DOCUMENT RESUME

ED 466 371 SE 066 075

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TITLE	The Carbon Cycle and the Earth Systems--Studying the Carbon Cycle in Multidisciplinary Environmental Context.
PUB DATE	2001-00-00
NOTE	14p.; In: Science and Technology Education: Preparing Future Citizens. Proceedings of the IOSTE Symposium in Southern Europe (1st, Paralimni, Cyprus, April 29-May 2, 2001). Volume I [and] Volume II; see ED 460 860.
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Course Descriptions; *Curriculum Development; *Earth Science; *Ecology; *Environmental Education; Science Instruction; *Science Programs; Secondary Education
IDENTIFIERS	*Carbon

ABSTRACT

This paper describes a method that attempts to confront the challenges of developing an environmentally-based earth sciences program. The research scheme includes five stages: (1) predevelopment study; (2) curriculum development; (3) implementation; (4) formative evaluation; and (5) curriculum modification. The research results indicate that the program contributed to meaningful learning in relation to the Global Carbon Cycle (GCC) and the achievement of cognitive goals concerning earth systems as well as to the role of man among natural systems. (Contains 15 references.) (MM)

The Carbon Cycle and the Earth Systems – Studying the Carbon Cycle in Multidisciplinary Environmental Context

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INTRODUCTION

During the last two decades the public has been exposed through the mass media to a lot of global environmental issues such as the increased greenhouse effect, depletion of the ozone layer and water pollution. As a result of our era of information disclosure, public awareness toward these topics has increased, as well as the awareness that human activity might cause damage to the natural systems and that such damage might in turn have a negative effect on the human population. However, the information provided through the mass media is often biased and even incorrect, thereby contributing to the development of misconceptions concerning environmental issues (Brody, 1994).

One of the results of the growing public awareness of these topics was a demand for more scientific research concerning global and regional environmental issues. This demand was followed by a change in the public's perception of the earth sciences: from a disciplinary approach (with a distinction between geology, hydrology, atmospheric science, oceanography, etc.) to a multidisciplinary approach, studying the interaction between the different earth systems as well as between the natural systems and human activity.

The change that took place within the scientific community had a major effect on science education as well. Consequently, many scientific curricula dealing with environmental multidisciplinary topics have been developed. However, the curriculum developers have had to confront the many alternative frameworks that students bring to the classroom as the result of a non–mediated exposure to the mass media.

This article describe a method that attempt to confront the challenges of developing an environmentally based earth sciences program.

THE RESEARCH SCHEME

The research scheme includes the following five stages: predevelopment study, curriculum development, implementation, formative evaluation, and curriculum modification.

The predevelopment study: The objectives of the predevelopment study are as follows: (a) to choose a scientific multidisciplinary topic with a distinct connection to global environmental problems, (b) to select the specific themes for the program, and (c) tó learn about student's previous knowledge, perceptions, and misconceptions concerning environmental problems in general and, the selected topic in particular.

In order to achieve the two first objectives the environmental educational literature was thoroughly reviewed, followed by several interviews with earth and environmental sciences researchers. Importantly this study revealed that multidisciplinary topics concerning biogeochemical cycles might serve as an ideal model for illustrating the interactions among the various earth systems and between them and man. Subsequently, it was later decided that the current study will focus on the Global Carbon Cycle (GCC).

In order to achieve the third objective, data concerning students' previous knowledge and interest in environmental topics was collected using Likert-type questionnaires and interviews. This study examined a high school population of about 70 students and its main findings were as follows:

a) Students declared high understanding of environmental problems and biologic processes. For example, global warming (mean of 3.3 in a 1–4 scale, S.D=0.8), climate change (M=3, S.D=0.8), ozone layer (M=3.1, S.D=0.9), and photosyntesis (M=3.7, S.D=0.5).
b) Students declared only partial understanding of more abstract topics connected to these environmental problems such as earth radiation balance (M=2.3, S.D=1), greenhouse gases (M=2.5, S.D=1), and albedo (M=2.6, S.D=0.9).
c) Most of the students understood that global warming is connected to the greenhouse effect (mean of 3.7 in a 1–5 scale, S.D=1).
d) Most of the students thought that greenhouse effect is directly connected to depletion of the ozone layer (M=3.7, S.D =1.1).

The interviews indicated that students hold the following alternative framework: the "hole" in the ozone layer allows more radiation to enter the atmosphere and then it was trapped by the greenhouse effect. Global warming is the result of the combination of these two elements: the hole in the ozone layer and the greenhouse effect. A similar findings were reported by Boyes & Stanisstreet (1993), Francis et al. (1993), Christidou (1994), Rye et al. (1997), and Boyes & Stanisstreet (1997).

The results described above show that students are aware of the environmental problems, but, on the other hand, their knowledge is very limited. This contrast supports Orion (1997) who claimed that the environmental problems are just symptoms of the real problem: the effect of human activity on natural balance among the earth systems.

These findings suggest that the environmental aspects of the carbon cycle are related to the student's daily life; however, any program that deals with such a topic should take into account that students would enter such a learning experience with some basic alternative conceptions.

CURRICULUM DEVELOPMENT

Program development was based on the constructivist (student–oriented) approach. The curriculum was built around the following three sub–units:

The Core Unit: The purpose of this unit is to provide students with a complete and balanced picture of the GCC. The first part of the program deals with the most obvious environmental topic that students are most aware of – the greenhouse effect and increased atmospheric CO_2. One of the objectives of this part is to demonstrate that in order to understand the atmospheric CO_2 balance all of the four natural earth systems: geosphere, hydrosphere, atmosphere, and biosphere must be considered, in addition to human activity.

In order to deal with students' alternative models, the core unit uses the cognitive conflicts strategy (Nussbaum & Novick, 1982). Cognitive conflicts are the result of additional information that does not fit students' previous knowledge and consenquently forces students to rearrange their knowledge and gradually enhances their perceptions of GCC.

Two additional learning materials were developed for the core unit. (1) a booklet that directs students' investigations through activities and (2) a booklet for scientific critical reading including popular articles, with directions ffor critically reading them.

The Individual Projects Unit: In this unit each student or group of students has to select one of the components of the GCC that they encounter in the "Core" unit and to elaborate it through self study the literature.

Geotop: This unit is based on a field study of the components of the carbon cycle that appears in a karstic cave in the Judean mountains. The learning is conducted as a "team–self" project, While each team of students has to identify a research question and to study it based on field observations and laboratory analysis.

IMPLEMENTATION

The new curriculum was implementated with 11th and 12th grades high school classes that participated in the program as part of the fulfillment of their earth sciences matriculation program of 5 credit point. The specific study population included one class of 15 students from a typical urban high school.

THE STUDY

The implementation of the whole three units of the new curriculum was followed by an extensive study. Our literature review identified few publications with some educational aspects of studying environmental issues in general and the global warming effect in particular (Wadingtton, 1994. Rubba et al, 1995. Fortner & Mayer, 1993. Bolden et al, 1991) However, no references were found concerning the cognitive aspects of learning and understanding complex and abstract topics such as biogeochemical cycles. Thus, the main purpose of this study was to shed some light on students' abilities and their difficulties in perceiving the dynamic and cyclic transformation of matter and energy among the different earth systems and the interactions among them. Since we had almost no reference on which to base our study, the current study was mainly phenomenological. Therefore we developed a research strategy that we named the "Fishing net" approach. The idea behind this approach was that dealing with a subject not yet explored is like fishing in a dark water and therefore in order to "catch" some meaningful insight the best strategy is to use a wide net with small holes in a relatively small area. Thus, in order to extend our ability to collect meaningful data, we based our study on a variety of qualitative and quantitative research tools, which operate on a relatively small sample. Fourteen different inventories were specialy developed for this study. In addition, the data were collected and analyzed through a "zoom in" method, namely from a level of the class as a whole to the level of the small groups of students that worked together as teams throughout the whole learning process to level of the individual student. This research structure enabled us to identify many dependent and independent variables that might affect the learning process. The quantitative tools enabled us to collect and analyze data in relation to the population studied as a whole, whereas the qualitative tools enabled us to detect cognitive processes within the level oof the individual (Denzin & Lincoln, 1994). The combination of the two methods allowed us to triangulate data collected by different tools and to increase the reliaibility of our findings and conclusions (Fraser and Tobin, 1992).

Table 1 describes 8 questionnaires out of the 14 inventories that were specially developed for this study. These research tools examined aspects such as knowledge and understanding of components and processes of the GCC, perception of systems, understanding the interactions among earth systems, understanding the principle of mass conservation and the quantitative perception of GCC. The tools include different types of questionnaires, namely closed (Likert type), open and matching, and were filled in by the students before (pre) and after (post) the implementation.

At the end of the core unit a cognitive test was conducted. It tested students' cognitive skills of critically reading a popular scientific article concerning environmental issues, analyzing models of GCC, and presenting matter (carbon) transformation within the earth systems. The last assignment provided a broader picture of students' knowledge concerning the processes of matter transferred among the different earth systems. Students were asked to describe two paths (continuity of processes) that transfer Carbon between two given points in earth.

The content validity of all the inventories used by this study was evaluated by 5 experienced researchers. Two of them were experts in earth science and environmental education, two were experts in science education in general, and one was a expert in environmental sciences. The construct validity of the differenet inventories was tested by the following procedures: (a) comparing the content of the inventory's items with the syllabus of the program and (b) reviewing the thinking skills level needed for answering those questions according to Bloom's taxonomy (Bloom, 1956).

Table 1: description of 8 out of the 14 questionnaires.

Questionnaire	Description	Type of questionnaire	Pre	post
Earth systems mass	Students were asked to assume the partial mass o each of the earth systems.	Likert (1-6) (1=<1% 6=>50%)		√
Mass change	Students were asked to answer whether the listed processes change earth mass.	Likert (1-2 / 1-3) (1=no change 3=major change)*	√	√
Carbon in earth systems	Students were asked to assume the distribution of the carbon among earth systems.	Likert type (1-6) (1: <1% 6: >50%)	√	√
Greenhouse effect	Student's agreement with statements concerning the greenhouse effect.	Likert (1-5)	√	√
Balance in earth systems	Student's agreement with statements concerning interactions between earth systems.	Likert (1-5)	√	√
Consequence of the greenhouse effect	Students were asked to describe the effect of increased atmospheric CO_2 on natural earth systems.	Open		√
Knowledge	Students were asked to describe their knowledge of concepts concerning GCC and environmental issues.	Likert (1-5)	√	√
Atmospheric CO_2	Students were asked whether the listed processes change atmospheric CO_2.	Likert (1-2 / 1-3) (1=no effect 3=direct effect)**	√	√

* In the pre test there were only 2 options (1–no change, 2–change). After analyzing students' pre questionnaires and interviews, the answer changed (1–no change, 2–minor change, and 3–major change).

** In the pre test there were only 2 options (1–no effect, 2–effect). After analyzing students' pre questionnaires and interviews, the answer changed (1–no effect, 2–not direct, and 3–direct effect).

The qualitative research tools included observations of the students during their learning process and interviews with several students.

The comparisons between pre and post data collected by the different questionnaires provided information about changes in students' knowledge and perceptions, whereas the final exam analysis provided a more precise picture of students' knowledge at the end of the program. The analysis of observations provided information about each individual student's behavior and participation in class and the interviews provided a deep understanding of the cognitive perceptions of individual students in the context of the interrelationship between the different earth systems.

DATA ANALYSES

The qualitative data collected was used to observe the changes in students' knowledge and perceptions. A wilcoxon non–parametric test was used to between the pre–test and the post–test of the Likert–type questionnaires. Students' answers to the open–

ended questionnaires were categorized and then the distribution of each category was analyzed quantitatively. In order to identify differences between individual students, a mean score was calculated for each student in relation to each of the questionnaires. These values were classified acoording to three levels: low, medium, or high (Table 2). This technique was found effective in pointing out differences between students and useful in spoting students' difficulties in relation to a specific category or subject.

Table 2: An example of the data analysis in showing differences between different students in relation to a specific questionnaire.

1	2	3	4	5	Student no.
2.2	2.4	1.8	1.9	2.1	Pre
3.2	2.8	3.4	2.9	2.9	Post

Low score	Medium score	High score

The final exam was evaluated according to the criteria that were defined for each of the questions, and students' answers were categorized and analyzed similarly.

Each process of categorization and matching of a student's answers to the different categories in relation to each of the inventories was validated by three experts in science education.

RESULTS

Global environmental problems

The comparison of the pre and post data of the "knowledge questionnaire" indicated a significant increase of students' declared understanding, after the core unit, concerning concepts related to GCC and the greenhouse effect. However, no change was detected concerning their declared knowledge of other environmental problems such as depletion of the ozone layer.

The analysis of the "greenhouse effect questionnaire" and the final exam indicated a significant change in students' perceptions of the role of man in creating the greenhouse effect. After the core unit, most of the students understood that the greenhouse effect is a natural phenomenon, which is affected by human activity. They were also aware of the fact that the degree of the effect is still unknown. These findings indicate that students' assumptions regarding the role of man with natural processes became more realistic. Table 3 shows a meaningful improvement of students' knowledge about the processes that emit CO_2 into the atmosphere. The major change found was regarding the effect of the geologic processes (element 3) and the change in the total biomass (element 4) on atmospheric CO_2.

No significant improvement was found concerning students' perceptions of the relation between the greenhouse effect and the depletion of the ozone layer.

Table 3: Results of the pre/post analysis of the "Atmospheric CO_2" questionnaire (N=15).

How would the processes listed below affect atmospheric CO_2 concentration?	Pre test		Post test		
	No effect	Effect	No effect	Indirect effect	Direct effect
1. Fossil fuel burning	20%	80%	0%	7%	93%
2. Industry and power stations	20%	80%	0%	0%	100%
3. Volcanic eruption	47%	53%	0%	13%	87%
4. Forest fires	27%	73%	0%	7%	93%

Processes in the global carbon cycle

A clearer picture was obtained concerning students' understanding of specific processes after studying the core unit obtained from the analysis of the "matter transfer" questionnaire. Table 4 presents students' results concerning "volcanic eruption" (one out of four processes that appeared in the questionnaire). Volcanic eruptions are those processes that emit matter from the geosphere. The matter emitted is molten rocks (back to the geosphere) and different gases (into the atmosphere and/or to the hydrosphere). Student's results indicated that they tend to overemphasize the role of the atmosphere as a sink compared to other earth systems. These results indicate that students are more aware of the effect of different processes on the atmosphere but their knowledge about the effect of those processes on other earth systems is limited.

Table 4: Results of the "matter transfer" questionnaire (n=15).

Volcanic eruption	To the hydrosphere	To the geosphere	To the biosphere	To the atmosphere	Total*
From the hydrosphere				1	1
From the geosphere	4	7	2	13	26
From the biosphere					0
From the atmosphere					0
Total*	4	7	2	14	

* Students could choose more than one answer.

The analysis of students' answers to their assignment of describing the paths (continuity of processes) that transfer Carbon between two given points in two separate earth systems reveals the following:

→ Students describe respiration by marine organisms as a process that emits CO_2 directly into the atmosphere.

→ For example, students used the diffusion process to describe the flow of carbon from the atmosphere into the ocean, but no student used this process to describe the flow of matter in the other direction. In order to explain this finding, it is important to note that the core unit included an experiment that demonstrated the diffusion of CO_2 from air into water. However, the reverse process was only mentioned orally and was not demonstated through active lab activity. This finding indicaate that students have difficulty in transferring knowledge from one situation to a similar one. Thus, the program should include more concrete demonstrations and after the concrete learning, more emphsis should be given to teach basic physical and chemical processes such the "Le Chatelye" principle.

→ Only a few students succeeded to integrate in their descriptions a path that crosses the hydrosphere (water cycle) and the geosphere (rock cycle).

These results indicate that most of the students have difficulties understanding abstract processes in GCC and only a few students are aware of the relationship of GCC and other global cycles.

Carbon reservoirs in earth systems and the mass of earth systems

Figure 1 demonstrates the mean scores of students' answers of the "carbon in earth systems" questionnaire that was administrated to explore the effect of the program on students acquaintance of the carbon reservoirs on earth. indicates an improvement of students' perceptions of the relative sizes of the different carbon reservoirs on earth. At the pre test no student ranked the rocks as the biggest carbon reservoir, whereas in the posttest 40% of the students ranked rocks as containing more than 50% of the carbon on earth. The number of students who showed a totally different view in relation to scientific reality dropped from 60% to 47%. The comparison between the pre test and the posttest, using a Wilcoxon matched paired test showed a significant change only in students' perceptions of the relative size of the rocks as carbon reservoir. However, it is important to note that even in relation to this improvement, the students' perceptions are still very far from the scientific fact that the rocks contain more than 99.9% of the total carbon.

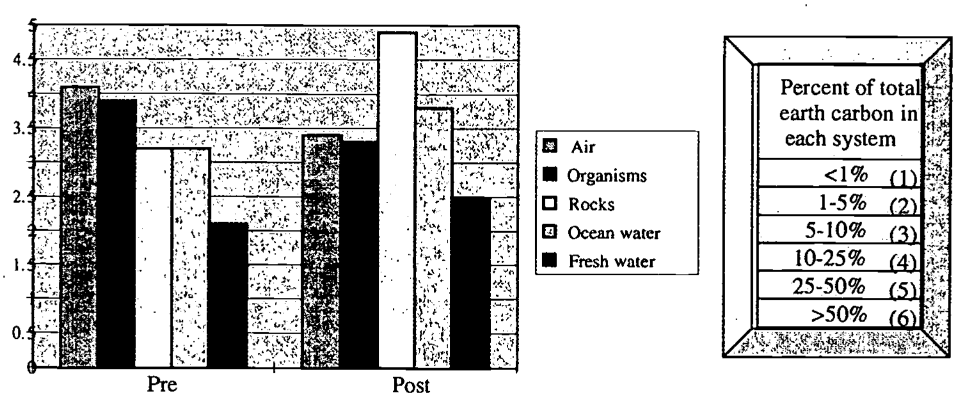

Figure 1: average students answers to "Carbon in earth systems" questionnaire

A comparison between students' answers to the "Carbon in earth systems" questionnaire and the "Greenhouse effect" questionnaire were conducted using a non–parametric correlation Kendell test. This analysis showed a significant correlation between the pre tests of these two inventories as well as between their post test data. These findings indicate a similarity in students' previous knowledge toward these topic and a similarity in the effect of the program on them.

A triangulation between the results of these two questionnaires and the results of the "earth system mass" questionnaire that explored students' perceptions of the partial mass of each of the earth systems indicates the following:

→ Fourty percent of the students ranked the rocks as the biggest carbon reservoir and the geosphere as the biggest earth system. However, only 20% of the students had correct scientific knowledge in all of the questionnaires.

→ Sixty percent of the students overemphsized the biosphere mass and/or the carbon reservoir in the biosphere. They perceived the biosphere mass as equal to or bigger than the geosphere or the hydrosphere.

Interaction between earth systems

A deep understanding of the carbon cycle, especially in the context of environmental issues, must include an understanding of the interactions between the cycles' components, namely the reservoirs and the processes. The "Balance in earth systems" questionnaire was given to explore students' awareness and understanding of the natural processes that balance the amount of carbon in the different earth systems. Students had to judge seven statements such as "the amount of water in the ocean gradually increases because rivers keep adding water to it" (7% failed to answer in the pre test) and "increased annual precipitation in the our region will cause an increase in the Mediterranean Sea level" (40% failed in both pre and post test). A Wilcoxon Matched Paired test revealed no significant change between the pre and post tests.

In the "Consequence of the greenhouse effect" questionnaire students were asked to describe the effects of an increased atmospheric CO_2 level on different earth systems. The students tended to describe changes in the CO_2 level as a result of increased temperature. Most students mentioned effects on the biosphere (66%) (death of animals) and on the hydrosphere (53%) (enhanced evaporation). Only a few students mentioned the possible effect on geologic processes such erosion and sedimentation (27%) and on oceanic CO_2 concentration (13%).

The role of man in natural systems

The analyzing of the interviews indicated that at the end of the learning, students said that their knowledge about human activity on natural systems is more realistic. On one hand, students believe that man should reduce his effect on the natural systems, but, on the other hand, students understand that, in a geologic time scale, the effect is negligible. Students also understand that all different environmental problems will affect the human population.

These results enable evaluating the effect of the program on students' knowledge according to the whole class average. Table 5 shows a more detailed analysis of the final exam results and compares individual students. Results indicate the students' final grades, which was all in the narrow range of 72–89. Comparisons between individual students' achievements in different parts of the exam and between different students in the same part show that there is no correlation between different parts of the exam. A comparison between different parts, using a non–parametric correlation Kendell test indicates a significant correlation (0.51 p=0.04) only between the first two parts. The wide variability of students' grades and its distribution along the different parts of the exam indicates that the learning process is an individual process and each student internalized different topics differently.

In order to get a more accurate picture about the effect of the program on the individual, three case studies of individual students were conducted and analyzed.

Student A (No. 14 in Table 5): The knowledge of this student about specific topics taught in class was improved and her perceptions of earth systems and processes in the carbon cycle approached the scientific knowledge. She views the effect of human activity as a factor that affects natural balance, but according to questionnaires, she has not internalized the topic of natural balance. This student has difficulties in transferring principles she had learned in the context of a specific topic under different conditions. She has difficulties in seeing the broad, complex picture of earth and earth systems. This is expressed by difficulties in focusing on a specific topic from the broad pictures and by the fact that she has not internalized the principle of matter conservation in the context of earth.

Table 5: The distribution of students' grades in the final exam (n=15).

Student No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	S.D.
Part a	12	12	12	12	18	12	12	12	12	12	12	12	12	18	12	12.8	2.1
Part b	20	22	20	18	23	21	18	17	24	20	15	24	21	24	22	20.6	2.7
Part c	15	22	22	21	20	18	17	21	22	18	22	20	18	20	22	19.9	2.2
Part d	25	27	26	23	27	30	29	26	31	32	28	29	22	21	21	26.5	3.5
Final grade	72	83	80	74	88	81	76	76	89	82	77	85	73	83	77	79.7	5.3

Student B (No. 11 in Table 5): The final exam and questionnaires of this student presented a relatively high level of knowledge. According to questionnaire results, his knowledge improved during the learning period. His achievements were most remarkable in the questionnaires dealing with balance and the interactions between natural earth systems. The interview supports this finding and reveals student perspective: the complexity of the whole system exited him. On the other hand, his knowledge concerning specific processes was quite poor.

The data analysis at the individual student level supports the finding about the variability between students, and adds another perspective: some students tend to focus on specific parts of the whole systems whereas others tend to concentrate on the full picture.

Discussion

The research results indicated that the program contributed to meaningful learning in relation to the GCC and to the achievement of the cognitive goals concerning earth systems as well as to the role of man among natural systems. Note that meaningful learning occurred mostly in the processes demonstrated in class using student–centered activities. The results support the effectiveness of using the constructivistic approach and a variety of teaching and learning strategies.

Two types of alternative frameworks (misconceptions) were identified by this study:

- Knowledge–related misconceptions. For example, the notion that the depletion of the Ozone layer influences global warming. In this misconception the advantage of using a constructivist teaching strategy focused on the specific topic.
- Perceptional misconceptions. For example, viewing the atmosphere as the biggest Carbon reservoir in comparison with the other earth systems. This misconception illustrates that more qualitative activities should be developed and integrated in the program.

Many students showed difficulties in transferring knowledge about processes of matter transfform between liquids and gas, to other exchange processes.

These difficulties illustrate the need to enhance students' background in chemistry and physics.

The results indicate a great variance between students' knowledge, understanding, and the ability to perceive the earth as a whole system. Based on these findings, four levels of system perception were identified:

- Level 1: **Knowledge** about the earth system's components and awareness of the connections (the transform of matter and energy) between them.
- Level 2: **Understanding** the exchange processes among various materials, between the systems.
- Level 3: Preceiving the interrelationships among the earth systems.
- Level 4: Preceiving the earth system as a unified whole.

It was found that there are three critical factors for achieving a unified system perception: (1) perception of an interrelationship between sub–systems, (2) the ability to perceive the cycling nature of materials on earth (also known as the principle of mass conservation), and a qualitative perception of size, rate, and quantity in relation to the earth systems.

Most students increased their knowledge and understanding in levels 1 and 2.

However, only two students achieved levels 3 and 4. Note that those two students did not get the highest scores in levels 1 and 2.

The findings regarding the hierarchical structure of unified system perception indicate that this perception is probably not knowledge related.

Note that this research should be considered pilot research because of the small target population and the fact that research tools were modified during the study.

This study contributed to following major areas:

A. The development of a meaningful interdisciplinary educational program dealing with four earth systems. importantly the teaching strategy demonstrated in this study can be applied to other "cyclically related" earth science and environmental topics.

B. The defining the primary factors that might affect students' ability to perceive a unifying system.

C. The identification of several important research questions that should be explored on a larger population.

D. The development of research tools that also should be tested on a larger population.

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Title: Proceedings of the 1st IOSTE Symposium in Southern Europe

1. Valanides, N. (Ed.). (2001). Proceedings of the 1st IOSTE Symposium in Southern Europe-Science and technology education: Preparing future citizens. Vol. I (pp. 456). (Section 1: Relevant teaching, incorporating curriculum, teaching approaches and assessment aspects. Section 2: Environmental issues including sustainable development and a culture of peace. Nicosia, Cyprus: Imprinta (2001).

2. Valanides, N. (Ed.). (2001). Proceedings of the 1st IOSTE Symposium in Southern Europe-Science and technology education: Preparing future citizens. Vol. II (pp. 400). (Section 1: Action research involving classroom related studies and professional development studies. Section 2: Resources supporting teaching, including locally produced equipment. Visualization ideas using new technologies.) Nicosia, Cyprus: Imprinta Ltd.

Author(s): Multiple authors

Corporate Source:	Publication Date:
Organizer of the Symposium : Nicos Valanides	April 2001

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