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Introducing talk and writing for conceptual change: a classroom study

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Abstract

As a naturalistic inquiry, this study has investigated in the learning environment of a class of fourth-graders the introduction of talk and writing to stimulate and sustain conceptual change in a science domain. During the implementation of ecological curriculum units, talk for learning characterised small- and large-group discussions about a knowledge object, while writing to learn took place individually at different times with different aims. The data provide evidence that reasoning and arguing collaboratively on different beliefs and ideas, as well as individual writing to express, clarify, reflect and reason on, and communicate own conceptions and explanations are fruitful tools in the knowledge revision process. The learners advanced conceptually, although not all at the same level of scientific understanding, and developed or refined metaconceptual awareness in reflecting on the development of their knowledge. Moreover, the data show the students' perception and evaluation of different functions and instructional aims of both activities, talk and writing for learning, which they valued while making sense of the new science concepts.

Keywords: Conceptual change; Peer group discussion; Social interaction; Writing for learning; Science education

1. Introduction

This descriptive study is part of a wider research project on classroom educational contexts that facilitate and sustain conceptual change in science domains (Mason, 1998; Mason & Boscolo, 2000). A class of an elementary school was involved to understand science concepts in fourth and fifth grades. The learning classroom

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environment was characterised as a community of discourse and learning (Brown, Ash, Rutherford, Nakagawa, Gordon, & Campione, 1993; Brown & Campione, 1990, 1994). In this paper only the processes of understanding ecological concepts in the fourth grade are introduced (see Mason, 1998, for results in the fifth grade).

For about three decades research on learning and instruction has shown that individuals construct personal knowledge systems on the basis of their everyday experience with the world and other people. School-age children's conceptions of the natural and physical world have been widely documented. This knowledge is often in stark contrast to the scientific knowledge taught in schools. Therefore, classroom meaningful learning does not require only the mere enlargement of information but rather the reorganisation of existing conceptions, that is conceptual change (Carey, 1985; West & Pines, 1985), which causes a massive rearrangement in an individual's cognitive structures. It has also been documented that students' personal conceptions are very resistant to change despite a great deal of instruction aimed at teaching the scientific perspective.

The study, focusing on the educational context in which conceptual change is desired to occur, deals in particular with talk and writing in the natural learning environment of a classroom to promote knowledge revision. Recent issues of research on the role of talk and writing in understanding will now be considered.

2. Collaborative oral discourse and conceptual understanding

In the social constructivist perspective, referred to in Vygotsky's work (1978), thinking processes and knowledge growth are seen as the result of personal interactions in social contexts and of appropriation of socially constructed knowledge (Moll & Greenberg, 1990; Resnick, Levine, & Teasley, 1991; Wertsch, 1985). Recently, the cognitive potential of collaborative work in school, that is the possibility to promote and support higher-level thinking and reasoning processes by social cognitive interaction, has been acknowledged. A classroom always consists of many students and the potential of "multivoicedness" to increase understanding and learning is there.

In a Vygotskian frame of reference, the basic assumption is that reasoning in children is mainly manifested in the externalised form of reasoning and arguing with someone else. In this regard, the collaborative work that can take place in classroom group discussions on specific knowledge objects, aimed at motivating inquiry and transforming the results into knowledge, has been investigated (e.g. Mason, 1996a; Meyer & Woodruff, 1995; Pontecorvo, 1987, 1990, 1993).

The typical discourse in a traditional didactical intervention is what Mehan (1979) called the initiation, response, evaluation (IRE) structure of recitation. The teacher initiates a question, the student makes a response, and then the teacher usually evaluates it. In such a context knowledge is something clearly fixed beforehand, and authority resides in teachers and textbooks. Students have very little experience (if any) of effectively practicing the language of science knowledge construction because they are not required to provide evidence to support assertions, ask questions, reflect, reason, and talk about their conceptions with others. On the other hand, teachers dominate classroom dialogue mainly to transmit information and require students to use oral discourse only to show acquired knowledge.

Alternatively, peer discussions can be collaborative learning contexts in which students are motivated to consider new or conflicting information they have previously disregarded as they begin to value their peers' viewpoints (Dole & Sinatra, 1998). The collaborative reasoning and arguing that may develop through argumentation processes can act as a kind of cultural apprenticeship to scientific ways of knowing, ideas and discursive practices of the scientific community (Driver, Asoko, Leach, Mortimer, & Scott, 1994, 1995).

Pontecorvo (1987, 1990, 1993) has pointed out that classroom discussion participants activate argumentative operations through which they carry out epistemic operations, that is, cognitive procedures which characterise the language of the domain, in our case science knowledge construction. In doing so, they can reach more advanced levels of understanding about the examined knowledge object (Mason, 1996b; Mason & Santi, 1998).

Analytic frameworks have been developed by researchers interested in the examination of the quality of talk in peer group discussion within different learning domains (e.g. Chinn & Anderson, 1998; Keefer, Zeits, & Resnick, 2000; Kumpulainen & Mutanen, 1999; Mercer, 1994, 1996; Pontecorvo & Girardet, 1993). These frameworks have contributed toward increasing our understanding of the various modes of talk and social thinking in peer group contexts.

The specific mechanisms underlying the effectiveness of social interaction in a discussion among peers are not yet completely clear. As Vosniadou (1994b) has underlined, collaborative learning is difficult to study because many factors are involved which may affect the quality of peer interaction. According to Larreamendy-Joerns and Chi (1994), the effectiveness of social interaction in enhancing science learning can be attributed to the fact that a collaborative learning context encourages the production of self-explanations about information which is unavailable, and yet required, to completely understand the concept to be learned. If a student gives a verbal explanation of a phenomenon, she or he can be required to give reasons supporting it and if it happens to be wrong after a critical examination, more advanced information can be constructed with peers to give a more satisfactory account of the examined situation.

A complementary point of view on the effectiveness of social interaction refers to the fact that, by assuring the confrontation of different ideas, a collaborative learning context can create and foster metacognitive awareness of one's own conceptions, considered as objects of cognition (Kuhn, 1993). By confronting different ideas and being criticised by others, students can check their plausibility and question their own knowledge systems (Kobayashi, 1994; Mason & Santi, 1998). Metaconceptual awareness of own representations through which to interpret and make predictions about the world has been acknowledged as essential in conceptual change (Hennessey, 1993; Mason, 1994a,b; Vosniadou, 1994a, in this volume). It is in fact the fundamental condition to experience the need for knowledge revision while trying to integrate new information into pre-existing conceptual structures.

3. Writing and conceptual understanding

To promote and support knowledge construction and reconstruction processes writing can be used in the classroom as well. In a traditional science class the main function of writing is to test whether students have acquired the knowledge delivered to them. Therefore, "students in this situation tend to write what they think the teacher wants them to write" (Peasley, Rosaen, & Roth, 1993, p. 10). Writing is not valued as a learning tool to construct new understanding but rather as a way to display the taught knowledge or, at best, only as a recording tool (Boscolo, 1995). When writing is required to show or record knowledge, the product is mainly considered, that is, the right answer (definition, explanation, formula, etc.). In contrast, when writing is used to learn, the emphasis is on the process activated while writing.

Several researchers have begun to focus on writing as a tool for thinking and domain content learning. Their seminal studies have pointed out that writing can be successfully applied to promote students' learning in different curriculum domains (e.g. Applebee, 1984; Emig, 1977; Langer, 1986; Langer & Applebee, 1987). Recent studies have shown that writing can act as a powerful learning tool across knowledge domains and subject areas at different educational levels (Tynjälä, Mason, & Lonka, in press). For example, Mason and Boscolo (2000) found that writing as a tool to express, reason and reflect on, and communicate beliefs and ideas facilitated fifth-graders in their understanding of the target concept of photosynthesis and metaconceptual awareness of the changes occurred in their conceptual structures as well as their conceptualisation of the writing activity itself. Moreover, Boscolo and Mason (in press) investigated whether writing as a learning tool could be used by students first for understanding in history and then for understanding in science by transferring a disposition toward writing as a meaningful activity in knowledge construction. The findings provided evidence that writing can be effectively introduced across the curriculum to support higher-order thinking processes to produce understanding. The experimental group students were able to transfer the attitude, which characterized their writing activity in history to the domain of science, reaching a deeper conceptual understanding in both disciplines, as well as more advanced metaconceptual awareness of their learning.

Hand, Prain, and Yore (in press) examined the effects on students' learning of science when they engaged with different single and sequential writing tasks. The findings showed that students who wrote to explain their ideas performed better on subsequent tests than students who undertook only the usual writing tasks (note taking, concept maps, summaries, review sheets). In addition, the students who undertook a sequence of two connected writing tasks also performed better on higher-order questions than students who did not undertake such tasks.

Tynjälä (1998) investigated the role of writing as a learning tool in a university study within a constructivist learning environment from the point of view of the students' learning experience. She found that the students who used writing described their own learning not only in terms of accumulation of information but also in terms of development of their thinking and communication skills.

Different aspects of writing as a form of learning have been particularly valued in science education (see reviews in Hand et al., in press, and in Mason, 1998). It has also been pointed out how writing can play an essential role in the process of meaningful learning when the new technology is used in school to effectively promote understanding about complex curriculum material. One of the basic characteristics of CSILE (Computer-Supported Intentional Learning Environments), designed to reframe and sustain classroom discourse in knowledge-building communities, regards students' writing activity as a means to give their contributions to a knowledge base in some curriculum areas. Through writing they communicate and think critically about ideas and conceptions in order to collectively produce and advance shared theories (Scardamalia & Bereiter, 1994).

4. Talking, writing, and conceptual change in the classroom

Most recent research issues concerning meaningful learning of science concepts in the classroom, which very often requires conceptual change, lead to state that a learning environment should encourage students' verbal explanations and their questioning, criticising, evaluating, and also writing to support thinking, knowledge construction, and communication about learning with other members of a learning community. Both oral and written texts are to be treated as thinking devices by teachers and students. As shown by Dysthe (1996), interrelating talking and writing provides more chances for students to learn than does talking or writing alone. In such an environment students are more likely to become intentional learners (Bereiter, 1990; Bereiter & Scardamalia, 1989) as they are stimulated to be aware of their ideas and have control over their own learning. In other words, they are metacognitively engaged at a high level in inquiring classrooms (Dole & Sinatra, 1998) where they can ask: What do I think? Am I aware of what I believe? Why do I think what I think? What are the differences between my ideas and those of others? What would it take to convince me about that point of view? Is it possible to reconcile the two points of view? Have I been able to integrate the new idea with the old one?

4.1. Objectives of the study

The qualitative study reported below is a naturalistic inquiry, in an authentic classroom environment, on the introduction of talk and writing to promote knowledge revision within a science learning community. The four major foci and objectives of the present study were to see:

- whether for the first time students could engage in collaborative discourse-reasoning about a knowledge object which could act as a facilitator in building more progressed knowledge on the new topic (interpsychological plane);

- whether for the first time students could use writing for different aims, that is as a means to express, reason on, monitor, and communicate their conceptions and developing understanding (intrapsychological plane);
- whether there were changes identifiable in learners' individual conceptual structures (intrapsychological plane) as a result of the learning activities that attributed crucial importance to oral and written discourse;
- how learners considered the role of talk and writing in constructing scientific knowledge, that is, their perception of the meaning and instructional purposes of the two activities which could shape their developing scientific conceptions.

5. Method

5.1. Participants

A whole class in a public elementary school in the Padova area (Northern Italy), made up of only 12 fourth-graders (ranging in age from 9 years and 3 months to 10 years and 1 month), was involved in the implementation of four ecological curriculum units (as already stated, the same class was also involved the following school year, see Mason, 1998). They shared a homogeneous middle-class social background. Half were girls and half boys. The classroom teacher in this study was an experienced teacher aware of the importance of social context to motivate and support students' construction of knowledge. She was used to giving the students the opportunity to talk to communicate their ideas during instruction but she had never systematically used collaborative discourse-reasoning on a knowledge object as a pedagogical strategy to facilitate and sustain learning. Neither had written discourse ever been used to promote learning in the science class. Sharing the theoretical bases and planning the educational intervention with the researcher (the author), the teacher created an interactive learning environment in which the oral and written discourse in the service of learning was greatly valued. The researcher fitted in with the educational setting in each session devoted to the curriculum units (a couple of hours once or twice a week for three and a half months). She interviewed the students at the beginning and at the end of the units and made observation notes during classroom activities.

5.2. Subject-matter

The subject-matter was the process of decay and the cycling of matter (at fourth-graders' level). In order to lead the students toward the scientific perspective on decay entailing knowledge on the role of decomposers in returning matter into the environment, among them micro-organisms, specific units were previously devoted to the concepts listed below.

Living organisms (What are their defining characteristics? How can they be grouped?).

Moulds (What are they? Where do they come from? Where do they grow better? Are they living things? Are they useful?).
Yeasts (What are they? When do we use them? Why? Why do grapes turn to wine? Are they living things? Are they useful?).
Bacteria (What are they? What makes milk go sour? Are bacteria useful? Are there bacteria in our body?).

A scientifically correct explanation of the decay process and of the concept of matter cycling would require the application of knowledge on the role of decomposing micro-organisms.

5.3. Educational context

The educational intervention was designed to elicit students' alternative conceptions and their developing understanding about the examined phenomena and to provide opportunities for class and group discussions as well as for individual writing in the service of learning before, during and/or after specific activities, such as planning and commenting experiments, hands-on activities, problem-solving, laboratory practice (use of a microscope), out-of-school educational visits (milk production centre). Discussions took place in large (the whole class) and in small groups of children. Writing was carried out individually at some moments of the unit implementations. For example, in the curriculum unit on moulds, the students:

wrote their own ideas on food moulding;
discussed to share their common initial knowledge on the familiar phenomenon;
formulated hypotheses on where mould came from and planned the first experiment;
carried out the experiment and observed what happened each day;
discussed the results of the experiment and planned other ones;
wrote about their developing new understanding;
discussed about what was happening in the new experiments;
discussed whether mould was a living thing;
wrote what they understood on mould as their final ideas.

Often, written student texts were used as discourse initiators in a group discussion, giving more students a chance to participate and introduce a wide diversity of conceptions.

After providing opportunities for the discussions of students' ideas and explanations of the examined phenomena, at the end of each unit the teacher prepared cards to synthesise the crucial information on the new concepts.

5.4. Data source and analysis

The data were students' individual pre- and post-instructional interviews, group discussions, and individually written productions during the science activities. A triangulation of data gathered from what the students said while interviewed, their discussions with their mates, and their written production was carried out to give more reliability to the data themselves. Each session was audiorecorded. All 26 discussions were totally transcribed as were the initial and final individual interviews. In the pre-instructional interview the participants were asked questions about the target concept of decay. In addition to the same questions on this topic in the final interview, the participants were asked about their thinking on the role of talking and writing in the science classes, that is, their perception of the meaning and purposes of the two activities. Interviews and collected individual written productions were analysed by two independent readers to evaluate whether there was evidence of change over time in the students' statements about the target concept of decay. The agreement between the readers was maximum for 10 of the 12 cases. Disagreement on the other two cases was very low and resolved after discussion in the presence of the author.

A qualitative analysis of the collected data was carried out to analyse: (a) the collaborative discourse-reasoning developed in the various group discussions in which the personal conceptions on the examined phenomena were expressed, evaluated, and criticised; (b) the written production to explore if the students actually used writing to express, communicate, and reflect on their developing understanding; (c) the changes in their own conceptual structures; and (d) how they perceived and evaluated talking and writing to learn science concepts in the classroom.

6. Results

6.1. Prior knowledge on decay

The pre-instructional interview allowed the researcher to ascertain how the students represented the process of decay and the ultimate fate of decayed matter. The interview started by showing them a photograph of a rotting apple on the ground under an apple tree and asking them: "What do you notice about the apple?"; "What do you think is making this happen?"; "Do you think that anything might happen to the other apples, left on the ground?"; "If nobody touches these apples after a whole year, what might happen?"; "Where might the 'stuff' that the apple is made of go to?"; "It is good, bad or the same for the soil, the rotting of the apple?"; "Supposing we could collect together everything from that apple—I know that it is not possible, but supposing we could (all the bits that were eaten and all the bits that rotted)—do you think we would have the same amount of apple?" (Leach, Driver, Scott, & Wood-Robinson, 1992). Before introducing what emerged from the collected data, I will very briefly refer to the findings of the previous studies on students' (aged from 5 to 16) ideas about decay carried out by Leach et al. (1992; see also Driver, Leach, Scott, & Wood-Robinson, 1994). These authors found that a number of younger children showed a certain degree of unfamiliarity with the phenomenon of decay. For the remainder rotting was perceived as "rotting away", that is, for example, a dead organism rots and does not leave material product. In the upper primary and lower secondary school students typically maintained that rotting things give fertility to the soil, not mentioning air or gases in their explanations of the processes involving living things. Only a minority of the older students held the idea of conservation of matter in decay, appreciating the role of decomposers in returning matter into the environment. The authors highlighted that the conservation of matter applied to living systems appears to be appreciated much later than for non-living systems.

In the present study some of the already found alternative conceptions were identified at the beginning of the educational intervention. The following were the different ideas about the ultimate fate of an apple on the ground expressed by the students.

1. *No conservation of matter*: Three students held no idea of conservation of matter during decay as they maintained that the stuff the apple was made of disappeared.
2. *Eaten by animals (visible small organisms)*: One student stated that all the apple would be eaten by ants.
3. *Partial conservation of matter*: Five participants, while stating that there would be less matter as a result of decay, also stated that some matter would go into the soil, indicating they held an intuitive idea of partial conservation of matter. A typical response to the question was: “The apple stuff’ll go into smaller and smaller pieces till all the stuff disappears, disintegrated in the soil. Only the seeds remain and then they can sprout and a tree comes out.”
4. *Partial recycling*: Three students stated specifically that the apple juices would give nutriment to the soil during decay, indicating they held an idea of partial recycling of matter. In the most advanced initial representations, regardless of the causal agents, the ultimate fate of an apple on the ground was “to be converted into soil, become like soil, part of the soil”, mentioned by two of these three students who consistently maintained that the rotting was a benefit for the soil which became fertile, “like humus”. None of the children mentioned that matter would go into the atmosphere as a result of the decay process.

The following were the different causations of decay expressed by the participants who mentioned one or more factors involved in an apple rotting.

1. *Physical causation*: Seven students referred to physical factors such as air, sun, heat, and rain as agents of decay: “The sun makes the apple ripen too much and then also the water, the rain in the soil, makes the apple rot.”
2. *Natural feature of apple*: Six students conceived decay only in terms of no more food for the apple on the ground from the tree: “It isn’t on the tree branch anymore so it isn’t fed anymore and so it rots.”
3. *Eaten by animals (visible organisms)*: Six students explained decay by referring to the action of birds or small soil animals such as earthworms, bugs, and ants that eat fruits on the ground: “The earthworms’ve eaten half the apple and they’ll eat in time also what has remained till now.”
4. *“Attacked” by microbes*: One student maintained that microbes eat apples: “There are microbes that eat the apple, that is, invisible microbes attack, hit it, then it

starts to lose pieces of its stuff. First the pieces are large, then smaller and smaller and they go in the soil."

Five students mentioned only one of these factors in giving their explanations of decay; another six expressed two factors, and one expressed three factors.

It is noteworthy that the class had been involved in the previous school year along with higher graders in growing organic vegetables in a vegetable garden in the field near the school. They took part in the preparation of a compost heap as a natural useful addition to the soil instead of chemicals. The children participated practically in it in the sense that they helped older schoolmates bring to the school organic waste from their kitchen and gardens, but no scientific concepts underlying the practical activity were dealt with. The only child who initially mentioned the action of microbes said that he had heard about invisible organisms from other schoolmates while working in the organic vegetable garden. However, his representation of the process included only a partial idea of conservation of matter and not the idea of cycling of matter.

To the question of whether we would have the same amount of apple by collecting everything from a decayed apple—supposing it was possible to do this—nine students responded affirmatively. Of the remainder, two denied the possibility because there were too many small pieces to be collected or that the juice was lost in the soil. The third said that "some stuff is combined with the soil".

In analysing the explanations of decay given by the students it is worth taking into account the complexity of the scientific explanation for this process which refers to the action of micro-organisms and the effect of physical factors on this action in addition to autolysis (the breakdown of structural material in an organism by its own enzymes) and the effects of physical factors on autolysis. Leach and colleagues (Leach et al., 1992; Driver, Leach et al., 1994) have pointed out that a development of more advanced explanations of decay requires students to consider that living material behaves by the same laws as other material substances and to establish connections with a wider set of other relevant knowledge. In particular, they have to take into account the action of no visible living things, i.e. micro-organisms, such as fungi and bacteria as decomposing organisms.

6.1.1. Prior knowledge on mould

Before implementing the curriculum unit on fungi, aimed at leading to conceptualise them as decomposers, the children expressed orally and in writing their own conceptions on mould. Almost all the students defined mould as "a kind of white and green foam that appears on things that we eat". For seven children the mould came from inside the food item. Of these seven, three stated that it came from outside ("Special substances in the air that collect on a piece of bread, for example") and two stated that their position combined both ideas: "There are little animals in the air, like a kind of substances, that are attracted by the substances inside the cheese". Moreover, eight students maintained that mould was not a living thing for several reasons, such as: "It doesn't eat"; "It doesn't grow"; "It doesn't reproduce"; "It doesn't move by itself"; "It doesn't do anything". The other four students held the opposite idea, attributing life to mould for the opposite reasons.

6.1.2. Prior knowledge on bacteria

The curriculum unit on bacteria also aimed to lead the children to conceptualise bacteria as decomposers. Initially, two students defined bacteria as "A kind of insect", another two as "Invisible particles", and the remaining three as "Special things that cause diseases" or "Living things that are very dangerous for us". Of the 12 participants, five stated that bacteria were in our body as well as in the air, as recognised by all the others, "especially in dirty places". Moreover, nine students attributed life to bacteria, maintaining that "They carry on activities such as bringing a disease"; "They eat in our tummy what we eat"; "They eat what's in our cells"; "They eat sugar". Another two students said that they were not living "because we can't see nor hear them" and one student stated that she could not express an idea on this point since "although when scientists see bacteria under a microscope they move around, I don't know whether bacteria move autonomously or are moved by some mechanism". None of the participants initially related moulds or bacteria to the decay phenomenon. They were more likely to have knowledge about bacteria in the context of disease than in the context of decay and recycling. The only student who had mentioned microbes in explaining the rotting of an apple when asked about bacteria did not refer any of their actions to decay.

6.2. Social construction of knowledge: collaborative oral discourse-reasoning

The learners were involved in discussions at different moments of the curriculum unit implementations aiming at: (a) expressing and comparing prior knowledge on a specific phenomenon or situation to create a common ground for the collaborative construction of knowledge; (b) formulating and comparing hypotheses before performing an experiment; (c) examining empirical data in the light of previous predictions; and (d) making a shared synthesis to propose a final explanation for an examined phenomenon. They discussed sometimes divided in two or three groups, sometimes all together. Here two sequences of discussions[1] are reported to give examples of the ways in which the students could engage highly in reasoning and arguing collaboratively to accomplish different goals in the process of constructing shared knowledge.

The first extract is taken from a small-group initial discussion on what happens to a rotting apple on the ground under an apple tree. The learners started by sharing the idea that decay was a natural feature of an apple that is no longer on the tree.

[1] The numbers in parentheses refer to the statements uttered in the classroom in the same order as they were made. The children's sentences were translated trying to keep the same "style" as in the original Italian version. Grammar and style errors were not corrected unless prejudicial to understanding.

(1) Alessio: My idea's that the apple rots when it doesn't have food anymore. When the apple's on the tree food goes to it but not on the ground.
(2) Maria: You're talking about sap.
(3) Alessio: Yes, its food. When it's fallen down it doesn't have food so it rots and dies.
(4) Giampiero: I agree, my idea's the same because when it falls is like if it died.
(5) Nicola: Yes, only when it's on the tree it receives food to stay alive and on the ground it rots.
(6) Maria: Also for me this idea's right because only when it's on a tree, not on the ground, it can absorb the nutriment it needs. Perhaps it can also become a substance that's good for plants.
(7) Alessio: Let's sum up: The apple on a tree grows and grows and then when it's ripe it falls down and it loses the food that the tree gave it to grow, so it dries up as we do when we don't have anything to feed on.
(8) Maria: Practically it dies.
(9) Alessio: More exactly it rots.
(10) Maria: But what rots?
(11) Alessio: There are cells inside the apple and they rot, they die because of lack of food.
(12) Giampiero: Where does the apple get to in the end?
(13) Alessio: By rotting it disintegrates, so to speak.
(14) Maria: We can say that it's decaying material.
(15) Alessio: Only a question: In what way does the apple rot? We have to explain this. How does it rot?

The extract shows how the students agree on the same initial idea of decay. From the argumentative point of view that idea was easily justified and the justification refined. In giving reasons to support the idea, the learners appealed to their prior knowledge on how an apple on the tree gets food. In this initial phase the discourse-reasoning sequence was characterised by co-construction. The question raised by Alessio is interesting: he perceived that they were not talking about the rotting mechanism and asked for an explanation which opened the way for them to explicit, compare, and critically evaluate different conceptions. This kind of question expresses a metacognitive reflection on the need to account for a phenomenon in order to interpret it in more complete terms.

The next transcription excerpt is taken from a small-group discussion on mould as a living thing. After performing an experiment to understand if mould came from inside a piece of food or from outside and other experiments to understand where it grew better, they reasoned and argued on the fact that mould could be a living thing possessing all the features attributed to it. The learners easily recognised that mould grew and reproduced but arguments developed on how it could feed. On the one hand, there were the children, like Maria, who believed that mould fed on the food on which it dropped, and, on the other hand, the children who strongly denied this fact by saying that mould only deposited on the surface of food taking nothing from it.

(6) Maria: I think it's living because it grows. The first dots were little, let's say, there were not a lot, or very big, then they began getting bigger.
(7) Erica: But there's a little problem: how does mould feed?
(8) Maria: I think it feeds on the things it drops on.
(9) Katia: Yes, I think so too.
(10) Maria: Let's say that it drops on a carrot, it eats the carrot.
(11) Erica: Do you think then that if we take away the mould then we'll see something that there isn't anymore, the carrot doesn't exist anymore, do you think?
(12) Alessio: Okay, if we leave the carrot there, you think that in a year's time it won't exist anymore.
(13) Erica: If we take all the mould away then it disappears just like that? There's more and more mould on the carrot, but only on the outside.
(14) Maria: The carrot gets smaller and the mould gets bigger.
(15) Erica: But no, only on the outside. Inside there's always the carrot.
(16) Maria: That's not true at all.
(17) Erica: Try and cut it, you'll see. Later we'll get the jars from the other room.
(18) Alessio: What Maria says is wrong; the wall doesn't disappear when there's mould on it.
(19) Marco: Very true!!!
(20) Maria: Sure, the mould gets bigger and the carrot gets smaller. That's for sure.
(21) Marco: Yes! What about the wall, then?
(22) Maria: That's got nothing to do with it, we aren't talking about the mould on the wall, but mould on food.
(23) Erica: But do you think that if you leave the carrot there for a long time, at the end there's a heap of mould?
(24) Maria: Of course. It also gets inside the carrot, not only on the outside.
(25) Alessio: Lucia' s brought the cheese with mould on it. It'd been there a long time, but the cheese hadn't got any smaller.
(26) Maria: But the mould got bigger.
(27) Erica: Listen. I give you an example: You've got some cheese, you leave it in the fridge and, say, some air gets into it, you know sometimes some mould goes on it. But when you cut it, the second slice hasn't got any mould on it.
(28) Maria: Who says?
(29) Erica: But I've never seen any mould after the first slice.
(30) Maria: But if you leave it there for a long time . . .
(31) Katia: But only by looking you can understand.
(32) Maria: It doesn't reproduce, it doesn't grow, it doesn't eat, does it?
(33) Marco: The carrot may disappear, but not because of the mould.
(34) Alessio: But the carrot inside the jar, the mould on it's the same, it doesn't get any bigger.
(35) Katia: Good grief!! Can't you see it's getting bigger? The dots used to be very tiny.
(36) Alessio: Yes. Earlier they'd got bigger, but now the mould's always the same.
(37) Maria: I don't agree at all.

(38) Katia: Me neither.
(39) Alessio: Well, perhaps I'm changing my mind. Wait a minute.

The extract shows that from the argumentative point of view the supporters of each position tried to justify it giving evidence. The development of arguments through claims, oppositions, justifications and counteroppositions required the participants to activate crucial cognitive procedures by continuously appealing to experience, facts, specific prior knowledge, hypothetical counterevidence. The learners who understood that mould reproduced on the food, feeding on the food itself, mainly appealed logically to the fact that a living being should feed to grow and reproduce, and empirically to the fact the mould damages the food on which it grows. The opposers doubted the feeding function by appealing to their experience that mould did not entirely decompose a piece of food and so they hypothesised that it could be fed on something in the air. When the discussion ended not all the group members shared the same idea. They will need further debate to come to a new advanced knowledge product.

6.3. *Writing to learn: individual written discourse*

Initially, the students, who for the first time used writing as a tool for learning science, were told that they should not worry about the "goodness" of an idea, spelling, grammar, etc., in writing, as this activity was aimed at other goals. The different ways to use writing in the science class, that is, to explicit an explanation, to communicate developing understanding or puzzling things, to reason and reflect on ideas were illustrated on a topic which was far from the ones faced.

The learners hesitated a little over writing down material in science class with aims different from the ordinary ones, but after a few moments they began to use writing in the service of learning to explicit, reflect on, and communicate ideas and beliefs. Examples of individual writing are introduced to illustrate how the students used this activity with different aims.

6.3.1. *Expression of personal ideas on a topic*

The students actively explored their own prior knowledge especially in writing for prediction explanations. The first example is Alessio's expression of his intuitive knowledge on mould at the beginning of the curriculum unit. His idea that mould grows better in a cold place is interesting as it is based only on his personal experience of material growing mould in a refrigerator, although he knew that it is used to preserve foods for a longer time.

> Mould is a green substance that comes from food. It appears in this way: vitamins and other things inside after a certain period of time "become big" and go out from the food and so mould originates. It is not something living because it does not feed and reproduce. You can see it in the refrigerator because it is cold and cold damages food.

6.3.2. Communication of what has been temporarily understood or what puzzles

After talking with others on their written ideas, the learners recorded the results of their developing understanding which were then used as a basis for the next group discussion. In communicating their progress while explaining the examined events, they often also managed to use writing to point out what they still could not make sense of in their effort to integrate new ideas into their knowledge structures. In doing so they expressed metacognitive awareness of their thinking processes. The following examples concern expressions of developing ideas on yeasts written by Giampiero and on mould by Maria.

> Now my new idea is that yeasts are living things and that without sugar they cannot "grow". I have understood this point through the experiment and the discussion. However, not everything is clear yet. I still do not know how yeast is born and also how it dies. I have to understand this.

> I have doubts on the fact that mould on food can be compared to a disease because I do know that mould comes from spores in the air which land on the food, that is from the outside like a disease which comes from a microbe getting into our body, but a disease can come also from our inside. I am struggling with this stuff.

6.3.3. Recording of any changes of ideas

The learners were able to reflect metaconceptually on their experience of changing ideas as a basis for writing about the newly constructed ones. The next example is Andrea's communication about his own knowledge revision on mould.

> I have to say that now I believe that mould is a living being because I have really understood that it's born, feeds, reproduces, and dies like every living being. Before the discussions I was wholly convinced that it was not living since I thought that it was transported by air, not by itself, and that it did not eat anything. Now I have understood that it is born because at the beginning we saw a very small spot of mould on the carrot and then it grew and in such a way it reproduced. It feeds on the food on which it lands; in fact if we touch the mould on the carrot or the bread, under them there is nothing. It dies when there is no more food.

6.3.4. Giving final explanations of a phenomenon

Writing in the final explanation sessions showed the learners' ability to use observations, new ideas developed in group discussions, and written material prepared by the teacher to synthesise crucial points. The next example reports a product written at the end of the entire work by Valentina.

> The apple left on the ground decays thanks to the decomposers of the fungi and bacteria kingdoms. It goes into the soil and it is transformed into mineral salts

that help the apple tree produce more apples, this is the cycle. If there were not the "planet sweepers" we would be buried by layers of organic waste because the apples would be one on top of the other and our planet would be covered by too many things. Decomposers like yeasts and bacteria eat fructose, for example, and release carbon dioxide in the air. This is why a piece of fruit bubbles when it rots. This is good for the soil because it becomes fertile. In fact when an apple decays it becomes mineral salts that feed the tree. At school, last year, preparing the compost heap we did the same for our organic vegetable garden without poisons but with natural things.

6.4. *Evidence of conceptual change*

First, it should be pointed out that because of the very small sample size it is difficult to generalise results beyond this particular context and the tasks used. Only the data concerning the final explanations of the ultimate goal, the decay phenomenon, given by the students are introduced here to show the conceptual progress they made in the particular learning context mainly characterised by the role attributed to the oral and written discourse for understanding. This phenomenon was the target concept of the part of the curriculum on decomposers. In order to understand decay at a more advanced scientific level the students had to change their initial conceptions about rotting and apply the new concept of micro-organisms as living things which act as decomposers, i.e. microscopic fungi and bacteria, in explaining the target phenomenon by establishing connections within a wide set of relevant knowledge. The attribution of life to fungi and bacteria can be interpreted in Chi's terms (Chi, 1992; Chi, Slotta, & de Leeuw, 1994) as a change across parallel categories, "non-living" and "living", within the ontological category of "matter", in particular the subcategory "natural kind". According to Vosniadou's (1994a) view, such a change requires the change of a specific theory, micro-organisms are living things, determined by a change of the framework theory that leads one to think that invisible things can also be living and have an active role in specific processes.

By triangulating the data from the oral statements in the final discussions on the topic, the written productions, and the individual interviews, it was possible to identify the students' conceptual change on decay. All 12 learners progressed with regard to their initial representations of the phenomenon, although at different levels. Initially, none of the participants held the idea that the stuff the apple was made of disappeared. Moreover, none of the participants referred any longer only to a natural feature of the apple, nor did they point to a single reason, either physical causation or the action of visible organisms, such as animals, in explaining decay.

6.4.1. *Some recognition of the role of micro-organisms*

One student progressed in learning the different agents involved in the decay process. In the pre-instructional interview he maintained that the apple in the picture would be eaten by ants in the soil. At the end of the work, in the written production and in the final interview he mentioned more agents involved in the process of decay, among them micro-organisms such as germs that eat the apple and the sun as rotting accelerating agent. However, he did not elaborate on an explanation of the phenomenon by referring to the different roles of the agents involved in the process.

6.4.2. Partial conservation of matter and recycling (partial understanding)

Five students showed a substantially correct but not articulated and complete understanding of the phenomenon. They gave a more advanced explanation of the decay process by mentioning and relating all the agents implied, in particular the action of micro-organisms, but only a partial idea of conservation and recycling of matter was integrated into their conceptual structures. At this level they did not mention that matter would go into the atmosphere as a result of the decay process.

6.4.3. Conservation and recycling (complete understanding)

Six students showed a complete understanding of the target phenomenon, in so far as fourth-graders can construct it. They possessed an integrated knowledge structure that led them to a correct conceptualisation of the conservation and cycling of matter in decay. They specifically mentioned the change of organic matter into minerals, which fertilise the soil, and carbon dioxide, which is used by plants.

To the transfer question about the ultimate fate of a little dead bird on a field, 10 children responded that it would be the same fate as the apple, mentioning all the agents involved in the process of its decomposition, but only the six students who reached the complete understanding of decay referred to the production of minerals and carbon dioxide as the result of the action of micro-organisms.

To the question about the likelihood of getting the same amount of apple by hypothetically collecting together everything from the decayed apple, 10 students responded negatively. Among them, five motivated their answer by appealing to the fact that carbon dioxide, for example, went into the atmosphere and might be used up by plants. The remainder denied the possibility by only maintaining that some stuff is always lost in some way.

In the final interview all the learners referred to the change of ideas experienced while learning the new science contents that they might have already stated in their written production. They showed metaconceptual awareness in reflecting on the development of their knowledge. In all the cases the students expressed at least one of the specific ideas they had changed and several of them also gave the reasons behind their own initial and final conceptions. For example, Nicola commented on his experience of successful revision of the previous conception on decay by stating:

> I believed that an apple was eaten, but by animals such as earthworms and ants. I didn't know about micro-organisms, that are sweepers, because I could see only the visible ones and I didn't think of other things being invisible. Now I understand that the apple's eaten also by microbes and bacteria, I mean it's transformed, and that at the end the stuff from the apple gives nourishment to the soil, it fertilises the soil.

6.5. *Perception and evaluation of talk and writing in the science class*

This descriptive study also aimed at evaluating how talk and writing produced in the science classes were perceived and experienced by the children involved in the learning community. In the final individual interview none of the students expressed negative evaluations on talk and writing in relation to learning and all were able to point out one or more specific aspects that made them recognise the value of discussing and writing to learn, in particular what distinguishes them and makes them complementary. A richer final individual interview would also be carried out at the end of the fifth grade, the second year of the class involvement in the research (see Mason, 1998), leading the students to point out and value more or less all the same meaning and instructional purposes of talk and writing to learn.

The kinds of reflections on the different aspects concerning the value of the two activities are introduced separately, giving examples only for the writing activity the children had used for the first time in the service of science learning.

6.5.1. *Talk*

All 12 participants maintained that through discussion they learned better and more: “You feel that an idea has really entered your mind, your brain”. In particular, they specified one or more of the following six different aspects of collaborative discourse-reasoning that make it a powerful tool in supporting meaningful science learning.

6.5.1.1. (a) Expression of own ideas. Three students recognised the fact that in the discussions they could freely express their own ideas without feeling the anxiety of being negatively evaluated.

6.5.1.2. (b) Procedural value. Three students maintained that the discussion procedure was useful as it started by talking about several ideas but then only a few passed critical examination. These were better than the initial ones, and then again the best of them could be developed and accepted as the most appropriate.

6.5.1.3. (c) Appealing to the logic of scientific discourse. Three students maintained that in order to sustain a put-forward claim a discussion participant had to continuously reflect on what she or he was saying by taking into account the need to coordinate theory and evidence.

6.5.1.4. (d) Scaffolding. Two students focused on the motivational and cognitive scaffolding exerted by the group who made reasoning and learning easier, and led to the collaborative construction of a new conception.

6.5.1.5. (e) Changing ideas. Five students pointed out that during a discussion it is possible to change an idea that has been recognised as incorrect after criticism by the others.

It is noteworthy that the second, third and fifth reasons refer to the metaconceptual dimension that is supposed to be created or refined in a discussion on a knowledge object.

6.5.2. *Writing*

With regard to the perception of the writing activity, first it should be stated that almost all of the children pointed out that writing without worrying about making mistakes was useful to freely communicate own ideas at different times of the curriculum unit implementation. They also underlined that writing in science classes was different from other forms of writing, for example those more typical in Italian classworks. For example, Katia said: "The Italian teacher wants us to write for a different reason, to see the mistakes we make and correct them. Here I've understood that the teacher and you [the researcher-interviewer] want to see if I write, for example, that mould is a living thing rather than making sure that I spell the word correctly." Moreover, each child highlighted one or more of the following valuable aspects of writing which was seen as a different tool from discussing for knowledge construction.

6.5.2.1. (a) Clarification to oneself of own ideas. Two students maintained that the writing activity allowed them to clarify to themselves their own ideas while writing what they were thinking. The next example is Alice's expression:

> When you write you can make your own ideas clearer to yourself because writing them is more difficult, you have to think about them and by writing they become clearer.

6.5.2.2. (b) Reasoning on ideas. Four students expressed that writing was a tool to carry on a reasoning process of thinking and struggling with concepts, in particular after a group discussion. The next example is Andrea's reflection:

> Generally after a discussion the teacher asked us to write down what we had discussed. In order to write about the discussion we had to reason on the ideas, to discuss them again by ourselves, that is, we along with ourselves.

6.5.2.3. (c) Awareness of what has been understood. Six students pointed out that writing was a way to reflect on the learning process and be aware of own newly developed understanding. The next example is Giampiero's reflection:

> If you write after a discussion in which you've heard many ideas, you really understand what you've understood. For example, in a discussion I'd said that yeast made a cake mixture inflate even without sugar but the others made me understand that only in the presence of sugar yeast works. In writing my final explanation I realised what I'd understood.

6.5.2.4. (d) Better remembering. Five students focused on the fact that when you have written something you remember it better. In case you do not remember something it is always possible to go back to what you have written. The next example comes from Michele's interview:

> By writing you keep more things in your mind and if you don't remember you can read all you've already written on that topic and so something comes back to your mind.

6.5.2.5. (e) Awareness of changing ideas: what and how. Seven students mentioned that in the writing activity they were able to report their experience of changing prior conceptions in understanding the new concepts and also to recognise the knowledge route which led them to the new conceptual understanding. The next example is Alessio's expression:

> Writing's useful to reflect on the difference between an idea and another, between what you think and reality, so you can see from beginning to end what ideas have been changed and why you've changed them . . . The work done on fungi took us more than one month, a long time to understand, really understand. On the way, when writing the different ideas I was developing I understood the difference between them and the initial ones. If the teacher one day came and said "Now we're going to study mould. You have to learn that mould is a living thing, feeds, reproduces, comes from spores in the air . . ." and so on, you could know these things but you couldn't see your reasoning, how your ideas would change from beginning to end.

All but one of the value aspects underlined by the learners refer to the metacognitive dimension involved in writing as a tool to reason on, monitor, and communicate developing knowledge.

Considering together the learners evaluations of oral and written discourse, it can be said that they perceived them in a positive way. They highlighted the different instructional purposes of the two activities which had helped them to learn the science contents. Two of them pointed out that writing was more difficult than talking but their experienced difficulty seemed related to the difficulty of the topic rather than to the writing activity itself. There was no evidence that writing difficulty had interfered with the learners' ability to write about their ideas.

7. Discussion

The first research objective of the study aimed at examining whether, for the first time, the students could engage in collaborative discourse-reasoning for the construction of more advanced collaborative knowledge about the new topics. The data show that they were able to discuss in a group on a specific knowledge object, reaching high levels of reasoning and arguing. Moreover, the data show that in almost all discussions a more progressed level toward the scientific perspective to be understood was reached collectively by the participants who shared the cognitive burden of collaborative thinking. More specifically, reasoning and arguing in group discussions indicate that through steps of critical opposition and co-construction, the learners negotiated and renegotiated meanings and ideas to construct on an interpsychological plane new common knowledge on which more advanced explanations of the examined phenomena were based. The argumentative dynamics developed in the discussions show that the learners put forward claims, oppositions, justifications, and counteroppositions as arguing strategies. At the same time they activated epistemic operations, that is, cognitive procedures to argue in the specific disciplinary domain while using its typical methodological and explicative procedures to support their own points of view.

The second research objective aimed at checking whether the students could for the first time use writing to learn as a tool to reason on, monitor, and communicate their conceptions and developing understanding. The data indicate that writing allowed them to express their current ideas about the science topics in a form that they could look at and think about. Written words provided a basis to verbally express ideas to others. Discussing with others helped them to see the limitations, or values, of their own ideas and to approach a new conception in the former case. Writing acted as a tool either to reflect on their previous ideas and experience the new conceptions they were understanding by changing them or to experience what they were puzzling over in trying to make sense of the developing knowledge.

The third research objective aimed at verifying whether there were changes in the learners' conceptual structures as a result of talking and writing activities encouraged to promote conceptual change. The data indicate that the students individually progressed in understanding the process of decay, the goal concept, although not all of them reached the same level of scientific understanding. At the end of the curriculum units none of the students held the idea that during decay matter vanishes. The major qualitative change in their individual explanations concerned the reference to the correct agents in the phenomenon, among them micro-organisms as decomposers, that led them to understand a partial conservation and recycling of matter and, for half the participants, a complete understanding of recycling implying, therefore, the total conservation of matter.

In the final individual interview all the learners were able to make explicit a successful change of conceptions they had experienced while learning the new science contents that could already be expressed in a written production. By taking into account also what they mentioned by evaluating the role of oral and written discourse, it can be hypothesised that collaborative discourse-reasoning created or refined their metaconceptual awareness of their own representations, making them recognise the need for knowledge revision, and that writing helped them reflect on their previous and current conceptions, increasing the awareness of the changes in their conceptual structures.

The fourth research objective aimed at identifying the learners' perception of talk and writing in constructing scientific knowledge. They expressed their enjoyment of the two activities and made explicit reflections indicating that they perceived the real meaning and instructional purposes of talking and writing to learn. In fact, they identified and valued the different aspects that made the examined activities effective in the process of knowledge revision while constructing their own understanding of the science topics.

8. Conclusions

The findings indicate the opportunity of creating a community of discourse and learning based on classroom discussions about knowledge objects in which students can question, criticise, and evaluate their different conceptions brought to the science class, going beyond "cold" cognition (Pintrich, Marx, & Boyle, 1993). Teachers should consider that in becoming socialised to the complex scientific culture of our society, students need to be engaged in sharing meanings and ways of reasoning and arguing. In a learning environment where there is a social construction of science knowledge, students are involved in seeing the value of their own conceptions, as well as their classmates', and in continually negotiating meanings, ideas, and solutions in a process of consensus building. They enter a kind of social cognitive apprenticeship to scientific and argumentation ways supported in gradually mastering some of the discursive practices characteristic of scientific communities.

Likewise, the findings, providing empirical evidence that also writing to learn can act as a valuable making-sense tool, call for new norms to be established for classroom writing in order to value it as a tool for sharing ideas with peers, puzzling through and reflecting on ideas, relating, and changing ideas.

When students are given the opportunity to use oral and written discourse in the service of learning, that is to reason and reflect on, and communicate their own conceptions and understanding, they are not only active but also intentional learners deeply involved on the motivational, cognitive, and metacognitive planes in taking charge of their own process of learning, having the responsibility to solve problems of knowledge (Sinatra & Pintrich, in press). Moreover, teachers may have rich learning assessment opportunities on which to assist them in the attainment of further educational outcomes.

To put classroom talk and writing in the service of learning, in this case of knowledge revision in a science domain, requires the change of many traditional instructional norms, first the role of teachers who are called for the implementation in "schools for thought" (Bruer, 1993) of "a pedagogy of understanding" (Perkins, 1992) aimed at effectively helping learners not only to possess certain information but also be enabled to think with and about that knowledge, and to do certain things with it.

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