STUDENT-TEACHERS EXPLAINING ACIDIFICATION IN THREE DIFFERENT SCALES: A CASE STUDY

Artemisia Stoumpa
University of Athens, Hellas
artemis.stoumpa@gmail.com

Anthimos Chalkidis
University of Athens, Hellas
achalkid@gmail.com

Constantine Skordoulis
University of Athens, Hellas
kskordul@primedu.uoa.gr

Abstract
In the context of Environmental Science in Education students study phenomena and problems occurring on a time and space scale which is too large to be immediately perceived. Such occurrences are interpreted through processes and changes taking place in macro scale, while the macro scale processes themselves are interpreted by means of models of systems and processes at cellular and atomic molecular scales – micro scale. In order for us to analyze the way student-teachers link the three levels of understanding (micro, macro and large scale) so that they will be able to explain the environmental phenomena and problems, we designed a didactic intervention addressing the issue of acid rain interaction with the natural environment on all the three scales. The students' pre-tests post-tests and worksheets analysis showed that, although the students were not eager to use models of the micro scale in their explanations, the contact with the models and processes on micro scale through educational software rendered the majority of them able to correlate the macro with large-scale changes in their explanations.
Keywords: *Environmental Science, student-teachers, acid rain*

INTRODUCTION

Recently, the need for introducing the environmental dimension of science in education has become prominent (Gough, 2002; Edelson, 2007). Usually, in the context of Environmental Science in Education students study the natural dimension of environmental systems, which are complex socio-ecological systems. This study concerns phenomena and problems such as the hole in the ozone layer, acid rain and the greenhouse enhancement effect, that take place on a very large scale of time and space (Mitchell, 1989; Tett *et al,* 2000; WMO, 2007; Akselsson *et al,* 2003), and, therefore, can not be fully perceived. These phenomena can only be conceived and interpreted via macro-scale changes and processes that can be perceived directly (ranging approximately from 1mm to 1km). Macroscopic systems and processes are explained "using models of systems and processes that are too small to see, at the cellular and atomic-molecular scale", micro scale (Anderson, 2007).
The objective of this study is to examine the way student-teachers link the three levels of understanding of the natural world (micro, macro, large) when interpreting environmental phenomena and problems. In particular, this is a case study examining student-teachers ability to perceive and explain the interaction of acid rain with the natural environment. The fundamental factor of this interaction is the acid / weathered bedrock reaction when acid rain penetrates the soil. When soil buffering capacity is strong (calcareous subsoil) the weathered rock (soil minerals and weathered bedrock) reacts with acidic water beneath the soil and neutralizes the acidity, thus protecting aquatic and terrestrial ecosystems. When soil lacks buffering capacity (siliceous subsoil) ecosystems are, in the long run, strongly affected (JCE, 2003). The occurring reaction is perceived at macro level but is explained at a molecular level (micro scale) and its results can be seen in ecosystems in a time range of some decades (large scale).

METHODOLOGY

The research questions of this article are:
1. In which way students describe and explain the reaction that underlies the different effect of acid rain on different ecosystems?

2. Which scales are used by the students when they describe and explain the acid rain effect on the natural environment?
3. In which way the students' contact with models and processes of micro scale influences their ability to explain the phenomenon in macro and large scale?
The research described here was conducted in a class of 59 pre-service teachers, students of the National and Kapodistrian University of Athens who attended the one-semester course "Natural and Environmental Sciences – a Laboratory approach" in 2008-2009. In the above mentioned course, students study modern environmental problems, acid rain being one of them. Acid rain is included in the course curriculum since Athens city has been faced with a serious acid pollution problem resulting in the permanent degradation of some of the most important monuments of its cultural legacy.
Nowadays, as a result of intense effort and environmental measures taken, a reduction of the acid pollution in Athens has been achieved, although acid pollutants have not been entirely eliminated (Adamopoulos *et al,* 2009). Although the main concern of our study is the acid rain / natural environment interaction, acid rain / human environment interaction is important for the course curriculum. Therefore, we constructed a didactical intervention in which, without underestimating the part of study concerning the acid rain effects on monuments, the study of acid rain / natural environment interaction is appropriately integrated and emphasized in the didactical activities.

The didactical intervention:
Before the actual didactical intervention a pre-test was filled in by the students. This pre-test contained both multiple-choice questions in which justification was asked for their choices, as well as open-ended questions. This pre-test was the first source from which we drew upon our first data collection for our research. More specifically, the students' answers in 7 key questions of this questionnaire comprised the 1st data collection.
Initially, students approached the acid rain / environment interaction in macro scale in the wet lab where they tried the way in which acids interact with siliceous and calcareous materials in order to elaborate on and answer the following questions: 1)How does the kind of the stone used as building material affect the vulnerability of constructions in case of acid pollution attack? 2) Is it possible that the underlying bedrock of an ecosystem can affect its interaction with acid rain and in what way? Students were given worksheets in which they concisely recorded the experiments they designed and executed, and answered the two questions according to their findings. The answers in the second question comprised our second data collection.
Afterwards, in the computer laboratory students, in groups of two, investigated the way acid pollution affects different semi-natural environments (large-scale approach) with the use of educational software. Approximately half of the groups built a virtual semi-natural landscape with underlying siliceous bedrock. The landscape consisted of a forest of various trees near a lake and an industry on the other side of the lake. Near the lake they also built a statue made of indigenous material (granite). The remaining groups built a similar virtual landscape but with calcareous bedrock and erected a statue from marble which was abundant in their local landscape. All groups filled in worksheets in which they recorded the changes that they observed occurring in the landscape under the influence of acid pollution. That means, changes to the statues' condition, changes in the life of ecosystems and the physicochemical properties of the abiotic factors of ecosystems such as soil pH, pH of rain clouds and fog, as well as the lake water pH. In addition, students were able to record some other physicochemical properties of abiotic factors such as detection of air pollutants, the presence of nutrients or poisons in the soil -depending on which of those properties they considered important for the study of the evolution of the landscape.
When the groups finished the exploration of the virtual landscapes, all of them discussed their findings together. They compared the different evolutions of their virtual landscapes, and they talked about their observations. Finally, they recorded their opinion on how acid rain affects the environment. These recordings are the third collection of data (texts) to be analyzed in order for us to answer our research questions.

The third stage of our didactical intervention took place in the computer laboratory again using the same educational software. Students, again teamed up in groups of two, investigated the nature of acid rain, and the importance of acid / rock reaction at the microscopic scale. More precisely, they built virtual landscapes (similar to the above mentioned) where they "zoomed in to the micro scale dimension" of the rain falling in order to "see" the acids dissociation and have a clearer idea of the concept of acidity and, consequently, of the meaning of acid rain. In order to "see" the deeper explanation that chemistry can offer on acid / rock interaction, all of them built virtual landscapes resting on calcareous bedrocks, with marble statues. Students zoomed in the microscopic scale of this reaction taking place on the statue material, an interaction that at macroscopic level is interpreted as monument erosion. They also studied the same reaction as it occurred in weathered bedrock (stones and minerals) as the acidic waters flowed in the soil, leading to neutralization and therefore, to ecosystems protection. In the last part, of this stage of the didactic approach, all groups discussed the way acid rain affected the city of Athens, which is founded on calcareous bedrocks, and wrote down their own conclusions. These last recordings comprised our 4rth data collection. After the didactic intervention, students completed post-tests. The post-tests were not identical to the pre-tests, but all questions corresponded to the pre-test questions. The students' answers in 7 key questions of the post-test, corresponding to the 7 key questions of the pre-test, comprised the 5th data collection. These pre and post-test key questions, gave students the opportunity to describe in detail how they perceived the acid rain / environment interaction. Four of these questions (1st set of questions) encouraged students to describe this interaction without introducing the "type of underlying rock" factor. The other three (2nd set of questions) encouraged students to describe this interaction by introducing this factor, thus providing students with the opportunity to express their opinion whether and how the rock may affect the impact of acid rain on ecosystems.
As far as these two sets of questions are concerned, a first analysis showed that in the pre-test students answered the two sets of questions in a different way. So, when analyzing pre-tests, we analyzed the two sets of answers separately. However, in the post-tests students answered all 7 questions in a way that their answers were complementary to each other, thus avoiding repetitions. The answers to the post-test 7 key questions were analyzed as a whole.
The fact that there were more than one questions concerning the same subject in the tests gave us the chance to compare the students' answers -in the varied questions- so that we would be able to interpret as accurately as possible the students' recordings. Thus, we accomplished internal validity which, obviously, is not identified with the strict objective validity of quantitative research (Winter, 2000; Velentzas, 2010, p. 183). Similarly, in the worksheets the key questions were themselves part of a wider recording context in case the respective answers seemed controversial or difficult to be classified. In such case they could be clarified by means of students' recordings in relevant parts of the worksheet. Moreover, the fact that both the tests and the worksheets were filled in the context of the didactical intervention in real class conditions increased the data validity since the students were motivated to give veracious and clear answers.

Defining categories and subcategories for data quantification

In order to analyze our data (students' answers), we referred to previous researches of science didactics examining the way students describe and explain phenomena at different scales. In particular, we focused on the researches in which the phenomena explanation is based on chemical or biochemical reactions since this is the central theme of our case study (Mohan *et al;* Anderson, 2007; Ahtee & Varjola, 1998; Barker, 1999; Hesse & Anderson, 1992; Ardac & Akaygun, 2005; Solsona *et al,* 2003). Finally, we decided to perch on the study of Solsona *et al* (2003) in which senior high school students were categorized according to the way they described the concept of chemical change, a concept that was interpreted at two scales (micro and macro) in school science. This decision was taken because in that research the data were in form of texts, and our data are mainly texts too. A second reason for this decision was the fact that the way students interrelate processes and changes described at the macroscopic scale to the processes described at the microscopic scale, plays a key role in the data analysis in this research. This is something of great importance in our research too. The initial (Solsona's and her colleagues') categories were modified and expanded so that our data could be displayed more precisely, and the large scale which is absent from traditional Chemistry curriculum but is crucial in Environmental Science in Education could be included. Below we describe the categories and subcategories as they solidified and finally turned out to be a tool with which we were able to quantify our data.

1st category: "Levels". In this research, we considered as highest performance on the part of the students, their ability to describe the acid rain / natural environment interaction as following: At large-scale level we expected them to describe the different effects of acid rain on terrestrial and aquatic ecosystems depending on how the subsoil allowed or prevented the soil and water acidification. At the macroscopic-scale level we expected them to interpret the different effects of acid rain on surface waters and soils through acid / rock chemical interaction.
Finally, we expected them to use models of the microcosm to explain this interaction (microscopic-scale level). For this category the following subcategories were distinguished:

- "Non reference to interaction". When students don't describe processes or changes at all. This is depicted as "LØ" in tables and charts.
- "Large-scale level description". When students describe how acid rain affects abiotic factors and life in ecosystems. There may be different versions of their descriptions regarding how detailed the latter may be, which properties of abiotic factors the students focus on, and whether they describe both abiotic factors and their impact on life or only one of the two. This subcategory is depicted as "La" in tables and charts.
- "Macro-scale level description". When students in order to describe how the acid rain affects the natural environment, they only describe the acidic water / stone interaction. This subcategory is depicted as "Ma" in tables and charts.
- "Description at Macro and Large scale levels which are not successfully interrelated". It is a combination of the two above mentioned levels, macro and large, but without establishing the correct interrelation between the macroscopic and large levels. That means that macro-scale processes are described in such a way that they are inadequate to explain and justify what is described in large scale. This subcategory is depicted as "Ma#La" in tables and charts.
- "Description at Macro and Large scale levels which are successfully interrelated". It is the correct combination between the macroscopic and large levels. This means that in their recordings, students describe the outcome they anticipate (or observe) of acid rain affecting ecosystems, and they explain their opinion based on the different way acidic water interacts with different kinds of rocks. This subcategory is depicted as "Rel(Ma,La)" in tables and charts
- "Description at Micro, Macro and Large scale levels which are successfully interrelated". It is the perfect and thorough way of describing the environmental phenomena and problems. This means that recordings classified in this subcategory, not only explain the different ways acid rain interacts with seemingly similar ecosystems through acid /rock interaction, but also explain this interaction using entities and systems of the microcosm. In order for a text to be classified in this category, it is not sufficient to contain references to some entities of the microcosm, but should be obvious in the texts why these entities are important. This means that the microcosmic entities and processes mentioned must substantially contribute to the explanation of the observed changes at the macro and large scales. This subcategory is depicted as Rel(Mi,Ma,La) in tables and charts

2nd category: "kind of change". Through this category we are trying to investigate how students understand the acidic water interaction with the natural environment in the two lower levels, namely microscopic and macroscopic level. As mentioned above, this interaction is defined by the acidic water / rock reaction in the soil, ie when this reaction is strong it buffers the acidity of abiotic factors (soil and water). Consequently, we are investigating how students understand and describe this very chemical reaction. In this category we distinguish the following subcategories.

- "No change statements given". This subcategory is depicted as "ChØ" in tables and charts
- "Erosion". When students refer to stone erosion, or stone plasterization by the acidic water percolating the soil, without giving more information about changes in properties or substances. This subcategory is depicted as "Ers" in tables and charts
- "Physical Change / Change in Properties". When students describe the change of properties (acidity, calcium and aluminum concentration) resulting from the acidic water / stone (in the soil) interaction. Some of the texts belonging to this subcategory describe the interaction as mixing, absorption, dissolution, while others regard it as reaction. However, even in the latter texts, it is not clear that the students have fully understood the nature of the reaction. This subcategory is depicted as "Ph/Pr" in tables and charts.
- "Substance change". When students, having fully understood the reaction, describe precisely the acid/stone interaction as formation of new substances from the initial substances which have practically disappeared. As the new substances' properties are different from the initial ones, the reaction results in the change of properties in the reacting system. This subcategory is depicted as "Sub" in tables and charts.

3rd category: "Effects on Ecosystems". Through this category, we are trying to investigate how students understand the acidic water interaction with the natural environment at the large level, ie at the level where the evolution of entire ecosystems is observed. These changes are exactly the subject of environmental science, and it is because we need to predict and explain them that we study the changes at the lower two levels (scales). In this category we distinguish the following subcategories.

- "No effect statements given / undefined" When students select "don't know" in multiple-choice questions, do not answer at all, or give an answer not relevant to the question. This subcategory is depicted as "NA" in tables and charts.
- "All Vulnerable". When students describe damage that occurs in terrestrial and aquatic ecosystems but without considering the possibility of any factor in the ecosystems playing an important role in protecting the ecosystems from acid pollution.
- "Calcareous Vulnerable" When students express the view that ecosystems with underlying calcareous subsoil are more vulnerable to acid rain attack than similar ecosystems with underlying siliceous subsoil.
- "Differentiated effects" When students consider that the different interaction of acid rain with the different rock types may be important to the ecosystems, but they also consider that the strong interaction with the calcareous rock results in both positive and negative consequences to ecosystems founded on such subsoils.
- "Calcareous Resistant" When students express the view that ecosystems lying on calcareous subsoil are more durable to acid rain attack than similar ecosystems lying on siliceous subsoil. This last view is the "correct approach" to the acid rain / natural environment interaction phenomenon.

RESULTS

Analyzing our data by means of the set of categories and subcategories described above, we derived the quantified results that are depicted on the tables that follow.

Table 1: quantification of 1st data collection, 1st set of questions

Effects on Ecosystems	Levels	kind of change	instances
NA	LØ	ChØ	1
	La	ChØ	1

All Vulnerable	LØ	ChØ	6
	La	ChØ	51

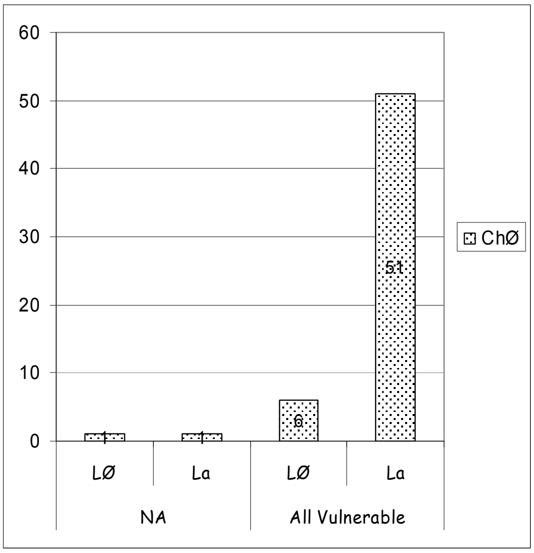

Chart 1: 1st data collection, 1st set of questions

Table 2: quantification of 1st data collection, 2nd set of questions

Effects on Ecosystems	Levels	kind of change	instances
NA	LØ	ChØ	6
	Ma	Ers	1
All Vulnerable	LØ	ChØ	1
	La	ChØ	1
Calcareous Vulnerable	LØ	ChØ	22
	Ma	Ers	22
	Rel(Ma,La)	Ers	3
Calcareous Resistant	LØ	ChØ	2
	Rel(Ma,La)	Ph/Pr	1

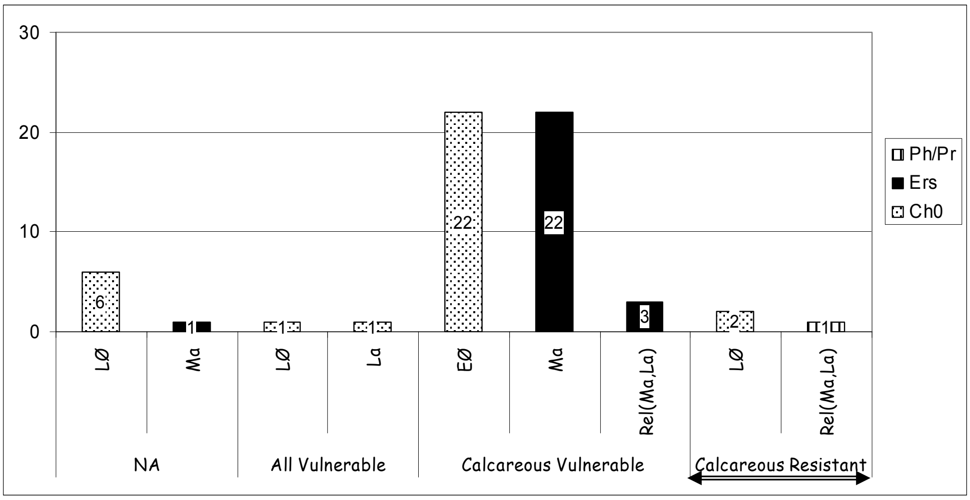

Chart 2: 1st data collection, 2nd set of questions

In the pre-tests students preferred to give large and macro-scale descriptions but without linking large scale changes described in the first set of questions to macro scale processes described in the second set of questions. So, in the first set of questions, the large majority (51 subjects) described the consequences that –in their view- acid rain had on ecosystems' abiotic factors (surface water acidification, soil erosion), but mainly on ecosystems' biota (trees and aquatic organisms). However, they didn't refer to the acidic water / rock interaction and, therefore, didn't distinguish between ecosystems more resistant or vulnerable to acid attack. In contrast, in the second set of questions, the majority of them (47 out of 59) thought that ecosystems resting on calcareous foundation were more vulnerable to acid rain attack. Approximately half of them justified their view by referring to their knowledge about acid rain / calcareous stones strong interaction. Therefore, they deduced that the rock vulnerability was somehow transferred to the ecosystem but without describing which factors of the ecosystem were influenced and in what way. Only 3 out of 47 referred to specific effects on abiotic factors (soil erosion, collapse of the terrestrial ecosystem). The other 22 did not justify their view at all.

Table 3: quantification of 2[st] data collection

Effects on Ecosystems	Levels	kind of change	instances
NA	LØ	ChØ	4
All Vulnerable	Ma	Ers	1
Calcareous Vulnerable	Ma	Ers	20
	Rel(Ma,La)	Ers	24
Differentiating effects	Rel(Ma,La)	Ph/Pr	2
Calcareous Resistant	Ma	Ph/Pr	3
	Rel(Ma,La)	Ers	1
		Ph/Pr	4

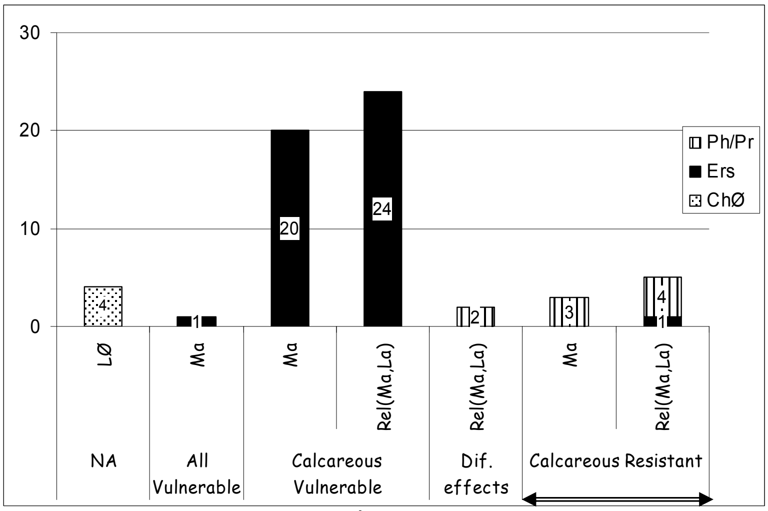

Chart 3: 2[nd] data collection

In the wet lab they tried different rock types interaction with acidic solutions and they confirmed their initial notion about the acid / calcareous stone strong reaction. From the experiment descriptions in their worksheets it can be derived that, although the vast majority of them measured the pH increase this interaction entailed, they persisted focusing on the destructive side of the reaction. Consequently, they deduced that this interaction led to natural environment erosion (which is wrong). Half of them suggested soil collapse, thus interrelating macro and large scales. However, a small part of the sample (9 subjects) begun to suspect the impact the pH change might have on ecosystems.

Table 4: quantification of 3[rd] data collection

Effects on Ecosystems	Levels	kind of change	instances
NA	LØ	ChØ	2
	La	ChØ	1
	Rel(Ma,La)	Ph/Pr	2
Differentiating effects	Rel(Ma,La)	Ers	2
Calcareous Resistant	La	ChØ	30
	Ma # La	Ers	3
	Rel(Ma,La)	Ph/Pr	19

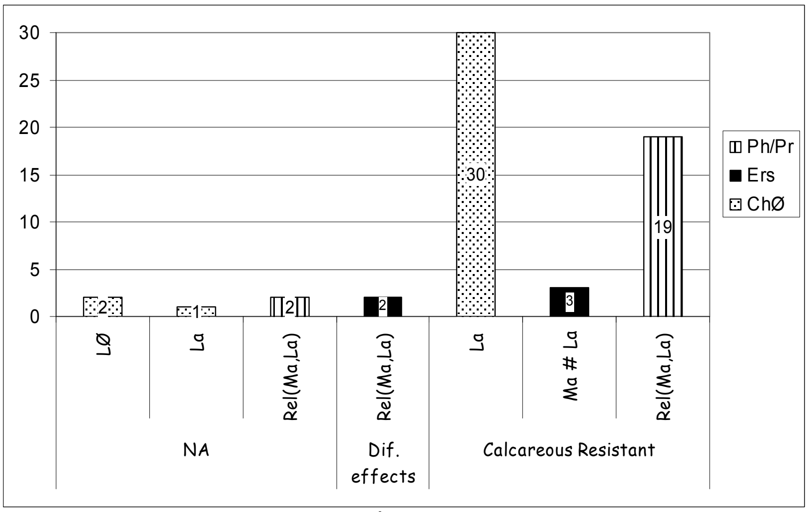

Chart 4: 3nd data collection

When, through the software, students approached the problem at the large-scale domain (ecosystems' long term alteration), the large majority described it at this scale correctly. Moreover, a remarkable part of the sample (19 subjects) were able to interpret the large-scale phenomena (different acid rain effects on, at first sight, similar ecosystems) by macro-scale processes, more specifically by the acid /stone interaction as acidic water percolated the soil. They described this interaction as a change in properties - mainly in acidity.

Table 5: quantification of 4th data collection

Effects on Ecosystems	Levels	kind of change	instances
Calcareous Vulnerable	La	ChØ	1
	Rel(Ma,La)	Ers	2
Differentiating effects	La	ChØ	2
	Rel(Ma,La)	Ers	2
Calcareous Resistant	La	ChØ	9
	Ma # La	Ers	2
	Rel(Ma,La)	Ph/Pr	20
		Sub	13
	Rel(Mi,Ma,La)	Sub	8

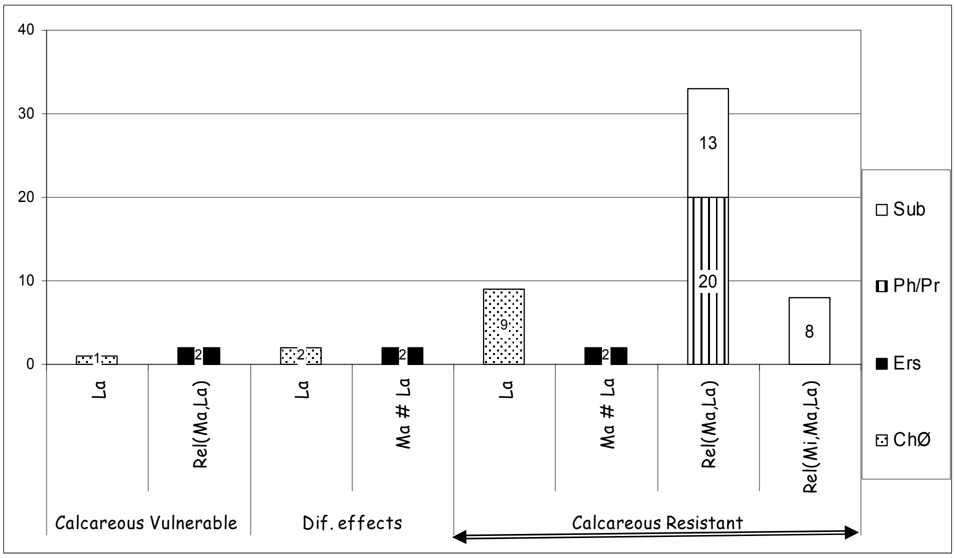

Chart 5: 4th data collection

When students, through the software, encountered micro scale systems and models they seemed to satisfactorily comprehend the chemical reaction and its significance to the ecosystem. Approximately one third of the sample described the reaction accurately as being a process of disappearance of some substances (the strong acid being among them) and a formation of new ones with different properties. One third of the sample described the reaction as a change in properties (mainly in acidity) without clearly defining this reaction. These two parts of our sample successfully explained what occurred at large scale through macro scale processes. However, only a small part of the sample (approximately 1/10), correlated the three scales (micro macro and large). Finally, students described acid rain / natural environment interaction in a similar way in the post-tests as depicted in the following table and chart.

Table 6: quantification of 5th data collection

Effects on Ecosystems	Levels	kind of change	instances
Calcareous Vulnerable	La	ChØ	2
	Ma	Ers	1
	Rel(Ma,La)	Ers	8
		Ph/Pr	1
Differentiating effects	La	ChØ	1
	Rel(Ma,La)	Ph/Pr	2
Calcareous Resistant	La	ChØ	6
	Ma # La	Ers	2
	Rel(Ma,La)	Ers	1
		Ph/Pr	20
		Sub	9
	Rel(Mi,Ma,La)	Sub	6

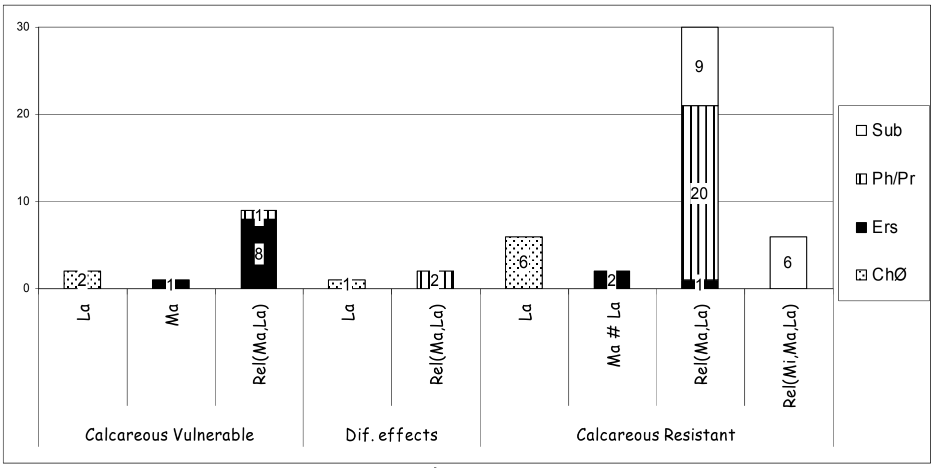

Chart 6: 5th data collection

CONCLUSIONS

In order to answer the research questions of the current study we had to observe and interpret the charts given in the results section. As far as the scales used by the students when they described and explained the acid rain effect on the natural environment are concerned, we noted the following: In the two first stages of the didactic intervention, students tended to describe the changes occurring in ecosystems (large scale), or macro-scale processes depending on the level on which the particular stage focused. A relatively small part of the sample tried to predict or explain the large-scale changes using deductions from the macro-scale ones. However, this did not occur in the third stage of the didactic approach which focused on micro-scale. That means that they did not incorporate microcosmic systems, entities and processes in their descriptions although microcosm was at play in this stage. However, it is worth mentioning that a larger part of them correctly interrelated changes and processes at the two higher levels, i.e. they correctly explained the way local bedrock offered (or did not offer) adequate protection to ecosystems from acid rain attack.

As far as the way in which students described and explained the acid / stone reaction is concerned, we noted that, initially, students (in the pre-tests and the first worksheets) described this reaction rather superficially, as damage to the stones. When the students interacted with the virtual landscape for the first time, they tried to explain their observations which, judging from their descriptions in the pre-test and the first worksheets, contradicted their initial views. Therefore, they began to describe the acid / rock interaction more precisely, by focusing on the properties changes this interaction resulted in. Finally, students' interaction with the virtual representation of the microcosm in the computer lab played a key role in the understanding of the very nature of this reaction.

In conclusion, we could say that it was difficult for the majority of the students to use micro scale systems, models and processes in their explanations. Their interaction with the micro scale world helped them to enhance their understanding of the chemical reaction, and this enabled them to associate macro scale processes with large-scale phenomena.

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