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Investigating the structure and the content of pupils' written explanations during science teaching sequences focused on conceptual obstacles

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Abstarct

The present paper aims at investigating the structure and the content of the written explanations produced by primary school pupils' (aged 11-12) during teaching sequences focused on the didactic elaboration of obstacles regarding temperature and heat. At first, teaching sequences targeted at the pupils' destabilising, restructuring and identifying the obstacles were designed and implemented. Next, the pupils' written explanations were analysed with respect to their structure and content. The results of the analysis indicate: (a) the differentiated levels of pupils' written explanations with regard to their structure and content, (b) the evolution of the levels concerning the structure and the content of the written explanations produced during the teaching sequences and (c) the relation between the levels concerning the structure and the content of pupils' written explanations.

Introduction

In the framework of science education, a wide range of initiatives have been directed to the design and implementation of novel didactic approaches aiming at transforming pupils' ideas and conceptions about science concepts and phenomena (e.g. Buty, Tiberghien & Le Maréchal, 2004; Komorek & Duit, 1995; Leach, 2007; Petri & Niedderer, 1998; Psillos & Kariotoglou, 1999; Scott, 2005). One of the approaches suggested, contrary to the "fragmental" elaboration of conceptions, is focused on the didactic elaboration of pupils' conceptual obstacles, which constitute the "hard core" of their conceptions (Astolfi & Peterfalvi, 1997; Peterfalvi, 2001; Plé, 1997; Skoumios & Hatzinikita, 2006). Moreover, during the last years, science education research has shown an enhanced interest about the investigation of the explanations pupils give during science instruction in the classroom (e.g., Bell & Linn, 2000; Driver, Newton, & Osborne, 2000; Kelly & Takao, 2002; McNeill & Krajcik, 2008; McNeill et al., 2006; Sandoval & Reiser, 2004). The structure of evidence-based pupils' scientific explanations constitutes an essential objective for science education (AAAS, 1993; NRC, 1996, 2000).

Despite the particular importance of the explanations produced by the pupils, there are quite a few studies investigating the structure of pupils' explanations during the teaching sequences followed in the classroom (Bell & Linn, 2000; Coleman, 1998; Herrenkohl, Palincsar, DeWater & Kawasaki, 1999; McNeill et al., 2006; Reiser, 2004; Reznitskaya & Anderson, 2002; Sandoval, 2003). The articles above refer exclusively to secondary education pupils while there is a lack of research data concerning the structure of primary school pupils' explanations. Moreover, there is an interesting debate about if the pupils' poor performance in structuring explanations is a result of their lack of general competences or it is due to their insufficient content-specific knowledge (e.g. von Aufshnaiter et al., 2008; Erduran, Osborne, Simon 2008; Hogan & Maglienti, 2001; Koslowski, 1996; Kuhn, 1991; Lawson, 2003; Sadler, 2004). Consequently, there is a necessity for further investigation into the relations between the structure and the content of the written explanations produced by the pupils in the classroom.

As far as the didactic approach focused on the elaboration of pupils' obstacles is concerned, neither the contribution of the teaching sequences to the quality of pupils' written explanations nor the relations between the structure and the content of pupils' written explanations have been investigated. The present paper analyses the structure and the content of the written explanations produced by primary school pupils (aged 11-12) during teaching sequences focused on the didactic elaboration of pupils' conceptual obstacles regarding temperature and heat. The relation between the structure and the content of pupils' written explanations is also investigated.

More specifically, the present paper aims at investigating the following research questions:

a) What are the structure and the content of pupils' written explanations during the didactic elaboration of their conceptual obstacles in the classroom?

b) What is the effect of the teaching sequences focused on the didactic elaboration of pupils' conceptual obstacles on the development of the structure and content of their written explanations?

c) What is the relation between the levels concerning the structure and the levels concerning the content of pupils' written explanations?

Theoretical Framework

Didactic elaboration of an obstacle

During the last decade, the approach followed in science education has given much focus on the didactic elaboration of pupils' obstacles rather than on their conceptions. "The obstacles may be described as structures and resistant modes of thinking, which often form their own systems and occur in diverse instances in every scientific learning object" (Astolfi & Peterfalvi, 1997, p. 193). The concept of obstacle is closely related to conceptions; however, they differentiate between them mainly because whereas the former constitute the "hard core" of the latter, the recurrence of conceptions, their resistance as well as their change and refutation are explained (Astolfi & Peterfalvi, 1997; Peterfalvi, 2001; Plé, 1997). In other words, conceptions constitute the manifestations of an obstacle rather than the obstacle itself.

Within the framework above, the didactic elaboration of students' obstacles has been produced including three phases: obstacle "destabilisation", "conceptual reconstruction" of obstacles and obstacle "identification" (Astolfi & Peterfalvi, 1997). The phase of obstacle "destabilisation" aims at the emergence of pupils' conceptions and the realisation of the disagreements between them. The phase of the "conceptual reconstruction" of obstacles aims at the construction of new conceptions, which will at least be as practical as the previous conceptions, regarding the way they are handled. Finally, the phase of obstacle "identification" aims at developing the pupils' competence to identify the manifestations of obstacles so that they are able to overcome them in case they are faced with those obstacles again.

Important aspects of the teaching strategy followed during the elaboration of obstacles included the discussion among the pupils, the written presentation of pupils' views and the encouragement the pupils were offered to justify their views -by using elements of their everyday experiences or previously elaborated teaching situations-, the "devolution" of problems from the teacher to the pupils and pupils' personal engagement, as well as the pupils' designing, conducting and assessing science investigations.

Various studies have investigated the efficiency of teaching sequences in the elaboration of pupils' obstacles and the conceptual change achievement in both the changes of matter (Astolfi & Peterfalvi 1993, 1997; Peterfalvi, 2001; Plé 1997) and the concepts of temperature and heat (Skoumios & Hatzinikita, 2002; 2004; 2006; 2007). The didactic elaboration of obstacles in school pupils was feasible and efficient.

Explanations in school science teaching

Explanations refer to how or why a phenomenon occurs (Chin & Brown, 2000). Within the framework of the classroom the quality of an explanation is described by its structure and content (McNeill et al., 2006; Lizotte, Krajcik & Marx, 2006; Sandoval & Millwood, 2005). The structure of an explanation refers to its components. According to McNeill, Lizotte, Krajcik and Marx (2006), a scientific explanation includes three components regarding its structure: claims, evidence and reasoning. The claim makes an assertion or reaches a conclusion addressing the original question or problem about a phenomenon. The evidence supports pupils' claims with the use of scientific data. The reasoning relates the claim to the evidence and shows why the data counts as evidence supporting the claim. As far as the content of an explanation is concerned, it is related to the accuracy or the adequacy of the explanation's components, when the latter are evaluated from a scientific point of view.

The pupils often have difficulty in articulating and defending their claims (Jiménez-Aleixandre, Rodríguez & Duschl, 2000; Sadler, 2004). More specifically, the pupils have difficulty in both providing sufficient evidence supporting their claims and using reasoning arguments relating to the evidence of their claims (Kuhn, 1993; McNeill & Krajcik, 2006; Sandoval & Reiser, 1997). Many studies have involved the implementation of a particular treatment and the evaluation of its impact on promoting pupils' structure of explanations (e.g. Bell & Linn, 2000; Kenyon & Reiser, 2006; McNeill & Krajcik, 2006; Sandoval & Reiser, 2004).

The present paper aims to add to the existing knowledge since it is focused on the structure of primary school pupils' explanations created "without effort" in the classroom during the didactic elaboration of pupils' obstacles.

Method

Overview of the study design and participants

The research was conducted in three stages. The first stage involved designing teaching sequences on the elaboration of pupils' obstacles regarding temperature and heat. The second stage was a 23-hour intervention incorporating the teaching sequences implemented in the last grade of primary school in Greece and, in particular, in a school class consisting of 17 pupils 11-12 years old. The pupils were divided into four groups. Before proceeding to the teaching sequences of the program, special permission was obtained from the school principal and the teacher of the class. The pupils involved as well as their parents were provided with detailed information about the nature, the purposes, the content, the experimental activities, the expected duration, the procedures used and the evaluation of the teaching sequences in order to give their consent. In the third stage the pupils' written explanations were analysed with regard to their structure and content.

The pupils' obstacles regarding heat-temperature as well as the teaching sequences aiming at the elaboration of those obstacles were presented in previous research publications (Skoumios, 2005; Skoumios & Hatzinikita, 2004; 2006; 2007). More specifically, five obstacles supporting the conceptions primary school pupils had about thermal phenomena were discerned. For each of the above obstacles an intended learning objective was proposed representing the conceptual progress aimed by teaching (Table 1).

Table 1. Pupils' obstacles regarding temperature and heat and intended learning objectives

Obstacles	Learning objectives
Obstacle 1: The temperature of an object depends on certain characteristics of the object.	Objective 1: The temperature an object reaches at when it is in a specific environment for a long period of time depends on the temperature of its environment.
Obstacle 2: The sense of hot or cold depends only on the temperature of the object.	Objective 2: The temperature can be measured only by thermometers. The sense of hot is connected with temperature and the different rate each object is transferring the heat.
Obstacle 3: The heat (considered as a qualitative measure) is the same as the temperature.	Objective 3: The amount of heat depends on the temperature, the mass and the composition of the object.
Obstacle 4: Cold is different from heat.	Objective 4: Cold is the lack of heat
Obstacle 5: The cause of heat transfer is related to the object.	Objective 5: The cause of heat transfer is the temperature difference among objects.

The teaching sequences consist of five units (A, B, C, D and E). Every unit is mainly focused on dealing with an obstacle. The didactic elaboration of each of the five obstacles detected with respect to temperature and heat followed the next phases:

Phase 1: Destabilisation of the Obstacle

At first, the pupils elaborated a problem in order to reveal their conceptions. Although divided in groups, the pupils worked individually and gave their answers IN writing. They were also asked to justify their answers.

Then the pupils discussed in groups aiming to realise their disagreements. The representatives of the various groups classified their peers' answers and announced them in front of the whole class. Then, and under the coordination of the teacher, the pupils discussed and formulated the problems to be investigated.

Phase 2: Reconstruction of the Obstacle

In order to answer the problems they had formulated the groups of pupils designed and conducted research with the help of suitable questions included in their worksheets. Next, they designed and set up experiments collecting the materials needed. Then they performed those experiments, collected the data they elaborated and finally reached the conclusions they were asked to justify. With the help of suitable questions, they compared the experimental results with their initial predictions. Throughout and after the end of the experiments they discussed their predictions and the experimental results.

Then the pupils worked in groups elaborating problems different from those previously negotiated (implementation in new situations). Finally, they were asked to justify their answers and discuss them within their groups.

Phase 3: Identification of the Obstacle by the Pupils

The pupils were asked to record their answers to questions previously elaborated in the framework of problems posed in the early stages of obstacle elaboration. Then they compared their initial answers –previously written in their worksheets– with their current answers and were encouraged to discuss within their group any similarities or differences between their answers and ideas.

The pupils were presented with pictures, charts and shapes including an "underlying" obstacle or an intended objective. They were asked to choose and justify which of them better resembled their initial mode of thinking, before the teaching sequences. They were also asked to describe the way they speculated on the above in order to match the pictures with their mode of thinking. Finally, the pupils discussed their answers within their groups.

The pupils were asked to properly complete two sentences that could better express their conceptions before and after the teaching sequences. Moreover, they were invited to describe their former mode of thinking in order to complete the sentences. Although the pupils were initially divided into groups, they later worked individually and recorded their conceptions, which they finally discussed within their groups.

The pupils formulated questions with an underlying obstacle; the ultimate purpose was to lure their fellow pupils into the "trap" of the obstacle. In the following step, they were encouraged to frame questions and pose them to their peers of the group. Finally, they discussed their answers within their group.

With a view to further clarifying the obstacle, the pupils elaborated on problems involving more than one obstacle. They initially worked individually and recorded their conceptions before discussing them within their groups.

Then, the pupils were asked to participate in activities involving the designing of the "lessons" elaborating the obstacles in order to "teach" another class in their school. They were also asked to propose problems and experimental activities that could help their "pupils" overcome the difficulties they had also been faced with. The pupils initially worked individually and then discussed within their groups the difficulties they had faced in understanding the previous teaching sequence on the temperature of objects. Finally, the whole class discussed under the coordination of the teacher.

In this paper the pupils' worksheets were used as data sources. The Appendix presents three representative problems included in pupils' worksheets. These problems pose questions asking the pupils to formulate claims and justify them. A total of 1105 pupils' explanations were collected and analysed during twenty-three teaching hours.

Assessing the structure of explanations

The assessment of the structure of pupils' written explanations is based on the analysis of the written answers they proposed during the lessons. According to the framework for structuring an explanation (claims, evidence, and reasoning) introduced by McNeill et al. (2006) with regard to the needs of the present paper, the pupils' explanations may be classified into three categories.

The first category comprises pupils' explanations including one or more claims in the direction of either the obstacles or the intended objectives (Level 1). The following examples of pupils' answers[1] comprise sentences including only claims and are therefore classified in *Level 1*.

"The temperature of metal objects is lower than the temperature of the room".

"The blanket warms the objects".

"Cold goes from the ice cube to the water".

The second category comprises pupils' explanations including claims and evidence supporting the claims (Level 2). The following examples of pupils' answers include a claim (first answer: "the iron rod will have a temperature lower than the wooden rod"). This claim is accompanied by evidence supporting the claim (first answer: "because we feel the iron rod is colder"). These answers are structured as "claim and evidence" answers and are therefore classified in *Level 2*.

"The iron rod will have a temperature lower than the wooden rod. Because we feel that the iron rod is colder".

"The cakes will have different temperatures because they are of different sizes".

"Since our hand is hotter than the glass, heat will be transferred from our hand to the glass with the cold water".

The third category comprises pupils' explanations including claims, evidence and reasoning relating those claims to the evidence (Level 3). The following answers are representative and include two sentences. The first includes a claim ("they will have the same temperature") accompanied by evidence supporting this claim ("because they are in the same room"). The second sentence of this answer ("the objects in the same environment acquire the temperature of their environment") provides reasoning relating the claim above to the evidence. This answer is classified in Level 3. Likewise, the two other answers, as long as they include claims, evidence and reasoning, are classified in *Level 3*.

"They will have the same temperature because they are in the same room. The objects in the same environment acquire the temperature of their environment".

"The water will be heated because it takes heat from the air. When the temperature of the air is higher than the temperature of the water, heat is transferred from the air to the water".

"They reach different temperatures since there is less water in container B. When they acquire the same heat, the water of less mass reaches a higher temperature".

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[1] Neither grammatical nor syntactic mistakes were corrected in pupils' answers.

Assessing the content of explanations

With regard to their content pupils' explanations were classified in three categories depending on whether they are obstacle-directed or intended learning objective-directed or they connect elements of the obstacles with elements of the intended learning objectives.

The first category includes explanations related to the conceptual obstacles pupils have (Level I). The following examples of pupils' answers indicate that the pupils consider that the temperature of an object left in an environment of constant temperature for a long period of time depends exclusively on certain characteristics of the object rather than on the temperature of its environment (obstacle 1) and, as a result, they are classified in Level I.

"The baking pan will be hotter than the cake because it's made of iron".

"Cold goes from the ice cube to the water".

"They will have different temperatures because the first one is bigger than the second".

The second category comprises pupils' explanations including elements of both the obstacles and the intended learning objectives in the school knowledge (Level II). The following pupils' answers are classified in Level II. For example, the first answer suggests that the pupils combine elements of both their initial conception of the obstacle 1 (the temperature of an object depends on its material) and the conception to be constructed (dependence of objects' temperature on the environmental temperature).

"Its temperature will be almost equal to the temperature of the room, although a little lower because it is made of metal".

"All things in a fridge are close to the temperature of the fridge but they never reach its actual temperature".

"The iron rod seems colder than the wooden one since it is cold from inside because of the material it is made from. We cannot have the same feeling about them because they are made from different material".

The third category comprises pupils' explanations concerning the learning objectives that represent the mental progress the teaching sequences are focused on (Level III). The following answers suggest that the pupils think that the temperature of an object left in an environment of constant temperature for a long period of time depends on (i.e. it is equal to) the temperature of the environment (learning objective of obstacle 1).

"This means that both cakes will have again the same temperature because they both are in the fridge".

"They will have the same temperature because they are in the same room. The objects in the same environment acquire the temperature of their environment".

"All things inside the same room acquire the temperature of the room".

Assessing the development of the structure and the content of explanations – Relating the structure and the content of explanations

The x^2 test investigated the extent to which there is a statistically significant relation between: (a) the levels of pupils' written explanations and the teaching units (A, B, C, D and E) and (b) the levels of pupils' written explanations with respect to their structure (1, 2, 3) and the levels of pupils' explanations with respect to their content (I, II, III). The relation is detected and interpreted according to the size of both chi-square and standardized residuals (Blalock, 1987; Erickson & Nosanchuk, 1985).

Results

The structure of pupils' explanations

According to their structure, pupils' written explanations were classified into three categories (Levels 1, 2, 3, see section "Assessing the structure of explanations"). In particular, Table 2 shows the distribution of pupils' written explanations by level regarding all written explanations analysed (a total of 1105 explanations). It seems that the majority of pupils' written explanations belong to Level 1 (54.2%). In other words, more than half of pupils' explanations include exclusively claims. A considerable percentage of pupils' written explanations belong to Level 2 (31.1%). These answers include claims and evidence supporting the claims. Finally, there seems to be a low percentage of written explanations classified in Level 3 (14.7%), which is the level of explanations including, apart from claims and evidence, reasoning arguments relating these claims to the evidence.

Table 2. Distribution of the structure of pupils' written explanations by level

Level 1		Level 2		Level 3	
N	N%	N	N%	N	N%
599	54.2	344	31.1	162	14.7

The content of pupils' explanations

With respect to their content, the pupils' written explanations were classified in three levels (Levels I, II, III, see section "Assessing the content of explanations"). Table 3 shows the distribution of pupils' written explanations (a total of 1105 explanations) regarding their content by level. Most of the pupils' written explanations belong to Level III (61.6%). Consequently, more than half of pupils' explanations are learning objective-directed. The percentage of pupils' written explanations classified in Level I (obstacle-directed) is also high (34.5%). Finally, there is a remarkably low percentage of pupils' written explanations classified in Level II (3.9%), including elements of both the learning objectives and the obstacles.

Table 3. Distribution of the content of pupils' written explanations by level

Level I		Level II		Level III	
N	N%	N	N%	N	N%
381	34.5	43	3.9	681	61.6

Development of the structure of pupils' explanations

The development of pupils' written explanations with respect to their structure was mapped by analysing them throughout all five teaching units. Table 4 outlines how the levels of pupils' written explanations are distributed among the five teaching units (A, B, C, D, E) included in the teaching sequences.

Table 4 shows that unit A is dominated by the answers classified in Level 1 (63%), while few answers are classified in Level 3 (5.9%). The next two teaching units (B, C) present reduced percentages of answers classified in Level 1 (57.9% and 59% respectively) and increased percentages of answers classified in Level 3 (9.2% and 8.8% respectively). However, the last two teaching units (D and E) present further reduced percentages of answers classified in Level 1, while the percentages of answers classified in Level 3 are further increased (20.4% and 22.9% respectively).

In addition, there was a statistically important relation between levels 1, 2 and 3 of pupils' written explanations and teaching units A, B, C, D and E concerning the elaboration of pupils' obstacles ($x^2 = 45.83$, df = 8, $p<0.001$). This relation could be attributed to the following pupils' tendencies (see Table 4):

Table 4. Frequency of the explanatory structure levels (1, 2, 3) used by the pupils in the teaching units (A, B, C, D, E) and the corresponding standardized residuals[2]

	Level 1	Level 2	Level 3
Unit A	97 [2.38] +	47 [0.01] +	9 [8.04] —
Unit B	69 [0.31] +	39 [0.10] +	11 [2.38] —
Unit C	182 [1.57] +	97 [0.03] +	27 [7.11] —
Unit D	111 [0.65] +	65 [0.21] +	45 [4.90] +
Unit E	140 [4.04] —	96 [0.01] +	70 [14.09] +

Level 1 explanations (including exclusively claims) tend to appear at the beginning of the teaching program (unit A) rather than in the final teaching unit (unit E).

Level 3 explanations (including claims, evidence and reasoning) tend to appear in the last teaching units (units D and E) rather than in the previous units of the teaching program (units A, B and C)

In other words, pupils' explanations tend to move from Level 1 to Level 3 during the lessons (from teaching unit A to unit E).

Development of the content of pupils' explanations

The development of pupils' written explanations with respect to their content was mapped by analysing them throughout all five teaching units; the analysis resulted in classifying them into three levels (I, II, III). Table 5 shows the way the levels of pupils'

2 Table 4 shows the following values: a) the observed values, b) the standardized residuals (in brackets), c) a sign indicating whether the observed value is higher (+) or lower (—) than the expected value.

written explanations are distributed among the five teaching units (A, B, C, D, E) included in the teaching sequences according to their content.

Table 5. Frequency of the explanatory content levels (I, II, III) used by the pupils in the teaching units (A, B, C, D, E) and the corresponding standardized residuals

	Level I	Level II	Level III
Unit A	88 [23.55] +	13 [8.34] +	52 [18.97] —
Unit B	79 [35.14] +	10 [6.22] +	30 [25.61] —
Unit C	91 [1.99] —	9 [0.71] —	206 [1.61] +
Unit D	57 [4.84] —	5 [1.51] —	159 [3.82] +
Unit E	66 [14.79] —	6 [2.93] —	234 [10.94] +

Table 5 shows that there are only a few of the pupils' explanations classified in Level II, with respect to their content, while most of them are classified in levels I and III. In addition, the percentage of pupils' explanations classified in Level I is reduced and the percentage of pupils' explanations classified in Level III is increased while the teaching sequences are in progress.

Moreover, there was a statistically significant relation between levels I, II, III of pupils' written explanations, with respect to their content, and teaching units A, B, C, D and E concerning the elaboration of pupils' obstacles (x^2=160.96, df = 8, p<0.0001). This relation may be attributed to the following pupils' tendencies (see Table 5):

Level I explanations (obstacle-directed) tend to appear at the beginning of the teaching program (units A, B) rather than in the last teaching units (units D, E).

Level III explanations (learning objective-directed) tend to appear in the last teaching units (units D, E) rather than in the first units of the teaching program (units A, B)

Relation between the levels of explanation structure and the levels of explanation content

Table 6 shows the way the levels of pupils' written explanations are distributed with respect to their structure (levels 1, 2, 3) and their content (levels I, II, III). The classification of pupils' written explanations in levels according to their structure and content reveals more information about the relation between the levels concerning the structure and the content of written explanations.

Table 6. Frequency of the explanatory structure levels (I, II, III) and content levels (1, 2, 3) used by the pupils in the teaching units and the corresponding standardized residuals

	Level I	Level II	Level III
Level 1	254 [10.91] +	24 [0.02] +	321 [6.28] —
Level 2	97 [3.94] —	13 [0.01] —	234 [2.28] +
Level 3	30 [11.97] —	6 [0.01] —	126 [6.28] +

Table 6 shows that the explanations including only claims (Level 1) are either in the learning objective-directed (53.6%) or obstacle-directed (42.4%). However, most of the explanations including claims and evidence (Level 2) are learning objective-directed (68%), while there are remarkably fewer obstacle-directed explanations (28.2%). As far as the explanations including claims, evidence and reasoning (Level 3) is concerned, there is a further increased percentage of learning objective-directed obstacles (77.8%).

In addition, there is a statistically significant relation between levels I, II, III of pupils' content-directed written explanations and levels 1, 2, 3 of structure-directed written explanations ($x^2 = 42.28$, df = 4, $p<0.0001$). This relation could be attributed to the following pupils' tendencies (see Table 6):

Level I explanations (obstacle-directed) tend to be classified in Level 1 (including exclusively claims) rather than in levels 2 (including claims and evidence) and 3 (including claims, evidence and reasoning)

Level III explanations (intended learning objective-directed) tend to be classified in levels 2 (including claims and evidence) and 3 (including claims, evidence and reasoning) rather than in Level 1 (explanations including exclusively claims).

Conclusions and discussion

Our analysis has shown that the teaching sequences focused on the elaboration of pupils' obstacles regarding temperature and heat have a positive effect on the structure and the content of pupils' written explanations. More specifically, the investigation presented in this paper has studied the levels of pupils' written explanations throughout a teaching sequences program, the development of the structure and the content of their written explanations during the teaching sequences, as well as the relation between the structure and the content of pupils' written explanations.

As regards the structure of pupils' written explanations, this study has shown that most of the pupils' answers are classified in Level 1, in which the pupils posed only claims, without accompanying evidence or reasoning. This confirms previous research findings showing that pupils' claims are not necessarily connected with evidence (Kuhn, 1993; McNeill & Krajcik, 2006; Sandoval & Reiser, 1997). Moreover, several pupils' answers are classified in Level 2, in which the pupils record only claims, without accompanying them with evidence or reasoning. However, there are significantly fewer pupils' explanations classified in Level 3, in which they expressed claims, evidence and reasoning relating these claims to the evidence.

As far as the content of pupils' written explanations is concerned, it emerged that most of them are classified in Level III, i.e. the pupils develop learning objective-directed conceptions. This finding suggests the efficiency of the teaching sequences. However, a considerable number of pupils' explanations are classified in Level I, in which the pupils develop obstacle-directed conceptions. This finding confirms previous research, which has shown that the pupils' obstacles are highly resistant to conceptual changes (Arca & Caravita 1993; Astolfi & Peterfalvi, 1997; Bednarz & Garnier, 1989; Gauld, 1989; Giordan & De Vecchi 1987; Goix, 1996; Monchamp, 1993; Peterfalvi, 2001; Peterfalvi, 1997; Skoumios & Hatzinikita, 2005; 2006; 2007). There are considerably few pupils' explanations classified in Level II expressing conceptions based on elements of both the obstacles and the intended learning objectives.

The teaching sequences focused on the didactic elaboration of pupils' obstacles regarding temperature and heat seem to have a noticeable effect on upgrading the level of the structure and content of pupils' written explanations. In particular, there is a relation between the levels (1, 2, 3) of pupils' written explanations with respect to their structure and teaching units (A, B, C, D and E) as well as between the levels of pupils' written explanations with respect to their content (I, II, III) and teaching units. Although no special technique helping the pupils in structuring their explanations was followed, the pupils improved the level of their written explanations as regards both their structure and their content.

The relation between the levels of pupils' written explanations with respect to structure and content and teaching units could be attributed to reasons connected with the teaching strategy followed and the teaching situations used. In particular, the learning environment enabling the pupils to express and safely elaborate their conceptions created the necessary conditions for discussion among them. The discussion within each group during every teaching situation, while the pupils were trying to support their claims and persuade their peers about the correctness of their reasoning, did help the pupils to structure high-level explanations. The development of scientific investigation abilities (formulating a question to be investigated, controlling variables, designing experiments, collecting and processing data, reaching conclusions) through the teaching sequences contributed to the development of the pupils' ability to structure explanations. Moreover, the teaching situations asking the pupils to compare their initial with their current conceptions and reconsider their mode of thinking, which led them to wrong answers, presented the pupils with the need to use data and reasoning more frequently. In addition, the teacher made a significant contribution to the development of the pupils' ability to structure explanations, since he systematically encouraged the pupils to record answers (claims) and justify them by using supporting data and reasoning relating these claims to the data.

The present paper also investigated the relation between the pupils' ability to structure explanations and scientific understanding. It was realised that there is a relation between the levels concerning the structure and the levels concerning the content of written explanations produced in the classroom during the didactic elaboration of pupils' obstacles regarding the concepts of temperature and heat. The pupils that structured explanations including claims, evidence and reasoning tended to activate intended learning objective-directed conceptions. On the other hand, the pupils that confined themselves to producing claims tended to express obstacle-directed conceptions. However, there were pupils that produced explanations including claims, evidence and reasoning, although they activated obstacle-directed conceptions. The relation that emerged between the structure and the content of pupils' written explanations suggests that when the pupils are engaged in classroom instruction, with explanation being an explicit goal, they increase their understanding of the content. The above view is in accordance with research findings helping the pupils in structuring explanations through teaching sequences (Bell & Linn 2000; McNeill & Krajcik 2006; Zohar & Nemet 2002).

It is encouraging that through the implemented teaching sequences even relatively young children (aged 11-12) were able to produce explanations including claims, evidence and reasoning, regarding their structure, while they were in the direction of the intended learning objectives regarding their content. However, further research is needed aiming at the investigation of the contribution of teaching sequences - focused on the elaboration of pupils' obstacles- to the structure and content of pupils' written explanations. As regards the structure of explanations, the availability of data supporting the claims as well as the extent to which this data is appropriate and sufficient could also be investigated. It is important to investigate the contribution of the phases of both the didactic elaboration of obstacles and the separate teaching situations to the process of pupils' structuring explanations. The knowledge produced by an investigation of this type could lead to the production of improved teaching material aiming at the development of pupils' ability to produce written explanations, including evidence and reasoning, at the effective elaboration of obstacles and at the structuring of conceptions in science as well.

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Appendix

Indicative problems included in pupils' worksheets

Indicative problem about the destabilisation of the obstacle "the temperature of an object depends on certain characteristics of the object"

Anne's mother bought a cake. She cut a small slice of the cake and put both cakes in iron pans and baked them in a slightly heated oven for two hours.

Will the cakes and the iron pans have the same or different temperature?

Can you justify your answer?

Discuss your answer with the peers of your group.

After the discussion with your peers do you still have the same idea?

Can you explain why you have the same or a different idea?

Indicative problem about the reconstruction of the obstacle "the sense of hot or cold depends only on the temperature of the object"

What are you going to investigate?

What is your idea?

Why do you have this idea?

Discuss your answer with your peers.

What are you going to do in order to investigate it?

What will I measure?	What will I keep the same	What will I change?

What materials will you need?

What is the experiment you propose?

Discuss your ideas with your peers.

What are you planning to do?

What have you found?

What did you realise after the research you did?

Is what you realised what you expected? Why?

What was difficult for you in this investigation? Why?

Indicative problem about the identification of the obstacle "the sense of hot or cold depends only on the temperature of the object"

A pupil of the sixth grade was in the yard of his school at the midday of a sunny day. He was asked about the temperatures of the iron rails of the enclosure and the wooden fences of the school garden. The answer was: "if we touch them, we will realise that iron objects are hotter than wooden ones. As a result, iron objects have a higher temperature than wooden ones".

Do you agree with the answer above?

Can you justify your answer?

Can you explain the way your fellow is thinking about the temperature of objects?

Discuss your answers with the peers in your group.

After the discussion with your peers, do you still have the same idea?

Can you explain why do you have the same or a different idea?