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Discourse Analysis: A Tool for Helping Educators to Teach Science

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Key words: teachers as researchers; collaborative inquiry; discourse analysis; companion meanings

Abstract: This article refers to a part of a collaborative action research project in three elementary science classrooms. The project aims at the transformation of the nature and type of teachers' discursive practices into more collaborative inquiries. The basic strategy is to give the teachers the opportunity to analyze their discourse using a three-dimensional context of analysis. The teachers analyzed their discursive repertoires when teaching science. They studied the companion meaning, i.e., the different layers of explicit and tacit messages they communicate about Nature of Science (NoS), Nature of Teaching (NoT), and Nature of Language (NoL). The question investigated is the following: Could an action research program, which involves teachers in the analysis of their own discursive practices, lead to the transformation of discourse modes that take place in the science classrooms to better communicate aspects of NoS, NoT and NoL in a collaborative, inquiry-based context? Results indicate that the teachers' involvement in their discourse analysis led to a transformation in the discursive repertoires in their science classrooms. Gradually, the teachers' companion meanings that were created, implicitly/explicitly, from the dialogues taking place during science lessons were more appropriate for the establishment of a productive collaborative inquiry learning context. We argue that discourse analysis could be used for research purposes, as a training medium or as a reflective tool on how teachers communicate science.

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1. Introduction

In the past two decades, the sociocultural studies on discourse have become an important theoretical avenue for analysis for those who are concerned with the study of learning in social settings (GEE, 1999; HICKS, 1996; KUMPULAINEN & WRAY, 2002; LEMKE, 1995; MERCER & HOWE, 2012; MORTIMER & SCOTT, 2003; WERTSCH & TOMA, 1995). By studying discursive activities within science classrooms, researchers have provided new insights into the complex and dynamic relationships between discourse, social practices, and learning (KELLY, 2007; KELLY & SEZEN, 2010; LEMKE, 1995; MORTIMER & SCOTT, 2003; WELLS, 1999; YERRICK & ROTH, 2005). An increasing amount of discourse analysis has focused on the examination of science classroom talk (KELLY, 2007; MORTIMER & SCOTT, 2003; ROTH, 2010; SCOTT, 1998). Moreover, it has focused on the companion meanings communicated during science lessons (ROBERTS & ÖSTMAN, 1998). The above analysis could make teachers aware of verbal communications that can either create cognitive obstacles or facilitate the learning process for students. [1]

In recent years, a new sociocultural approach has emerged: viewing the learning process as an appropriation and transformation through participation in evolving discourses and practices in science lessons (ANDERSON, 2007; ROGOFF, 2003). A number of important programs applying this approach have been used: "collaborative inquiry approach" (ROSEBERY, WARREN & CONANT, 1992, p.61), "designing communities" (ROTH, 1998), "thinking together" (DAWES, MERCER & WEGERIF, 2000), "dialogic inquiry" (WELLS, 1999), and "collective argumentation" (BROWN & RENSHAW, 2000). Situating the above in science education, scientific literacy development involves knowledge construction through social negotiation and collaborative inquiry during science lessons. [2]

MORTIMER and SCOTT (2003, p.10) recommend: "If you are interested in how learning occurs in science classrooms, then the place to start is to examine the talk and other modes of communication of science classrooms." In our research, we applied this recommendation to help teachers reflect on their discursive practices during science lessons. Here, learning can be constructed as a meaning-making and collaborative inquiry process (WELLS, 1999). Specifically, we approached the teaching and learning of science by acknowledging the key role of language in learning (DRIVER, ASOKO, LEACH, MORTIMER & SCOTT, 1994; LEMKE, 1990; MORTIMER & SCOTT, 2003). [3]

The goal of this collaborative action research was to transform the nature and type of teachers' discursive practices through a collaborative framework of inquiry project in three elementary science classrooms in Athens, Greece. To fulfill the goal, we used a type of discourse analysis (GEE & GREEN, 1998; KELLY, 2007; KELLY & SEZEN, 2010; LEMKE, 1995; MORTIMER & SCOTT, 2003) that presupposed both the researchers' and teacher-researchers' active participation in analyzing their dialogue. Teachers analyzed companion meanings (i.e., "the different layers of explicit and tacit messages communicated through the science curriculum," ROBERTS & ÖSTMAN, 1998, p.ix) on Nature of Science (NoS), Nature of Teaching (NoT), and Nature of Language (NoL). In general, NoS refers to key principles and ideas that provide a description of science as a way of knowing and as the characteristics of scientific knowledge (LEDERMAN, 2007, MATTHEWS, 1998; McCOMAS, CLOUGH & ALMAZROA, 1998). The terms NoL and NoT are assumptions about learning and teaching theories and approaches. SHERRARD (1991) views discursive repertoires as the discursive resources available to an actor (in this case, a teacher). These are shaped by the culture and time in which one exists and speaks. In our research, we adopted these strategies to promote sociocultural perspectives of NoL (SCOTT, 1998; SUTTON, 1998) and NoT (WELLS & CLAXTON, 2002; YERRICK & ROTH, 2005). [4]

In Section 2, we discuss the sociocultural approach on learning as a meaning-making process during collaborative inquiry (PILIOURAS & EVANGELOU, 2012; see also MORTIMER & SCOTT, 2003; WELLS, 1999). We describe the role of companion meanings in science education, and then review NoS, NoT, and NoL. We also identify problems that might manifest when teachers talk about science. Section 3 explores the methods (i.e., research design, data collection, and data analysis), and sections 4 and 5 describe how valuable it is to involve teachers in an action research project where they analyze their discursive practices. [5]

2. Theoretical Framework

2.1 Learning as a mediated process of collaborative inquiry

Central to our approach is the Vygotskian concept of artifact-mediated joint activity (VYGOTSKY, 1987 [1934]; WERTSCH, 1991), which involves change and transformation of participants and settings over time. Sociocultural theorists argue that science teaching and learning should be both exploratory and collaborative (WELLS & CLAXTON, 2002). This means reconstituting classrooms and schools as communities of inquiry. Within this context, WELLS (2002) states:

> "the classroom is seen as a collaborative community: Joint activity, by definition, requires us to think of the participants, not simply as a collection of individuals, but also as a community that works towards shared goals, the achievement of which depends on collaboration" (p.60). [6]

Accordingly, teachers play a key role in facilitating scientific understanding and scientific literacy during classroom interaction because they organize activities and discourse (LEMKE, 1990). This has profound effects on how students come to know and learn science and familiarize with NoS, NoT, and NoL. Sociocultural approaches reveal that teachers' discursive repertoires are fundamental in promoting collaborative inquiry-based learning (PILIOURAS & EVANGELOU, 2012). [7]

We created a working group of two researchers and three teacher-researchers to promote a collaborative inquiry-based learning environment in each of the teacher's classrooms. Interactions within working groups were such that teachers felt confident to think about and analyze their discursive repertoires in the areas of NoS, NoT, and NoL. [8]

2.2 Teachers' companion meanings when teaching science

Discourse analysis theorists argue that discourses can never be ‘neutral' or value-free. This means that discourse always reflects ideologies, systems of values, and social practices (FAIRCLOUGH, 1989, p.21). The way teachers talk about science during lessons communicates various meanings about science and learning. [9]

ROBERTS and ÖSTMAN (1998) refer to companion meaning as different layers of explicit and tacit messages about power, status, method, ontology and epistemology communicated through science curriculum. Companion meanings accompany scientific meanings in science education. These can be deliberately or unintentionally incorporated into teaching (as with curriculum emphasis). As ÖSTMAN (1998) states**,** companion meanings are located in science classroom discourses in ongoing ways. The discursive practices of student's learning environments are fundamental parts that shape the quality and character of their learning (LEMKE, 1995, 2001; ROTH, 2010). In this context, science education is viewed as an ongoing struggle about knowledge and ontology. A consequence of this struggle is the dominance of empiricist versus pluralistic views of science in science classrooms. [10]

A basic agent for the companion meanings communicated in science lessons is the teacher. We assert that the types of discursive repertoires that teachers contribute in science learning are of fundamental importance in establishing a collaborative, inquiry-based environment. Companion meanings expressed by science classroom discourses are determinative for students' learning. In our case, we focus on how teachers talk about science and analyze the companion meanings communicated. We used a three-dimensional context of analysis concerning NoS, NoT, and NoL. The three-dimensional context was inspired by the five dimensions of effective practice by BARTHOLOMEW, OSBORNE and RATCLIFFE (2004). [11]

2.3 Changing views about NoS, NoT, and NoL

The science education research community has studied NoS school-based teaching and training (ABD-EL-KHALICK & LEDERMAN, 2000; AKERSON, CULLEN & HANSON, 2009; DRIVER, LEACH, MILLAR & SCOTT, 1996; HODSON, 1988; LEDERMAN, 2007; MATTHEWS, 1998; McCOMAS et al., 1998). DUSCHL (1994) argues that there is no agreement among researchers about the development of scientific knowledge. However, scholars mention views that have been broadly accepted and should be reflected in every curriculum in science education and teacher training (LEDERMAN, 2007, McCOMAS et al., 1998; OSBORNE, RATCLIFFE, COLLINS, MILLAR & DUSCHL, 2003). [12]

According to BELL, LEDERMAN and ABD-EL-KHALICK (2000, p.564), a currently accepted view about the development of scientific knowledge is that

> "Scientific knowledge is (a) tentative (subject to change), (b) empirically based (based on and/or derived from observations of the natural world), (c) subjective (theory laden), (d) partly the product of human inference, imagination, and creativity (involves the invention of explanation), and (e) socially and culturally embedded, and it necessarily involves a combination of observation and inferences." [13]

McCOMAS et al. (1998, p.5) describe the following views that have been broadly accepted:

- Scientific knowledge, while durable, has a tentative character.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
- People from all cultures contribute to science.
- Observations are theory-laden.
- Science is part of social and cultural traditions.
- Scientific ideas are affected by social and historical milieus. [14]

Understanding NoS is essential for scientific literacy. Being acquainted with scientific literacy requires the creation of a collaborative inquiry-based environment and a basic dimension of effective practice. According to BARTHOLOMEW et al. (2004) the understanding of NoS shapes teachers' pedagogical practices when they teach science. Literature and research have given us another view on NoS, and these sources have also provided novel insights into NoT and NoL. [15]

The impact of sociocultural perspectives on teaching and learning science led to studies that explore meaning-making through language and other semiotic means (HANRAHAN, 2002; MORTIMER & SCOTT, 2003; SCOTT, 1998; SUTTON, 1998; WELLS, 1999; YERRICK & ROTH, 2005). MERCER (2002, p.141) argues that "the prime aim of education ought to be to help children learn how to use language effectively as a tool for thinking collectively," reciprocally, participation in collective thinking stimulates individual cognitive development. For LEMKE (2002), participation in socially meaningful activities is not just what we learn, it is also how we learn. [16]

It is the responsibility of the teacher to mediate the language of science and to provide congruence with students' literacy and cultural backgrounds. HICKS (1996) suggests diverse communicative spaces in the classrooms which promote speaking and involvement. These communicative spaces are different from the typical "initiation-response-evaluation" formats in classrooms, where teachers do the majority of the talking and thinking. [17]

In this project, we, the researchers, worked closely with three teacher-researchers to promote collaborative inquiry-based learning conditions in science classrooms. We adopted the following principles and strategies concerning NoT and NoL aspects of science teaching (PILIOURAS & EVANGELOU, 2012, p.348; PILIOURAS, PLAKITSI & NASIS, 2015, p.99):

- inquiry as the organizing principle of curricular activities;
- using discursive strategies to scaffold students' learning;
- activities designed to help students practice in using language:
    - teaching students to talk about science;
    - bridging between colloquial and scientific language;
    - teaching about science and scientific methods. [18]

With the above insights into NoT and NoL, we drafted the teachers' training course. Teachers attended a basic professional development course and continued with their discourse analysis. They focused on recording their discursive repertoires when teaching science and afterwards analyzed their findings with the researchers. These courses enhanced teachers' discursive practices, improved their understanding of science and they therefore became better science teachers. [19]

2.4 Issues when teaching science in classrooms

Studies have shown that high school science students' and in-service teachers' views of NoS are not consistent with the current accepted definitions (AKERSON, ABD-EL-KHALICK & LEDERMAN, 2000; DRIVER et al., 1996; LEACH, MILLAR, RYDER & SÉRÉ, 2000; LEDERMAN, 2007). A significant proportion of teachers have no recognition of the tentative nature of scientific knowledge, while others hold outmoded positivist or empiricist views of the nature of science (BARTHOLOMEW, OSBORNE & RATCLIFFE, 2002). For example, most teachers and students believe that all scientific investigations adhere to an identical set and a sequence of steps known as the scientific method (McCOMAS, 1996). They do not recognize the fact that scientists' disciplinary training and commitments, as well as their personal experiences, preferences, and philosophical assumptions do influence their work (AKERSON et al., 2000). [20]

Sociocultural shifts in views on NoT and NoL are in conflict with the teaching practices of many science teachers. In many research studies examining the role of the teacher, it has been clear that the majority of teachers are not familiar with sociocultural learning principles. They mainly function as dispensers of knowledge and less as facilitators. Furthermore, they are authoritative during the whole learning sequence (even in the part of the science lesson in which an exploration of student views and ideas should take place). Lastly, teachers are not open to dialogue (NEWTON, DRIVER & OSBORNE, 1999; NYSTRAND, 1997). [21]

LEMKE (1990) asserts that a major reason for students' alienation from science is the way teachers orally present science, that is to say the nature of teachers' language. As he argues, "the language of classroom science sets up a pervasive and false opposition between a world of objective, authoritative, impersonal, humorless scientific fact and the ordinary, personal world of human uncertainties, judgments, values, and interests" (p.129). Consequently, science teachers' discursive practices are many a time in direct opposition to sociocultural views on NoT and NoL. [22]

2.5 Research question

The hypothesis underpinning the present study was based on previous research about teachers' views on NoS, NoT and NoL. In the light of these findings, the three teacher-researchers acknowledged the empiristic or sociocultural views of Nos, NoT and NoL when teaching science. At this point, the researchers underlined the discourse analysis as a means to achieve more pluralistic views on Nos, NoT and NoL. [23]

The research question is as follows: Could a collaborative action research program which involves teachers in analyzing their own discourse practices, lead to the transformation of discourse modes into more productive ones for the teaching of NoS, NoT and NoL within a collaborative inquiry-based context? [24]

3. Methods

3.1 Research design

We conducted a collaborative action research program. According to HERON (1996), collaborative action research/inquiry is a form of participatory method, which takes place jointly with teachers and researchers. In this study, teacher action research is defined as a systematic self-improvement of teaching practices. For this purpose, researchers and teacher researchers collaborated in a two-year project, constantly transforming classroom discourses. [25]

The actions implemented, had all the basic effective characteristics of an implicit and reflective professional development approach (collaborative inquiry research in cooperation with the teachers, teacher as researcher, model lessons by researchers, co-teaching, collaboratively planned lessons, observing and providing feedback to teachers about their instruction). A key component of this study is collaborative discourse analysis. [26]

For this study, we used a purposive sampling method (COHEN, MANION & MORRISON, 2007, pp.114-115; EMMEL, 2013, pp.33-44). In the context of purposive sampling, the researchers are reflexive, making adjustments and considering the implications of sampling on interpretation (GUETTERMAN, 2015, §5). In our approach, a reflexive teacher-researcher is embedded within the world of research via his or her own lived experience. Following this, two researchers and three in-service teacher-researchers participated in the working group. The three teacher-researcher volunteers agreed to participate in the collaborative action research in order to become more familiar with collaborative inquiry-based approaches in science lessons. All teachers were experienced in teaching science. The three teacher-researchers had not attended professional (pre-service/in-service) development programs about inquiry-based learning in science. However, each teacher-researcher declared a clear intention to enhance his/her science teaching practices using collaborative inquiry-based strategies. Their ages varied from 35 to 45 years old and they had been teaching in Greek primary schools for more than 10 years. [27]

The study took place in two primary schools in Athens, Greece over a two-year period. Teachers taught science in three classrooms with a total of 64 fifth and sixth grade students between the ages of 11 and 12. In all classes, the students worked in diverse groups from the very beginning of the program. They carried out collaborative inquiry-based learning tasks. During the lessons, students had at their disposal work sheets with activities suitable for collaborative inquiry learning. [28]

3.2 Data collection

Data was collected through field notes, video recordings of the science lessons and teachers' diaries on these lessons. Field notes were taken by the researchers as observers of the science lessons (EMERSON, FRETZ & SHAW, 1995). Both concurrent and retrospective field notes were kept throughout the research project. Concurrent field notes were kept upon completion of the science lessons concerning NoS, NoT and NoL. Retrospective field notes consisted of conversations between the researchers and teacher-researchers during some meetings where the working group analyzed how teachers talk about science, highlighting NoS, NoT and NoL. Part of our analysis is the researchers' reflection on the processes observed within the classrooms and later discussed in meetings. [29]

We followed all legal and ethical standards. Furthermore, we obtained the appropriate license and legal consent of the authorities and students' parents or guardians. Researchers recorded lessons with wide angle cameras in order to observe students and teachers in each classroom. Video is a basic medium for collecting data for educational and social research projects (HALL, 2000). Videos can preserve more aspects of interaction including talking, gesture, eye movement and manipulatives (ROSCHELLE, 2000, p.709). The duration of the videos we collected ranged from 80 to 90 minutes. Overall, during the two-year period, we collected and transcribed 30 videotaped lessons (10 lessons for each teacher). These were divided into smaller activity instances in order to be studied and analyzed. [30]

Teacher-researchers were encouraged to reflect upon their practices and write in their diaries how they experience their dialogues when teaching science and how these dialogues affect their practices. Afterwards, they made comparisons regarding the similarities and differences in their communicative repertoires in the evolution of the program. [31]

The variety of sources and types of data allowed the triangulation of data and the construction of teacher-researchers' profiles on their changing views on NoS, NoT and NoL and their discourses practices. The data for this article was derived from four science lessons delivered from by one of the three teacher-researchers, a male teacher with 12 years of experience in teaching. He divided his class of twenty into five groups of four students each. The first two extracts (1 & 2) of teacher-student dialogues come from two lessons that took place in the 5th grade at the beginning of the first year of the research project. The other two extracts (3 & 4) come from two lessons that took place at the end of the second year, now 6th grade, of the research project. All four extracts analyzed activity instances that took place with the guidance of the teacher. [32]

The teacher-researcher tried to explore group and individual views while guiding them to work with scientific ideas. We present these four representative extracts because they highlight the changes of companion meanings on NoS, NoT and NoL throughout the project. [33]

3.3 Data analysis

Descriptive contexts are educational researchers' attempts to describe the common features when teachers talk about science. The reason for teachers to become acquainted with a series of discourse analysis tools and descriptive contexts was to give them the capacity of doing research and immerse in each rationale. We followed prominent sociocultural principles and strategies for learning, derived from relevant literature about sociocultural theory embedded in science education (BARTHOLOMEW et al., 2004; GUTIERREZ, 1993; KUMPULAINEN & MUTANEN, 1999; LEMKE, 1990; MORTIMER & MACHADO, 2000; MORTIMER & SCOTT, 2003; WERTSCH & TOMA, 1995). Most importantly we used: [34]

1. A descriptive context of BARTHOLOMEW et al. (2004, p.664), entitled "five dimensions of effective practice": These five dimensions consist of a) teachers' knowledge and understanding of the nature of science; b) teachers' conceptions of their own role; c) teachers' use of discourse; d) teachers' conception of learning goals; and e) the nature of classroom activities: According to BARTHOLOMEW et al.,

> "... there are five critical dimensions that distinguish and determine a teacher's ability to teach effectively about science. Whilst these dimensions are neither mutually independent nor equally important, they serve as a valuable analytical tool for evaluating and explaining the success, or otherwise, that individual teachers of science have when confronted with teaching aspects about science ... we have found these dimensions of teacher practice to be a useful tool for distinguishing teachers, and for thinking about salient features of the lessons we observed" (p.655).

Teachers are anxious about their understanding	***1. Teachers' knowledge and understanding of the Nature of Science*** ⟷	Confident that they have a sufficient understanding of NOS
Dispensers of knowledge	***2. Teachers' conceptions of their own role*** ⟷	Facilitators of learning
Closed and authoritative	***3. Teachers' use of discourse*** ⟷	Open and dialogic
Limited to knowledge gains	***4. Teachers' conception of learning goals*** ⟷	Includes the development of reasoning skills
Student activities are contrived & not authentic	***5. The nature of classroom activities*** ⟷	Activities are owned by students and are authentic.

Table 1: "Five dimensions of effective practice" (ibid.) [35]

2. "The flow of discourse" descriptive context of MORTIMER and SCOTT (2000): Flow of discourse descriptive context provides a set of "analytical tools for reviewing and identifying the different kinds and patterns of classroom talk" (p.126). The framework consists of three aspects of the discourse: a) the content of discourse; b) the form of utterances; and c) the patterns in the flow of discourse. [36]

3. An analytical framework of five aspects of science teaching (MORTIMER & SCOTT, 2003): The analytical framework of MORTIMER and SCOTT (p.101) is a tool for analyzing and planning science teaching interactions in science classrooms. It is based on five linked aspects, which focus on the role of the teacher and are grouped in terms of teaching focus, approach and action (Table 2).

Aspect of analysis		
i. Focus	1. Teaching purposes	2. Content
ii. Approach	3. Communicative approach	
iii. Action	4. Teacher interventions	5. Patterns of interaction

Table 2: The analytical framework of MORTIMER and SCOTT (ibid.) [37]

For the analysis of teacher-researchers' classroom talk, we followed a qualitative sociocultural discourse analysis, which focuses on the use of language as a tool for teaching and learning, constructing knowledge, creating joint understanding and tackling problems collaboratively (MERCER, 2004, p.137). The sociocultural discourse analysis differs from linguistic discourse analysis in being less focused on language itself and more on its functions for the pursuit of joint intellectual activity (ibid.). [38]

The analyzed data consisted of video-recordings and associated field notes of the whole class actions and teacher-guided sessions, focusing on group activities during science lessons. In our action research working group, a researcher and the teacher-researchers met every fifteen days. During these meetings, we watched the videos of the science lessons and also studied and analyzed the classroom talk data. Our analysis was concerned with identifying teacher-researchers' communicative repertoires concerning NoS, NoT and NoL companion meanings during science lessons. A methodology called sociocultural discourse analysis (MERCER, 2004) was applied. The qualitative analysis consisted of a detailed examination of science lessons' videos and transcripts in which we noted, highlighted, discussed and analyzed teachers' communicative repertoires concerning NoS, NoT and NoL. Following MORTIMER and SCOTT (2003), in doing our analysis, we tried to get a sense of the overall flow of discourse of a sequence of lessons concerning aspects of science teaching. Concurrently, we focused on chosen activity instances so as the teachers could have the opportunity to reflect in a concrete way on their own communicative repertoires. [39]

In this article, we focus on the implementation of a three-dimensional context on discourse analysis (Table 3).

Companion meanings about the Nature of Science Teachers' knowledge and understanding		
One-dimensional-empiricist views of NOS	⟵⟶	Pluralistic views of NOS
Companion meanings about the Nature of Teaching Teachers' views of their own role		
Dispensers of knowledge Closed and authoritative	⟵⟶	Facilitators of learning Open and dialogic
Companion meanings about the Nature of Language		
A system of transmitting information	⟵⟶	An interpretative system for making sense of experience

Table 3: A three-dimensional context of analysis [40]

Based on BARTHOLOMEW et al. (2004), we focused on the first three dimensions of effective practices interpreting them on the field of Nos, NoT and

NoL. As we can see in Table 3, we consider that a teacher communicates a variety of meanings about NoS, NoT and NoL explicitly or implicitly as companion meanings. Concerning NoS, on the one hand teachers could be doubtful about their understanding of NoS and communicate companion meanings with static and one-dimensional empiricist views. On the other hand, when teachers hold a more sufficient understanding of NoS, they are more confident and communicate pluralistic views of NoS. Concerning NoT, teachers could communicate companion meanings that identify them as dispensers of knowledge or facilitators of learning. And finally, concerning NoL, teachers' use of discourse could be closed and authoritative or open and dialogic. It is important to note that every dimension is a continuum along which teachers position themselves (ibid.). [41]

The choice of the descriptive context was made in order to facilitate teacher-researchers' acknowledgment of the multifaceted pedagogy when teaching science (ibid.). Using this context, teacher-researchers analyzed their own discursive repertoires about NoS, NoT, and NoL aspects. [42]

4. Research Findings and Discussion

4.1 Findings: Initial phase

In the first weeks of the 1st year, the program with the active participation of the teacher-researchers was implemented in the 5th classes. The data analysis indicated, during the first weeks of the first year, that teachers had difficulties cultivating a collaborative inquiry-based learning environment, and a dialogical model of meaning-making in their science lessons. The latter was more obvious when exploring the students' views. [43]

Below, we present two characteristic dialogues which took place in the initial phase of the program. All translations from Greek to English reported below are ours. [44]

4.1.1 Discourse analysis of Extract 1

Extract 1 preceding the analysis, is the teaching of the concept of friction in a fifth-grade class. Students had to conduct an experiment to measure friction using different materials like sandpaper, a plasticine surface, and a greased surface. The question they explored in this investigation was about the friction force created (how far from the book's edge a coin traveled) when a coin slides against the surface of an inclined book which is covered by different surface materials. The extract concerns a teacher-guided session which follows the investigation of one of the five student groups.

1	Teacher	You? *(Teacher is addressing one of the five groups)*
2	Student (as a group representative)	We have found that on the sandpaper it is 75, on the plasticine, it is 75, as well as on oil. (*Students measured the coin's distance traveled along the edge of the book and they announced their results without making reference to the units of measurement*)
3	Teacher	Even on the oiled surface? *(Emphatically)*
4	Student	Hmm, yes.
5	Teacher	Didn't the surface change?
6	Student	Hmm, yes.
7	Teacher	What should you have found then? Less or more?
8	Student	Less.
9	Teacher	Less? But we do not know how much. This means you have made an error somewhere in your experiment.

Extract 1: December 2004 (5th grade, lesson: "Friction in our lives") [45]

We continue with the analysis of the companion meanings about NoS, NoT and NoL made by the teacher-researcher with the support of the researchers upon his own talk of Extract 1: [46]

Companion meanings about NoS

The group representative gave only numbers without being able to logically prove their conclusion ("We have found that the sandpaper is ..."). The evaluation of the process was carried out in the form of closed questions posed by the teacher. With his words, the teacher demanded specific answers using specific means of inquiry and specific ways for guiding students to the "correct" conclusion. This way teachers communicated a one-dimensional aspect of NoS ("What should you have found then?"). [47]

Companion meanings about NoT

The teacher posed closed questions which aimed to help students rethink their results and their conclusions. The answers were obvious; therefore, he enacted a learning procedure of indirect knowledge distribution ("What should you have found then? Didn't the surface change?"). [48]

Companion meanings about NoL

Through his words, the teacher guided the students very strictly creating the meaning of the language exclusively as a system of transmitting information. The students had to reply using a specific linguistic code or perhaps using specific words (*Teacher: What should you have? ... less or more*). The teacher offered students only two choices, so the representative student of the group had to reply immediately without being able to justify his answer. He posed closed questions and received monosyllabic answers from the students. A triadic dialogue pattern (initiation-response-feedback) was dominant in a very closed and oppressive manner. [49]

4.1.2 Discourse analysis of Extract 2

Extract 2 concerns a teacher-students dialogue from the same fifth-grade class at the initial phase of an experimental activity in which students didn't understand what they had to do. In this activity, students studied the properties of liquids when poured from one container to another of a different shape.

1	Teacher	Who is going to tell me what this work demands? Read and tell me what the exercise demands.
2	Student 1	We pour ... *(The student started to read from the worksheet)*
3	Teacher	*(Interrupting the student)* Don't tell me "we pour." What does the exercise ask you to do? To take the water out of one container and then? Who is going to tell me? Be quiet there! It asks you to take this *(He shows the device)* and do what? Tell me! *(Addressing the same student)*
4	Student 1	*Eee ... (The pupil tries to say something)*
5	Teacher	*(He continues)* ... and to pour it ...
6	Student 2	To pour it into the three transparent containers.
7	Teacher	It is already in one of them. Pour it into the other two and after that, what should you observe? Can we agree on that? After that, what does it ask you to observe?
8	Nancy	The shape that the water takes in each container.
9	Teacher	Go on to the next page.
10	Student 3	Shall we do the experiment?
11	Teacher	Yes ...

Extract 2: February 2005 (5th grade, lesson: "The properties of liquids") [50]

What follows is the analysis of the teacher-researcher in cooperation with the researchers of the companion meanings about NoS, NoT, and NoL concerning teacher-researcher discursive repertoires of Extract 2: [51]

Companion meanings about NoS

The teacher's communicative actions, without this being his intention, presented to students a static and one-dimensional view about science. As indicated in his discourse, words corresponded in a simple way to the features of the external world, and generally there was only one correct answer (*... what should you observe?* Can we agree on that?). [52]

Companion meanings about NoT

The teacher insisted on demanding the students answer in the way he had in his mind (*Teacher: [Interrupting the student]: Don't tell me "we pour." What does the exercise ask you to do?*). Here, the teacher guided the learning process entirely. He asked students to say or do exactly what he wanted, creating the impression that the teacher and worksheet views were important, demeaning students' initiatives and views. (*It asks you to take this and do what? Tell me!*). [53]

Companion meanings about NoT

By reading the activity guides, the teacher expected students to understand exactly the same things that he did. This way, the role of the language is mainly a system for transmitting information (*Teacher:* Can we agree on that?). The teacher used many imperatives and raised his voice more than needed. His communicative actions (*Read and tell me ...Tell me!*) indicated that he assumed complete student compliance with his plans (characteristics of a closed and monologic mode of teaching). In the dominant triadic dialogue pattern the third part of the interaction was only the teacher's view and does not provide the students' point of view. [54]

Overall, the analysis in the initial phase of the research indicated that the implicit companion meanings of NoS, NoT and NoL were not so suitable for establishing a collaborative inquiry-based learning environment. For example, the physical world was presented in an authoritarian perspective as LEMKE (1990, p.126) states "not as a way of talking about the world, but as the way the world is." In the above extracts, the teacher was the absolute master of how the science lesson should proceed, allowing students little or no opportunity to talk in their own way and makes a substantive contribution to the topic under discussion. Thus, in the initial phase of the research, teacher-researchers were very often closed-minded and authoritative. This even occurred in the phases of the learning sequence that was more appropriate for the exploration of students' ideas and contributions. Certainly, it is the job of the science teacher to intervene, to introduce new ideas and terms, and to move the scientific story along. As MORTIMER and SCOTT (2003, p.71) argue "authoritative interactions are an equally important and fundamental part of science teaching, and this, of course, is consistent with the fact that the social language of school science is, itself, authoritative in nature." But this mode of talk is not suitable in the face of exploration of students' ideas and views. [55]

Furthermore, in the initial phase of the program, teacher-researchers had difficulty in implementing strategies suitable to promote collaborative inquiry conditions. They had difficulties in using discursive repertoires to scaffold students' learning and they didn't give students many opportunities to practice using language (teaching students to talk about science; bridging between colloquial and scientific language; teaching about science and scientific methods). [56]

4.2 Findings: Final phase

The analysis of two representative extracts of teacher-students' dialogues (from the same teacher-researcher and his sixth-grade class) from the final phase of the program is provided below. [57]

4.2.1 Discourse analysis of Extract 3

Extract 3 is a science lesson named "The roots of plants," in the sixth grade class of the same teacher-researcher. The specific extract concerns the student group's statement during an activity regarding the classification of different kinds of buds. The teacher guided the learning process in the context of a whole class discussion.

1	Teacher	Classify these plants in the table below. You will read carefully what the table demands; discuss among yourselves and then write your ideas down ... if someone has questions, discuss them. Do not write someone's ideas down immediately. ... Let's hear what you have decided and have written down in your group. Let's start. Apostoli, what does your group say?
2	Apostolis (as a group representative)	Fibrous bud category. We put the almond tree and the rosebush in this category.
3	Teacher	The members of this group have placed the almond tree and rosebush in the fibrous bud category. What about the other groups? Do you agree or not?
4	All groups	Yes.
5	Teacher	Is there any group that disagrees?
6	All groups	No.
7	Teacher	Indeed, the almond tree and rosebush have fibrous buds. They have bulky and fibrous buds. Ok? Let's proceed to the category of vacuous bud. Let this group tell us. Danai tells us.
8	Danai (as a group representative)	Stubble.

9	*Teacher*	Stubble. Do we all agree? Do the other groups agree? You are welcome to express your opinion. *(Giving the representatives of another group the chance to talk)*
10	Maria (as a group representative)	We agree but we have added something else into this category. It is wheat.
11	Teacher	Of course, wheat. Wheat has vacuous buds too. Ok? Well, it is wheat and stubble as well. Let's go to the next. Let's hear the next group. Sara.
12	Sara (as a group representative)	The soft bud category. We put the daisy and the poppy in this category...

Extract 3: March 2006 (6th grade, lesson: "Classifying plants with different buds") [58]

The analysis from the teacher-researcher of Extract 3 is provided below. [59]

Companion meanings about NoS

The teacher was open to all answers coming from the group representatives. He seemed to accept the diverse experience and meaning making of the group. Also, he accepted all different interpretations of the physical world (*Is there any group that disagrees?*). He avoided the creation of meanings as a representative of infallible authority. The message about science, in this case, was that the process of learning can involve approaching concepts indirectly, starting from everyday knowledge, with the teacher being a facilitator of the learning process rather than just a source of information. [60]

Companion meanings about NoT

The teacher's statements led to the emergence of meanings associated with a collaborative inquiry-based environment (*Classify these plants in the table below. You will read carefully what the table demands; discuss among yourselves and then write your ideas down*). He and his students were working collaboratively to perform the activity of classification. Students were involved in the procedure not only as individuals but also as group members. He didn't hurry to confirm a group view, but sought the support or rejection from the other groups (*Stubble. Do we all agree? Do the other groups agree?* Take your turn). He used first person plural inferring respect and confidence in all the opinions. The whole class, instead of the teacher alone, assessed all the opinions and suggestions. Generally, he tried to function as a facilitator of learning and to be open and dialogic. [61]

Companion meanings about NoL

The use of first person plural indicated non-monological companion meanings about the role of the language (*We discuss ... We all agree ... We put in ...*). Teacher's communicative actions could be characterized as open to challenge and controversy (*Stubble. Do we all agree? Do other groups agree?*). He was trying to direct his communicative actions towards the support of a collaborative mode of inquiry and to help in the representation of all the student voices (*The members of this group have placed the almond tree and rosebush in the fibrous bud category. What about the other groups? Do you agree or not?*). [62]

4.2.2 Discourse analysis of Extract 4

Extract 4 concerns a teacher-student dialogue from a sixth-grade class that took place during a science lesson entitled "Energy transformations." Students, with a worksheet at their disposal, initially read a poem concerning a thermal accumulator and then the teacher asked them to describe how a thermal accumulator works.

1	Teacher	We are continuing our conversation. I want somebody to remember from the introductory verse, what is going to get caught? Catherine.
2	Catherine	The sun.
3	Teacher	The sun. What is going to catch the sun? ... Constantine.
4	Constantine	The thermal accumulator.
5	Teacher	How is the thermal accumulator described?
6	Constantine	Like ... a modern box.
7	Teacher	Like a modern box. What does a thermal accumulator mean to you?
8	Student	*(He starts speaking after the teacher's nod)* The heater.
9	Teacher	The heater. *(Approving)* Let's see, could somebody remind me how the heater works? *(Time is given to the students)*
10	Teacher	Mary.
11	Mary	The sun's rays fall on the glass panel which is black and accumulates them.
12	Teacher	Indeed. Discuss it and write it down, where it says *(He means the worksheet)* "We describe the function" *(Worksheet expression)* how the thermal accumulator works ... Discuss it and write down where it says "I describe the function", how the heater works. *(Time is given to the groups. The teacher approaches the groups and guides them)*

13	Teacher	*(He says to the members of a group) All together! (While he is approaching another group)*
14	Teacher	Write down what you have agreed. *(After he approaches the third group while he also pays attention to the fourth)*
15	Teacher	Each group that finishes announces what they have written down ... Angelo, what do you have to say?
16	Angelo (as a group representative)	The heater collects the sun's rays on a black glass surface and warms up the water.
17	Teacher	Indeed *(Time goes by and the teacher notices that the other three groups have not finished yet).*
18	Teacher	Alexander, I am listening to you, it is your turn, what did you write down?
19	Alexander (as a group representative)	The heater collects and stores the solar energy on the black glass surface and warms up the water.
20	Teacher	Vicky, the other group says that the heater collects and stores the solar energy on the black glass surface and warms up the water. *(He addresses to the third group)* Odysseus, we are listening to you, it is your turn.
21	Odysseus (as a group representative	The heater ..., the heater traps solar energy and transforms it into thermal energy and warms up the water.
22	Teacher	Indeed. Georgia. *(He addresses the fourth group)*
23	Georgia	The heater finally traps the sun's rays on a black glass plate and warms up the water.
24	Teacher	Good. Discuss and write down ... write down which energy transformations occur in that situation ... *(Again addressing the groups that have just started working)* Which energy transformations do we have; which energy exists initially ... what is it transformed into? This is what we are looking for. *(Time is given to the groups ... which discuss the subject in a lively way)*
25	Teacher	Each group should announce what they have written. Antigone tell us what you have written? ...

Extract 4: May 2006 (6th grade, lesson: "Energy transformations") [63]

The analysis of teacher-researcher in cooperation with the researchers of Extract 4 is provided below. [64]

Companion meanings about NoS

The teacher posed a question (*What does a thermal accumulator mean to you?*) that respected students' views, a question that allowed students to speak without the fear of a "wrong answer." In this context, students were more likely to join any discussion that took place. The message from the statements contributed by the teacher about school science, and more broadly scientific knowledge itself, seemed to be that the process of construction of knowledge can involve approaching concepts through a collaborative inquiry-based process, starting from everyday knowledge. And most importantly the teacher being a facilitator of the learning process rather than just a source of knowledge. [65]

Companion meanings about NoT

A discourse strategy that the teacher followed was to repeat the student's words (Lines 19 & 20) which was an indirect way of confirmation without contributing complimentary comments. Frequently the students could expect a compliment, but they also got anxious because they were afraid of a possible rejection. The teacher was trying to address the groups and also the individuals. This was good practice because it changed the type of activities or activity patterns according to LEMKE (1990). In addition, he was also trying to combine ideas and ascertain relationships between individual and group views (*Write down what you have agreed ...Vicky, the other group says*). Equally important, he gave the groups plenty of time to discuss the questions posed. He continuously approached the groups, guiding, making remarks and motivating the group members to participate. Furthermore, he chose other ways to judge student statements in order to avoid any frustration they might otherwise have felt avoiding the usage of the words "correct" and "wrong." [66]

Companion meanings about NoL

The teacher referred to both the scientific term and the term we use in our daily life (*thermal accumulator*, *heater*). He aimed to enable students to follow the instructions and also to remind them that the thermal accumulator is what we call "heater" in everyday life. In Line 11 the teacher indirectly approved the expression of Alexander's group (Line 10) or to state it differently, he purposefully repeated the phrase "*The heater collects and stores the solar energy"* as this is the one used by the scientists. Additionally, he did not disapprove of the words that were used by other groups (*Angel: The heater collects the* sun's rays *..., Odysseus: The heater ..., the heater traps solar energy ..., Georgia: The heater finally traps the sun's rays ...*). On the contrary, he allowed students to speak freely promoting an interpretive inquiry-based approach. [67]

We can see from the analysis of Extracts 3 and 4 (from the final phase of the project) that the companion meanings which were communicated when teachers talk about science, created the conditions for more collaborative inquiry-based conditions. Overall, during the course of the project**,** teacher-researchers gradually appropriated a series of important discursive strategies to scaffold students' learning, such as assisting students to combine ideas or making connections, checking on group progress and involving other students or groups in discussion. In the words of a teacher-researcher:

> "By analyzing my communicative actions, which I contributed during the science lessons, I discovered aspects of my teaching practices of which I was not aware of. I could not imagine the power of our discourse. Out of all the actions of our collaborative action research, including the study of the research literature concerning discourse, interaction and learning, the design of learning activities, I found my involvement in the analysis of my own discourse during science lessons to be most valuable, important and critical." [68]

5. Discussion: Discourse Analysis as a Reflective Tool for Teachers

> "It is not enough to expect teachers to know instinctively how to use talk productively. Teachers can be taught to be more conscious of the ways they speak and how to use talk strategies in imparting information" (GRUGEON & HUBBARD, 2006, p.242).

Meaningful dialogical involvement in science lessons might occur within a discursive space that is itself more open to question and negotiation. The research question, combined with the aforementioned sociocultural principles, directed our study to a discourse analysis-oriented research methodology. This approach gave teachers the opportunity to immerse themselves in the theory and practice of sociocultural approaches in science education (ANDERSON, 2007; LEACH & SCOTT, 2003; LEMKE, 2001; MORTIMER & SCOTT, 2003; WELLS & CLAXTON, 2002) and also to work along with the researchers. [69]

By examining selected extracts of teacher-student linguistic interactions of science lessons during the entire program, we tracked and analyzed the ways in which science learning was carried out in their science classrooms. This was accomplished with the cooperation of teacher-researchers, using a variety of discourse analysis tools. The evolution of our research indicated that the analysis by the teacher-researchers of their own discourse practices could function as a reflective transformative tool. The discourse analysis mediating tools contributed in the enhancement of the quality of social interactions in their science classrooms into more collaborative inquiry ones. [70]

In the initial phase of the project, we found that teachers' discursive repertoires were not suitable for the establishment of a collaborative inquiry-based environment. A major reason for this predicament in science teaching classrooms is that teachers very often presented unsuitable companion meaning about NoS, NoT and NoL (see also LEMKE, 1990). This was also ascertained in our collaborative research. For instance, in Extracts 1 and 2 and in most of the extracts analyzed from the initial phase of the research we found a lack of extended discourse contributed by students. Furthermore, we found that the teachers gave the students few opportunities to articulate their ideas. This, in our opinion, is associated with the dominant traditional discourses that teacher have experienced in their school and university studies. Despite the fact that they were informed, at a theoretical level, concerning the contemporary pedagogical principles of collaborative inquiry, in their science teaching practices they reproduced the static and authoritative discourses they had participated in for years. [71]

However, teacher-researchers became more dialogical and less authoritative, especially in the phases of the science lessons' learning sequence where an interactive/dialogic approach was needed. MORTIMER and SCOTT (2003, p.69) call it the "explore" phase. Furthermore, teacher-researchers used a more systematic inquiry as the organizing principle of teaching activities. The companion meanings created implicitly or explicitly from the dialogues that took place for NoS, NoT and NoL were more appropriate for the establishment of more suitable collaborative inquiry-based conditions. [72]

An important feature of focusing on teachers' discursive repertoires and involving them in the discourse analysis procedure, as our research effort shows, is encouraging them to develop dexterity. This gives the chance to determine which approach from their repertoire is appropriate for communicating desired aspects of NoS, NoT and NoL, and under which circumstances (GUTIERREZ & ROGOFF, 2003), taking into account the principles of sociocultural approaches. [73]

Recent studies (BELL, MATKINS & GANSNEDER, 2011; SMITH & SCHARMANN, 2008) have provided evidence supporting the use of an explicit, reflective-based approach to help teachers develop more pluralistic conceptions of NoS. We believe that such explicit instruction tallies with our adopted discourse analysis strategy. [74]

WERTSCH (1991) regards conscious reflection like discourse analysis actions done by teachers themselves as an important element in development within mediated action. BURBULES and BRUCE (2001) argue that the more someone develops this analysis of discursive repertoires, the more he or she is likely to understand the possibilities of forming desirable learning practices in classrooms. The above recommendations were ascertained in praxis. We not only provided teachers with the analytic tools to evaluate classroom activities and their discourse during science lesson but we also gave them the chance to be involved in a long-term procedure of reflecting on their "progress" concerning the companion meaning about NoS, NoT, and NoL. This active involvement in research helped teachers to implement in their science lesson more collaborative inquiries using a variety of scaffolding discourse strategies, such as: assisting students to combine ideas or relate science to their everyday lives, assisting when interactions broke down, checking on group progress, involving other students or groups in discussion, scaffolding students' learning, and introducing and reinforcing subject-specific concepts and language. [75]

Finally, we should notice the limitation of our research concerning the meaning of "meaning." ROTH (2001), referring to DERRIDA, MERLEAU-PONTY and BAKHTIN, argues: "Meaning is a very problematic concept … we are never in control of what we say or write. In the utterance, we speak or the sentence we write there is a dialectic tension: it is both ours and not ours" (§18). Also, ROTH expresses his concerns about the distance between theory and practice and that discourse analysis is enacted by academics rather than by practitioners operating in their everyday settings. In our research, we took this concern into account, involving the teacher-researchers in the analysis of their own science teaching discourse and "researched a form of teaching praxis that simultaneously became a form of research praxis" (ROTH, 2006, §1). [76]

6. Conclusion

Currently, the social character of human cognition and the determinant role of language and communicative interaction in the transformation and appropriation of knowledge are well recognized (MORTIMER & SCOTT, 2003; ROTH, 2010; SFARD & KIERAN, 2001; WELLS & CLAXTON, 2002). Many researchers are probing school science from a sociocultural perspective, giving particular attention to the ways in which language events in the classroom shape the school subject, as well as how the school subject, in turn, shapes classroom discourse (ROWELL & EBBERS, 2004; YERRICK & ROTH, 2005). [77]

In our attempt, we tried to put into practice our critical reflection on our habits of meaning-making, enlarging our range of possible action (GEE & GREEN, 1998; LEMKE, 1995). Furthermore, our collaborative action research was founded on the sociocultural driven assumption that learning is a community process of appropriation-transformation through participation in sociocultural activities (ROGOFF, 2003). Accordingly, we focused on the teacher-researchers' changing participation in their science learning practices. We especially focused on discourse analysis as a reflective self-awareness tool of the three teachers discourse when teaching science. [78]

Our two-year study indicates that the process of transforming a learning environment to a more collaborative inquiry one is a slow and demanding procedure that requires teachers' active participation in analyzing their own discourse practice. It is very important to involve teachers in the research and provide them with analytic tools, such as the "five dimensions of effective practice" (BARTHOLOMEW et al., 2004). Also, it is very important for the teachers' professional development to improve all the basic effective characteristics of an implicit inquiry and reflective professional development approach (to be long-term, do collaborative inquiry research in cooperation with the teachers and reflective practice). As we theorize student learning as a meaning-making collaborative inquiry-based process, the same applies to the nature of teachers' learning and their professional development. [79]

The novelty of our effort is that we involved teacher-researchers in the discourse analysis procedure thereby leading to the teachers' awareness of the companion meanings that they created and maintained concerning NoS, NoT and NoL. The involvement of the teachers in analyzing their own discourse practices led to a transformation in the discursive repertoires in the science classroom. Gradually, the teachers talk about science and companion meanings that were created, implicitly/explicitly, from the dialogues taking place during science lessons were more appropriate for the establishment of collaborative inquiry-based learning context. [80]

In our opinion, teachers cannot become familiar with pedagogical strategies only through traditional training programs, but they have to be involved in the practice itself and research the ways they teach. WERTSCH (1991, p.126) asserts that:

> "meditational means (like discursive cultural repertoires of teachers) are used with little or no conscious reflection. Indeed, it is often only when confronted with a comparative example that one becomes aware of an imaginable alternative. This conscious awareness is one of the most powerful tools available for recognizing and changing forms that have unintended and often untoward consequences." [81]

In conclusion, discourse analysis as a methodology can offer important insights into aspects of science teacher development. Discursive practices are the most important practices in a community, because they produce and mediate communication, embed all other practices and constitute the members' world (ROTH, 1998). Teachers gradually internalized/appropriated aspects of the discourse toolkit of sociocultural pedagogy that led to an automatization (HUTCHINS, 1997) of the use of more suitable communicative actions and discourse scaffolding strategies during science lessons. [82]

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