation of the scientific explanation is not likely to lead to correct understanding, unless the explanation includes a number of explicit steps, such as that it is not the Sun that moves but the Earth, the Earth is a solar object that revolves around the Sun and turns around itself, it is not the revolution that explains the day/night cycle but the rotation, etc. Alternatively, the misconception chosen to be negated should be closer to the scientific explanation in terms of the conceptual changes necessary for complete understanding.

For reasons such as the above, we believe that it is important to further critically examine the argument that misconceptions are often hybrid conceptions and can be formed online through the generation of invalid inferences that attempt to bridge the readers' existing knowledge with an incongruent scientific explanation. This is the purpose of the present research. In order to conduct this type of research, we need a subject matter area that is well understood in terms of students' initial understandings and the progressive misconceptions they generate during science learning. This is why we selected the explanation of the phenomenon of the day/night cycle.

Children's difficulties with the scientific explanation of the day/night cycle

Research in science education and developmental psychology has shown that elementary school children find it difficult to understand that the day/night cycle is caused by the Earth's axis rotation (Baxter, 1989; Blown & Bryce, 2006; Chiras & Valanides, 2008; Dunlop, 2000; Kampeza, 2006; Kikas, 1998; Nussbaum, 1979; Sadler, 1987; Schwarz, Schur, Pensso, & Tayer, 2011; Sneider & Pulos, 1983; Vosniadou & Brewer, 1994). Young children usually start with initial explanations of the day/night cycle according to which the Sun (and often the Moon) is the causal agent of this phenomenon (the Sun goes down behind mountains and the Moon comes up, the Sun goes behind clouds or goes far away and the Moon shows up, etc.). Research shows that the change from such initial, phenomenal explanations to the scientific explanation is a gradual process that can give rise to fragmented and synthetic conceptions. For example, some children say that the Sun goes down to the other side of the Earth, that the Sun and the Moon revolve around the Earth every 24 hours or that the Earth revolves around the Sun every 24 hours. Some children understand that the Earth rotates around its axis but believe that the Sun and the Moon are stationary and fixed at opposite sides of the Earth. Finally, about 25% of children provide mixed or fragmented explanations that have no internal consistency and no explanatory power. Figure 1 presents some of the most important synthetic models obtained by Vosniadou and Brewer (1994) and shows how they gradually change

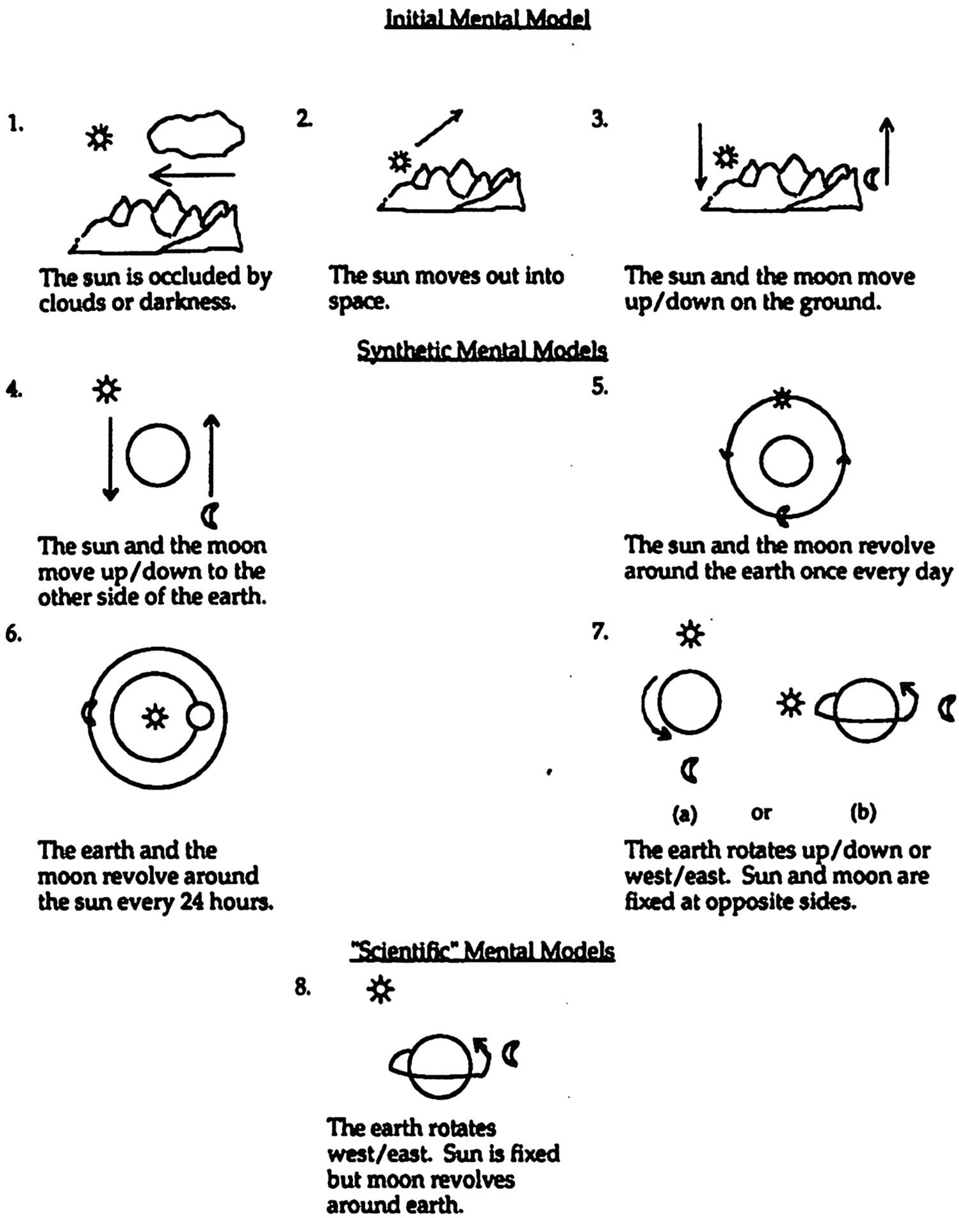


Figure 1. Children's mental models of the day/night cycle (Vosniadou & Brewer, 1994).

as students move from an initial closer to a scientific explanation of the alternation from day to night.

In the present research, we argue that we can use the information above obtained from cross-sectional developmental research to make predictions about the comprehension difficulties that students might have after reading a text that presents the scientific explanation. The theoretical framework we propose is the following: Comprehension difficulties manifest themselves when there is incongruity between background knowledge and scientific information. This incongruity is greatest when students have initial explanations prior to reading the text, which are in conflict with the scientific explanation. In such cases, the reader's prior knowledge does not support the creation of a situation model of the text and the reader must create an altogether new and counter-intuitive representation. As a result, the reader might either ignore the new, scientific information altogether or generate invalid inferences in an effort to bridge the gap between prior knowledge and scientific information. These invalid inferences might lead to the creation of new, hybrid conceptions, similar to the fragmented and synthetic models obtained in developmental research.

In the present study, we investigate the hypotheses generated by the theoretical framework described above by examining students' recalls and explanations of the day/night cycle before and after they read one of two expository texts that provided an explanation of the day/night cycle. One of the expository texts presented an initial explanation of the day/night cycle in terms of the Sun going down behind mountains and the Moon coming up (hereafter *initial text*). The other text described the scientific explanation (hereafter *scientific text*). Both texts were presented as representing the opinion of another child 'Paul said that … '. The children were asked to provide written and pictorial explanations of the day/night cycle before reading the text. After they read the text, they were asked first to recall it and then to provide written and pictorial explanations of the phenomenon again.

We selected the participants in this study to be third and fifth graders because the children are exposed to instruction regarding the scientific explanation of the day/night cycle during these grades. We predicted that at the time of the pretest, all the children would generate mostly initial and alternative (synthetic and fragmented) rather than scientific explanations of the day/night cycle (Hypothesis 1). Although we expected that the fifth graders will produce fewer initial and a greater number of scientific explanations than the third graders because of exposure to further instruction (Chiras & Valanides, 2008; Kikas, 1998), we still predicted that they would have difficulties understanding the scientific explanation and that they would produce mostly alternative explanations. This prediction was based on the findings of prior research that shows that children of this age produce mostly initial or alternative explanations of the day/night cycle (e.g. Baxter, 1989; Sadler, 1987; Vosniadou & Brewer, 1994).

With respect to text recall, we hypothesised that the recall of the scientific text will contain less information compared to the recall of the initial text (Hypothesis 2), and that it will generate a greater number of invalid inferences (Hypothesis 3), for the children who produced at the time of the pretest explanations of the day/night cycle incongruent with the scientific explanation. We hypothesised that incongruity between existing knowledge and text information would be more likely to interfere with text recall and result in the generation of invalid inferences in the case of the scientific compared to the initial text, because only in the case of the scientific text the students would have to create an altogether new and counter-intuitive situation model. The children with incongruous knowledge in the initial text condition would be the children whose current explanation of the day/night cycle would be closer to the scientific one. These children would have to create a situation model which, although inconsistent with their current knowledge, would still be consistent with their pre-scientific beliefs and with their phenomenal experience, and therefore not altogether unfamiliar or counter-intuitive.

Finally, we hypothesised that, particularly the children with incongruent prior knowledge who read the science text would be likely, at the time of posttest, to either ignore the scientific information altogether, or create new misconceptions similar to the fragmented and synthetic conceptions obtained in previous developmental research (Hypothesis 4).

The children were tested as a group in their classrooms. In addition, a small number of children were tested individually, only in the scientific text condition. The purpose of the individual interviews was to obtain more information about the comprehension difficulties of the children and, when applicable, to find out whether they did not use the scientific explanation because they had not understood it or because they did not agree with it.

Method

Participants

A total of 99 children – 50 third graders (mean age 8.8 years) and 49 fifth graders (mean age 10.6 years) participated in the study. All the children came from the same elementary school in a middle-class suburb of Athens, Greece. Seventy-nine of these children were given a group test: 40 attended third grade (mean age 8.6 years) and 39 attended fifth grade (mean age 10.4). The remaining 20 children were interviewed individually: 10 attended third grade (mean age 8.9 years) and 10 attended fifth grade (mean age 10.7 years).

Materials

Two expository texts explaining the day/night cycle from the point of view of a hypothetical child (e.g. 'Paul said that … ') were written in Greek. The *initial text* provided an initial explanation, namely that it changes from day to night because the Sun goes down behind mountains and the Moon comes up. The *scientific text* was similar in kind to science texts found in the elementary school curriculum. It stated that the Earth is round and that day/night happens because the Earth turns around itself and therefore the Sun's light falls on the other parts of the Earth where it was previously night. It was also explicitly stated that the Moon does not play a role in the day/night cycle. Both the texts were of similar lengths (114 and 120 words, respectively) and of comparable readability level, appropriate for third and fifth grade, according to the Flesch–Kincaid Grade Level Scale (the Flesch index was 97.84 for the initial text and 92.36 for the scientific text) (Table 1).

Procedure

Group test

After they were randomly assigned to one of two experimental groups, all children were given a group pretest in which they were asked (a) to draw a picture of a person living

Table 1. Translation of the scientific and initial texts explaining the day/night cycle.

Scientific text
Paul said that the Earth is round and day changes to night because the Earth turns around itself. Sunlight reaches only one side of the Earth, the side that is turned towards the Sun. On this side it is day. On the other side, which is not reached by sunlight, it is night. As the Earth turns around itself, the side that had night now faces towards the Sun and it becomes day. On the contrary, the side that had day now faces away from the Sun and it becomes night. The Moon is not responsible for the day and night cycle. Thus, it changes from day to night because the Earth turns around itself, and the sunlight shines on a different side of Earth.
Initial text
Paul said that the Earth does not move and day changes to night because the Sun moves and goes behind the mountains. When the Sun is high up in the sky, sunlight shines all over the Earth. Then it is day. During day the Moon is behind the mountains and we cannot see it. As the Sun gradually goes down in the sky, it gets darker. When the Sun is entirely hidden behind the mountains, it stops shining on the Earth and it is night. Meanwhile, the Moon, which was behind the mountains, slowly comes up in the sky. Thus, it changes from day to night because the Sun goes down behind the mountains and the Moon comes up in the sky.

on the Earth when it is daytime and then when it is night-time, and (b) to write an explanation of how day/night happens. When the pretest answers were collected, a copy of one of the expository texts was distributed. The students were told that the day/night cycle explanation presented in the text was that of another child and that they should read it carefully in order to understand it and recall it. At the end of the reading period, one of the experimenters read the text aloud with the students to make sure that the children and particularly the third graders could decode all the words. After the text was removed and recalls were collected, the students were given a new sheet of paper and were asked to explain how it changes from day to night again, both in words and in a drawing (posttest). Testing took place in the children's classrooms. At the end of the testing period, the experimenters and teachers discussed the day/night cycle with the children and provided the scientific explanation.

Interview

Interviews were conducted on the scientific text only. The exact same scientific text, written pretest and posttest questionnaires, and instructions used in the group testing were used in the interview study. However, after the written posttest was completed, the children being interviewed were asked to further clarify their posttest explanations particularly if these were different from the scientific one and also to explicitly say whether they agreed or not with the explanation of the day/night cycle given by 'Paul' in the scientific text and why. Testing and interviews took place in a small interview room in the children's school. The children were told the scientific explanation at the end of the interview.

Scoring

Pretest and posttest explanations

Children's explanations of the day/night cycle were evaluated using criteria obtained from prior research (Vosniadou & Brewer, 1994). The scoring was based on the verbal explanations provided by the children while the information from the drawings was used to further clarify the verbal explanations, particularly with respect to the movement of the Earth. For example, the verbal statement 'the Earth turns' can be unclear as to how exactly the Earth turns. Children's drawings were used to clarify if the children meant rotation, revolution or some other kind of movement. The same procedure used to score the pretest was used to score children's posttest explanations.

Responses were marked using an ordinal scale, starting with initial responses (scored as 1) and ending with scientific responses (scored as 9). As shown in Table 2, initial were considered the responses that showed no reference to scientific information at all. For example, the explanation 'Night happens when the Sun sets behind the mountains' does not show any influence of scientific information and was considered initial. Alternative (fragmented/synthetic) were considered explanations that showed some reference to scientific information but were incorrect or incomplete. They received scores from 2 to 7 depending on their degree of closeness to the scientific explanation. Each response that moved closer to the scientific explanation and revealed an improvement from the one preceding received a higher score in the ordinal scale.

The responses 'The Sun (or Moon) revolves around the Earth' and 'Both the Earth and the Sun move' are distortions of scientific information but are considered an improvement over initial responses. The first introduces the notion of rotational movement of the solar objects and received a score of 2. The second starts to conceptualise the Earth as a moving solar object and for this reason received the score of 3. Responses such as 'The Earth turns' (4), 'The Earth revolves around the Sun (and Moon) (5)' and 'The Earth turns around itself' (6) show an understanding that the day/night cycle is caused only by the movement of the Earth and an increasing understanding of how the Earth moves and are further improvements over the preceding explanations, but they still do not provide a complete explanation of the day/night cycle. The response that received the score of 7 in the ordinal scale is an advanced synthetic model observed in previous research according to which day/night happens because the Earth turns around itself while the Sun and the Moon are stationary at opposite sides. Response 8 was considered an incomplete scientific explanation because it does not make reference to the Moon. Response 9 was considered a scientifically correct explanation because it was based on the Earth's axis rotation and explicitly mentioned that the Moon is not causally implicated in the day/night cycle.

Two experimenters created a scoring key after examining 25% of the responses in common. They then scored all the remaining responses independently. Agreement was 85%. All cases of disagreement were discussed exhaustively until completely resolved. Kendall's tau correlation analysis showed that the agreement between the judges was statistically significant ($\tau = 0.703$; $n = 79$; $p = .005$). The inter-coder measure of agreement was also statistically significant (Kappa = 0.788; $n = 79$; $p = .001$; Asymp. Std. Error: 0.045; Approx. T: 22.432).

Based on their pretest explanations, the children were placed in two prior knowledge groups: *congruent* and *incongruent*. In the scientific condition, the incongruent group consisted of the children who gave pretest explanations based on the movement and/or disappearance of the Sun/Moon (explanations 1, 2 and 3 in Table 2) while the congruent group consisted of all the remaining children who provided pretest explanations based on the movement of the Earth. In the initial text condition, the criteria for placement in the congruent and incongruent groups were reversed. The incongruent group consisted of the children with pretest explanations based on the movement of the Earth, and the congruent group consisted of the children who gave pretest explanations based on the movement and/or disappearance of the Sun/Moon.

Table 2. Frequency/percent of children placed in different explanation categories of the day/night cycle in the pretest and the posttest: group testing.

			Scientific text				Initial text			
			Third grade ($N = 21$)		Fifth grade ($N = 19$)		Third grade ($N = 19$)		Fifth grade ($N = 20$)	
			Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Initial	1	'When the Sun sets or goes behind the mountains (clouds/sea/other parts of the world) it becomes dark (then Moon & Stars come)'	19 (90%)	12 (57%)	2 (11%)		9 (47%)	11 (58%)	8 (40%)	9 (45%)
Alternative (fragmented and synthetic)	2	'The Sun (and the Moon) revolve(s) around the Earth'			1 (5%)		3 (16%)	3 (16%)	2 (10%)	1 (5%)
	3	'Both the Earth and the Sun move (and sometimes the Moon moves also)'		**7 (33%)**	1 (5%)	1 (5%)	2 (11%)	1 (5%)	1 (5%)	2 (10%)
	4	'The Earth turns (unspecified)'	1 (5%)	1 (5%)	3 (16%)	4 (21%)	1 (5%)		2 (10%)	1 (5%)
	5	'The Earth revolves around the Sun (and Moon)'			2 (11%)	2 (11%)			2 (10%)	2 (10%)
	6	'The Earth turns around itself (and around Sun and Moon)'					1 (5%)	1 (5%)	1 (5%)	1 (5%)
	7	'The Earth turns around itself and it is day on the side of the Sun and night on the side of the Moon (Sun and Moon are stationary on opposite sides)'			3 (16%)	**5 (26%)**	3 (16%)	3 (16%)	2 (10%)	2 (10%)
Incomplete scientific	8	'The Earth turns around itself and the side that is lighted by the Sun has day when the other has night'	1 (5%)	1 (5%)	7 (36%)	5 (26%)			2 (10%)	2 (10%)
Scientific	9	'The Earth turns around itself and the side that is lighted by the Sun has day when the other has night. The Moon plays no role on the day/night cycle'				**2 (11%)**				

Recall protocols

The written recalls of the children were parsed into clauses and were scored on the basis of the number of clauses recalled. Each clause was matched to the text sentences according to a gist criterion (Kendeou & van den Broek, 2005). The initial and scientific texts had the same number of clauses. The recalls were also examined for the presence of *inferences*. Inferences were considered all statements that were not explicitly mentioned in the text but could be inferred on the basis of prior knowledge. *Valid inferences* were consistent with the information presented in the text, and *invalid inferences* were inconsistent with the information presented in the text. For example, the scientific text did not state explicitly that 'when it is day here, it is night in other countries'. However, this is an inference consistent with the information included in the text, and therefore it was scored as a *valid* inference. On the contrary, the statement 'the night turns slowly on our side and it gets dark' is not included in the scientific text and is inconsistent with its meaning. It was therefore considered to be an *invalid* inference.

The valid or invalid inferences were always meaningful statements whose meaning could be analysed with respect to whether it agreed with the particular text the children read. A common invalid inference in the case of the initial text was a reversal of causality. Whereas the text says 'As the Sun gradually goes down in the sky, it gets darker and darker', some children said 'When it gets dark, then the Sun goes behind the mountains'. We checked this error to see if it was accidental, but it often happened in the case of children who had some idea that the day/night cycle happens because of the movement of the Earth and not because of the movement of the Sun. In an interesting way, this reversal in cause and effect changes the text information from being inconsistent with the scientific view into being consistent with it. We paid attention to such subtle changes in meaning because they are indicative of the way incoming information is distorted in order to agree with incongruent prior knowledge, causing misconceptions to happen.

Twenty-five per cent of the protocols were coded in common by the two experimenters and the remaining protocols were scored independently and were then compared, with an agreement of 93%. All disagreements were resolved through discussion. Kendall's tau correlation analysis showed that the agreement between the judges was statistically significant ($\tau = 0.989$; $n = 79$; $p < .001$). The inter-coder measure of agreement was also statistically significant (Kappa = 0.853; $n = 79$; $p < .001$; Asymp. Std. Error: 0.041; Approx. *T*: 33.005).

Results

Group testing

Pretest

Table 2 shows the frequency/percent of children placed in each explanation category in the two text conditions. As predicted (Hypothesis 1), the children provided mostly initial and alternative explanations. There were no scientific responses in the pretest, but there were some incomplete scientific responses. The Kruskal–Wallis non-parametric test was applied separately to test for gender differences (not significant) and group type (initial * scientific) differences (not significant). When grade (third grade * fifth grade) was used as the independent variable, the results showed the expected significant effects for grade ($x^2(1) = 16.703$; $p < .001$) in favour of the fifth-grade students.

Recall protocols

The mean clauses recalled in the two experimental conditions were subjected to a Kruskal–Wallis test with text type (initial * scientific) as the independent variable. The results showed a statistically significant main effect for text type ($x^2(1) = 4.689$; $p = .030$) in favour of the initial text (8.997) compared to the scientific text (7.631) (Table 3).

In order to test the effect of prior knowledge on text recall, we divided our sample into two groups, based on the participants' prior knowledge (congruent * incongruent). A Kruskal–Wallis test with text type (initial * scientific) as the independent variable was applied separately to each group. The results showed a statistically significant main effect for text type in favour of the initial text in the case of the incongruent group ($x^2(1) = 8.889$; $p = .003$) only. The students with incongruent prior knowledge who read the initial text recalled more information (8.944) compared to those who read the scientific text (6.432), confirming Hypothesis 2 (Figure 2). There was no significant main effect for text type in the congruent group ($x^2(1) = 0.054$; $p =$ n.s.).

A Kruskal–Wallis test with grade (third grade vs. fifth grade) as the independent variable also showed main effects for grade on text recall ($x^2(1) = 20.585$; $p < .001$) (Table 3). In order to test for a possible interaction between text type, prior knowledge and grade, a linear multiple regression analysis with grade (third * fifth), text type (initial * scientific) and prior knowledge (congruent * incongruent) as independent variables and recall score as the dependent variable was applied. The results showed a significant regression equation ($F(3,75) = 9.291$, $p < .001$) with an R^2 of 0.271. The three independent variables explained 27% of the variance and were all significant predictors of the dependent variable (text: Beta = −0.570 ($t = -3.420$; $p < .001$); prior knowledge: Beta = 0.363 ($t = 2.021$; $p = .049$); grade: Beta = 0.421 ($t = 2.295$; $p = .025$)). Prior knowledge and grade predicted the dependent variable positively, meaning that older children and the children with congruent prior knowledge recalled more information from the text. Text predicted the dependent variable negatively, meaning that the children in the scientific text condition recalled less information compared to the children in the initial text condition.

Valid and invalid inferences

All valid and invalid inferences appearing in children's recalls were categorised in the inference types shown in Table 4. A Kruskal–Wallis test with text type (initial * scientific) as the independent variable and invalid inferences as the dependent variable showed a statistically significant main effect ($x^2(1) = 5.417$; $p = .020$) in favour of the scientific text. The students who read the scientific text created more invalid inferences (mean = 0.588, SD = 0.095) compared to the students who read the initial text (mean = 0.231, SD = 0.097).

Table 3. Mean number of clauses recalled as a function of grade and text.

	Number of clauses recalled					
	Third grade		Fifth grade		Mean total	
	Mean	Std. error	Mean	Std. error	Mean	Std. error
Initial text	6.868	0.660	11.125	0.643	**8.997**	**0.461**
Scientific text	6.262	0.628	9.000	0.660	**7.631**	**0.455**
Mean total	**6.565**	**0.455**	**10.063**	**0.461**		

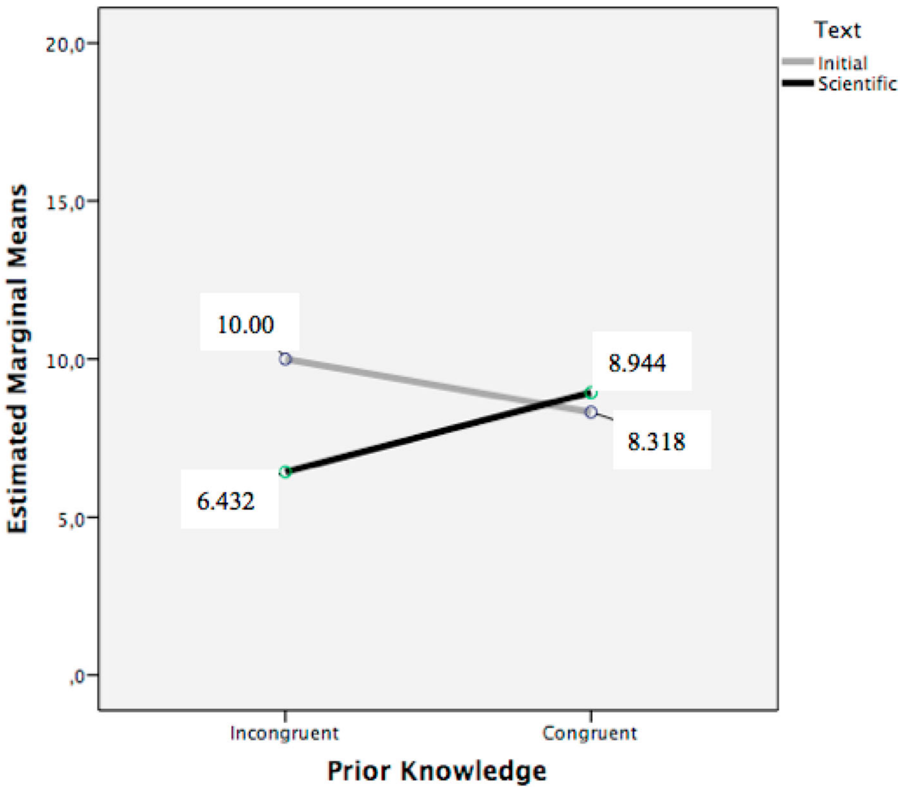


Figure 2. Mean clauses recalled as a function of text and background knowledge.

A Kruskal–Wallis test with text type (initial * scientific) as the independent variable was also applied separately to the congruent and incongruent prior knowledge groups. The results showed a main effect for text type only in the case of the incongruent prior knowledge group ($x^2(1) = 7.466$; $p = .006$). The students in the incongruent prior knowledge group created more invalid inferences in the case of the scientific text (mean = 0.955, SD = 0.128) compared to the initial text (mean = 0.235, SD = 0.145). There was no main effect of text type in the case of the congruent prior knowledge group ($x^2(1) = 0.001$; $p =$ n.s.). These results confirm Hypothesis 3.

In order to test for a possible interaction between grade, prior knowledge and text type, a multiple linear regression analysis with grade (third * fifth), text type (initial * scientific) and prior knowledge (congruent * incongruent) as independent variables and the number of invalid inferences as the dependent variable was applied. The results showed a significant regression equation ($F(3,75) = 5.576$, $p = .002$; R^2: 0.182). The independent variables explained 18% of the variance and the significant predictors were text (Beta = 0.330 ($t = 2.288$; $p = .025$)) and prior knowledge (Beta = −0.321 ($t = -2.018$; $p = .047$)). Grade was not a significant predictor. Prior knowledge predicted the dependent variable negatively, meaning that the greater the prior knowledge the fewer invalid inferences were obtained.

Most of the invalid inferences in the scientific text condition represented intrusions of initial conceptions having to do with the movement of the Sun and the Moon as the cause of the day/night cycle and resulted in distortions of the scientific text information. For

Table 4. Types of valid and invalid inferences created in children's recalls.

Scientific text	Third grade ($N = 21$)		Fifth grade ($N = 19$)	
	Congruent ($N = 2$)	Incongruent ($N = 19$)	Congruent ($N = 16$)	Incongruent ($N = 3$)
Type of valid inference				
(1) 'Earth is round like a ball'		1		
(2) 'The Sun does not move'			1	
(3) 'The Sun does not shine on the whole Earth'		1	2	
(4) 'When it is day here, it is night in other countries'	1	1	2	
(5) 'The other countries in between have afternoon'			1	
(6) 'This happens again and again'			2	
(7) 'Day and night happen in the same way'			1	
(8) 'The Moon plays no role at night or day'			2	
Total number of valid inferences	1	3	**11**	
Total number and per cent of children who created valid inferences	1 (50%)	2 (11%)	8 (50%)	
Type of invalid inference				
(1) 'The Sun goes to the other side of the Earth'		6		
(2) 'The night turns slowly on our side and it gets dark'		5		
(3) 'The Sun and the Moon play no role in the day/night cycle'		2		
(4) 'One side of the Earth is turned towards the Sun. There it is day. The other side of the Earth is turned towards the Moon. There it is night'		3	2	2
(5) Other: 'The Earth is round like a disk'		4		
Total number of invalid inferences		**20**	2	2
Total number and per cent of children who created invalid inferences		14 (74%)	2 (13%)	2 (67%)
Initial text	Third grade ($N = 19$)		Fifth grade ($N = 20$)	
	Congruent ($N = 12$)	Incongruent ($N = 7$)	Congruent ($N = 10$)	Incongruent ($N = 10$)
Type of valid inference				
(1) 'The Sun sets behind mountains or in the sea'	1			
(2) 'The Moon takes the Sun's place'		1	2	
Total number of valid inferences	1	1	2	
Total number and per cent of children who created valid inferences	1 (8%)	1 (14%)	2 (20%)	
Type of invalid inference				
(1) 'When it gets dark, then the Sun goes behind the mountains'	1	2	2	2
(2) Other: 'The Sun gets dark'	2			
Total number of invalid inferences	3	2	2	2
Total number and per cent of children who created invalid inferences	2 (17%)	2 (29%)	2 (20%)	2 (20%)

example, Chris, a third-grade child, said in his recall: 'The Sun goes to the other side of the Earth. On the side where the Sun shines, it is day. On the other side, it is night'. Mary, a fifth grader, said: 'The Earth rotates around itself. One side of the Earth is turned towards the Sun. There it is day. The other side of the Earth is turned towards the Moon. There it is night'. In contrast to the scientific text condition, there were very few invalid inferences in the initial text condition even by the children in the incongruent prior knowledge group (see Table 4). Finally, there were only a few valid inferences. They occurred mostly by the fifth-grade children who read the scientific text and were in the congruent prior knowledge group.

Pretest–posttest changes

Small gains were observed in students' performance in the posttest compared to the pretest, in the scientific text condition (Table 5). A Friedman non-parametric test showed a significant main effect for pre–posttest differences ($x^2(1) = 27.000$; $p < .001$) in the scientific text condition only.

The children who changed their explanations tended to move to a fragmented or synthetic explanation, which, however, was closer to the scientific one in the ordinal scale described earlier. Only two children changed to a scientific explanation. The qualitative analysis of the posttest explanations showed the following:

Scientific text – third graders: As shown in Table 2, 8 of the 21 children changed their explanations in the posttest. None of these children produced a scientific explanation. One of them went from an initial explanation at pretest to another initial explanation at posttest, while the remaining seven went from an initial explanation at pretest to a fragmented explanation at posttest. More specifically, all these children said at pretest that the Sun moves but changed their explanation at posttest and said that both the Sun and the Earth move, producing an internally inconsistent, fragmented response. Examples of this change can be found in Table 6.

Scientific text – fifth graders: Only 7 of the 19 fifth graders who read the scientific text changed their original responses (see Table 2). Of these children, two had an initial explanation at pretest and created either a fragmented explanation (Table 7; John's example) or a synthetic explanation at posttest. One had a fragmented explanation at pretest and went to a synthetic one at posttest. The remaining four children changed from a synthetic explanation at pretest either to a more advanced synthetic explanation (explanation 7, see Table 2) or to a scientific explanation at posttest. Same examples of these types of changes from both age groups are found in Table 7.

To summarise and conclude, most children did not change their explanations. Of those who changed, most moved to a fragmented or synthetic explanation with the exception of two fifth graders who were in the congruent group and had a synthetic model at pretest. The results support Hypothesis 4 according to which when children read a scientific text that presents new information incongruent with their prior knowledge, they will be likely to either ignore the scientific information altogether or create new misconceptions. These new misconceptions were fragmented and synthetic conceptions, similar to those obtained in developmental research. However, they were more advanced compared to the explanations the students had at pretest, in the sense that they were closer to the scientific explanation in terms of their content.

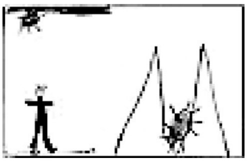
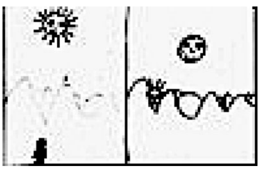
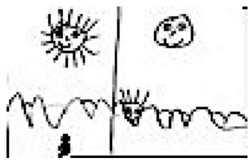
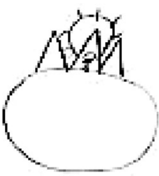
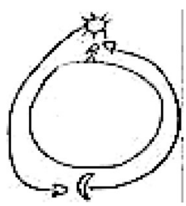
Interview study

Table 8 shows the pretest and posttest explanations provided by the third- and fifth-grade students who were interviewed. These students read the scientific text only. Only 8 (out of 20) children changed their explanations in the posttest, after reading the scientific text. With the exception of one child who changed into a scientific explanation (from a

Table 5. Mean score of student's performance in pretest and posttest as a function of text.

	Pretest		Posttest	
	Mean	Std. error	Mean	Std. error
Initial text	3.051	0.340	2.892	0.301
Scientific text	**3.225**	0.336	**4.585**	0.297

Table 6. Examples that show changes from an initial conception to a fragmented one.

Pretest	Posttest
Peter, third grade When the Sun goes behind the mountains it's getting dark and then the Moon and the stars come up on the sky	When the Earth turns around the Sun moves and goes to another country. This other country that previously had night, now has day
	
Helen, third grade The Sun goes behind the clouds and the mountains. Then it does not shine anymore and the Moon takes the Sun's place and starts to shine	The Earth is round and turns around. Then, in order to get dark the Earth turns and the Sun moves to the other side and then it changes to day
	
John, fifth grade	
	
The Sun moves and when it is night it goes behind the mountains	The Earth will turn and the Sun will go down and the Moon will come up

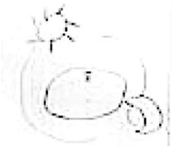
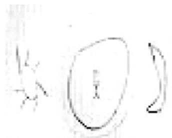
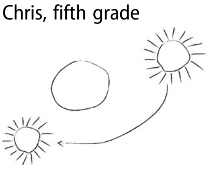
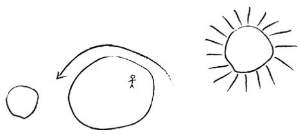
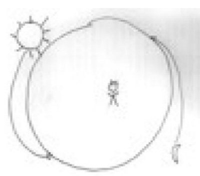
synthetic one at pretest), the remaining seven children created new, fragmented or synthetic explanations at posttest, confirming again Hypothesis 4.

In the interview, the children were asked explicitly whether they agreed with the explanation given in the text. Seven of the 20 children from both age groups (35%) seemed to be able to understand the scientific explanation but did not agree with it. Disagreements occurred in the areas where the new information conflicted with prior knowledge. One such area had to do with the belief that the movement of the Sun causes the day/night cycle. The following is an example:

E: Can you tell me what you understood from the text?

C: I understood that the Earth turns and it is not the Sun that goes up and down. The Earth turns around itself.

Table 7. Examples that show change from an initial or synthetic conception to a new synthetic one.

Pretest	Posttest
Sam, third grade	
 As time goes by the Sun goes down and the Moon comes up	 The Earth will turn around and the Moon will come
Alex, third grade	
 The Sun moves and goes behind the Earth and the Moon comes	 The Earth turns around and the child that turns with the Earth faces the Sun and then faces the Moon
Chris, fifth grade	
 The Sun moves and goes to the other side of the Earth	 The Earth turns around itself. The Sun is on one side of the Earth and it shines there. And then when it is night the little child is found on this side where the Moon is
Natalie, fifth grade	
 The Sun goes down behind the mountains and then it gets dark everywhere	 The Sun turns and goes down and then the Moon comes up

E: Do you agree with Paul's explanation?

C: A little

E: At what point do you disagree?

C: It should be the Sun that turns and not the Earth.

Another area of disagreement had to do with the belief that the Moon is causally implicated in the day/night cycle, as in the example that follows:

(The child gave a correct recall of the text)

Table 8. Frequency/per cent of children placed in different explanation categories of the day/night cycle in the pretest and the posttest: interview study.

			Scientific text: interviews			
			Third grade ($N = 10$)		Fifth grade ($N = 10$)	
			Pretest	Posttest	Pretest	Posttest
Initial	1	'When the Sun sets or goes behind the mountains (clouds/sea/other parts of the world) it becomes dark (then Moon & Stars come)'	5 (50%)	3 (30%)	4 (40%)	2 (20%)
Alternative (fragmented and synthetic)	2	'The Sun (and the Moon) revolve(s) around the Earth'	2 (20%)	1 (10%)	1 (10%)	2 (20%)
	3	'Both the Earth and the Sun move (and sometimes the Moon moves also)'	1 (10%)	2 (20%)	1 (10%)	
	4	'The Earth turns (unspecified)'	1 (10%)	2 (20%)	1 (10%)	
	5	'The Earth revolves around the Sun (and Moon)'			1 (10%)	1 (10%)
	6	'The Earth turns around itself (and around Sun and Moon)'				
	7	'The Earth turns around itself and it is day on the side of the Sun and night on the side of the Moon (Sun and Moon are stationary on opposite sides)'	1 (10%)	2 (20%)	2 (20%)	4 (40%)
Incomplete scientific	8	'The Earth turns around itself and the side that is lighted by the Sun has day when the other has night'				
Scientific	9	'The Earth turns around itself and the side that is lighted by the Sun has day when the other has night. The Moon plays no role on the day/night cycle'				1 (10%)

E: Do you agree with this explanation?

C: A little, because the Moon shines at night. So, it has something to do with the night. But Paul does not say that.

Finally, it is interesting to note that some of the children distorted the text information and then said they agreed with it.

E: Can you tell me what you understood from the text?

C: As the Earth turns, the Sun turns with it and then the Moon also moves and comes on our side.

E: Do you remember what you told me before, when I asked you how do you think it changes from day to night?

C: I said that the Sun goes down and the Moon comes up.

E: Do you agree with Paul's explanation?

C: Yes, it seems to be right.

Discussion

As was predicted (Hypothesis 1), the students who participated in the present study gave mostly initial and alternative (fragmented and synthetic) explanations of the day/night cycle at pretest. These explanations were very similar in kind and content to the explanations obtained in previous developmental and science education research (Nussbaum, 1979; Sadler, 1987; Sneider & Pulos, 1983; Vosniadou & Brewer, 1994). Also as predicted, the recall of the scientific text contained less information and generated more invalid inferences than the recall of the initial text. The separation of the students into an incongruent and a congruent prior knowledge group showed that it was the students in the incongruent compared to the congruent prior knowledge group and in the scientific text condition who recalled less information and created more invalid inferences. These were the students who gave initial or alternative explanations of the day/night at pretest that were based on the movement of the Sun and the Moon and not on the movement of the Earth. The above support Hypotheses 2 and 3 and are consistent with existing text comprehension research showing that incongruent prior knowledge results in the production of lower recall and more invalid inferences reading a science text (Diakidoy et al., 2003; Kendeou & van den Broek, 2005, 2007).

The significant grade differences showed that the third-grade children recalled less information and created more invalid inferences from the scientific text than the fifth-grade children. This finding might be interpreted to indicate that the younger children lacked the cognitive prerequisites to construct the scientific representation. The construction of the scientific representation of the day/night cycle requires taking the non-egocentric perspective of someone who is looking at the Earth from space as opposed to standing on the Earth. Although cognitive perspective taking abilities are required to form the scientific representation of the day/night cycle, the present results suggest that it was not age per se but incongruent prior knowledge that influenced students' text understanding. The students with incongruent prior knowledge in both age groups made more invalid inferences and recalled less information compared to the students in the congruent knowledge groups. This argument is also supported by the results of the regression analysis that showed that only text type and prior knowledge predicted the generation of invalid inferences and not grade. Finally, even if we assume that some children did not have the cognitive abilities to create the mental representations required by the scientific explanation, this does not explain why they produced the particular invalid inferences and posttest misconceptions obtained in the present study.

Unlike the science text, the reading of the initial text by readers with incongruent prior knowledge produced very few invalid inferences. This indicates that the children who gave explanations of the day/night cycle based on the movement of the Earth at pretest were capable of understanding correctly a text incongruent with their current beliefs. We can conclude from the above that the incongruity between prior knowledge and text information results in the creation of more invalid inferences mainly when the text presents new, scientific information. How can we explain this finding?

A possible explanation is that in the case of a scientific text, readers with incongruent prior knowledge must construct a totally new representation, which is inconsistent with their prior knowledge. Although the readers of the initial text with incongruent prior knowledge must also construct a situation model different from their current beliefs, this situation model does not need to be constructed from scratch. The initial explanation of the day/night cycle, based on the movement and disappearance of the Sun and the Moon, is consistent with phenomenal experience and lay culture and is constructed well before exposure to systematic science instruction. The present results suggest that this initial explanation continues to exist in the conceptual repertoire of the reader, and it is not difficult even for young children to retrieve it from memory and use it to create a situation model of the initial text. This explanation agrees with the results of recent research showing that initial conceptions coexist with scientific ones even after conceptual change has been achieved (Babai et al., 2010; Shtulman & Valcarcel, 2012). This is an important new finding that adds to existing research which has not so far investigated the exact nature of readers' incongruent prior knowledge and how it affects text comprehension and learning from text.

Another set of important findings of the present research centre around the nature of children's misconceptions generated after reading particularly the science text. First, we found that none of the children in the incongruent prior knowledge group who had initial explanations at pretest gave a scientific explanation at posttest. Most of these children retained their original explanations and did not change at all. Of the children who changed, they all produced fragmented or synthetic explanations. Only two children gave a scientific explanation after reading the science test, and these children were in the congruent prior knowledge group and already had a synthetic explanation at pretest. Finally, the results from the interview study indicated that many children with incongruent prior knowledge but who were somehow capable of understanding the scientific explanation, still refused to accept it because it seemed improbable to them.

The above confirm Hypothesis 4. They agree with prior research showing that it is difficult to understand and/or accept scientific information that is incongruent with one's prior knowledge and that it is likely that this information will be ignored, rejected and/or distorted (Chinn & Brewer, 1993; Legare et al., 2012; Vosniadou, 2013; Vosniadou & Brewer, 1994). However, the present results go further than existing research in a number of ways. First, all the distortions observed in children's inferences and posttest explanations are produced from constructive processes taking place during or immediately after reading a text rather than from the description of interview data or the analysis of historical examples. As such, they provide additional information about the knowledge revision process. Their examination shows that the process of knowledge revision is gradual and that when the distance between the current state of knowledge and the scientific explanation is too big (as is the case when the students start with an initial explanation at pretest), it is almost certain that the new information will be ignored or that hybrid conceptions will be generated.

The findings of the present research have implications for theories of conceptual change and science education. They support the argument that *misconceptions* is a too broad term to be useful, and that we need to distinguish particularly between *initial* conceptions formed before exposure to science and *fragmented* and *synthetic* conceptions, which are hybrids and represent amalgamations of initial conceptions and scientific information.

At the theoretical level, the results are consistent with a constructivist approach to learning and demonstrate how the use of constructive learning mechanisms can lead to distortions when the learner's prior knowledge is incongruent with scientific information. At the practical level, they suggest a change of mindset in the treatment of misconceptions, which although incorrect seem to represent intermediate steps in the process of learning science. Instead of focusing on how to replace misconceptions, which is the goal of many science education programmes, science education should provide students both with the information and the conceptual change strategies they need in order to generate the valid inferences necessary to bridge their initial conceptions with the counter-intuitive scientific explanations. With respect to the information that needs to be provided, this information must be sufficient to lead students incrementally from their assumed existing conceptions to the scientific explanation covering all the intermediate steps. With respect to conceptual change strategies, we refer to strategies such as noticing inconsistencies, examining them, suspending existing beliefs in order to understand new information, creating valid inferences, evaluating the inferential process, testing for internal consistency, etc.

The present results have some implications for text comprehension research also. They suggest that a more sophisticated approach should be taken in the treatment of misconceptions in refutation and expository text research realising their complex and constructive nature. Models of comprehension such as the Landscape Model (Van den Broek et al., 1999) and the Resonance Model (O'Brien & Myers, 1999) can be improved by taking into consideration the discrepancy between readers' prior knowledge as revealed by their misconceptions and the scientific information included in the text. With respect to writing science text, the results indicate the importance of providing links between the readers' assumed incongruent prior knowledge and the scientific information so that valid bridging inferences can be made. Justifications of the scientific explanations must also be provided so that the readers will find them believable and persuasive (see Alexander, 2001; Murphy, 2001).

Limitations and implications for further research

It could be argued that the science text used in the present study is not reader-friendly and much better texts explaining the day/night cycle could be written. This is true, although it is important to point out that the text used here is representative of the texts one finds in science textbooks. Furthermore, our purpose in the present research was not to write reader-friendly expository text but to test specific hypotheses.

It could also be argued that it is a limitation of the present study that the two texts used were both about the day/night cycle and employed only a typical expository text structure. Although it is often the case that only one kind of text is used in text comprehension studies (see, e.g. Danielson, Sinatra, & Kendeou, 2016; Jaeger & Wiley, 2015), it is important to replicate the results using additional texts from other subject matter areas of science. The advantage of our texts is that they were from a subject matter area that is well researched and understood in terms of students' difficulties making it possible to study in great detail the nature and sequence of their fragmented and synthetic conceptions. With respect to text structure, refutation texts have been found to produce better comprehension and learning outcomes than non-refutation texts (e.g. Kendeou & van den Broek, 2007; Mason & Gava, 2007; Tippett, 2010), and it is possible that if we had used a refutation test we would have found fewer invalid inferences in the recalls of the children. However, there is no reason to believe that the obtained invalid inferences would have been different from the ones observed in the present research.

The participants in the present experiment were young children who may have had particular difficulties learning new information and particularly counter-intuitive information from a text. Future research will need to replicate the results with older students and investigate other possible sources of difficulty such as children's cognitive and perspective taking abilities as well as reading comprehension.

Finally, some would argue that it was a limitation of the study that the texts were presented as the opinion of another child because this might have reduced the number of children willing to accept the scientific explanations (Lin, Horng, & Anderson, 2014). We argue on the contrary that it is an advantage that our texts were expressed as the opinion of another child because our aim was not to increase the number of children who accepted the scientific explanation but to better understand children's problems and difficulties. The lack of authority made children more likely to express their opinions and ambiguities, the understanding of which can lead us to the creation of more persuasive texts.

Despite the above limitations, the present study represents a valuable piece of research, which can happen only when there is a great deal of information about knowledge revision in a specific and narrow domain, and which contributes to our understanding of how students learn science and how they comprehend and learn from text.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Sixth Framework Programme of the European Commission (NEST, STREP Contr. 029088).

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