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Biogeochemical cycles for combining chemical knowledge and ESD issues in Greek secondary schools
Part II: Assessing the impact of the intervention

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ABSTRACT: In searching effective ways to combine science/chemical education with EE/ESD, new didactic materials were designed and produced focussing on biogeochemical cycles and their connection to sustainable development. The materials were experimentally applied in 16 Greek schools under the newly introduced compulsory "school project" which offers an excellent opportunity for development EE/ESD projects. The effectiveness of the intervention was assessed on the basis of questionnaires including knowledge and attitude questions and considering several factors (students' performance/grades, sex, previous participation in EE/ESD programmes, parents' educational level etc). The results demonstrated positive impact on students' knowledge not only on biogeochemical cycles, but also on aspects of them related to sustainable development. Similarly, several components of students' attitudes *vis a vis* the environment and sustainable development (e.g.: "Action commitment", "Efficacy perception of personal action" and "Sustainable orientation of the positive attitude towards the environment"), were influenced positively.

KEYWORDS*: Education for Sustainable Development (ESD), knowledge, attitudes, biogeochemical cycles, didactic material impact, school project.*

Introduction

The present research examines the potential of chemistry/science education and, in particular, the study of biogeochemical cycles as appropriate and effective vehicles for introducing learners, not only to the environmental but to all facets of sustainable development (Scoullos, 2010). The introduction of Environmental Education (EE) and Education for Sustainable Development (ESD) concepts, methods and competences into formal education was one of the key goals of the UN Decade of ESD (UNDESD) and is commented as priority in the post Nagoya Global Action Programme (GAP) (UNESCO, 2014). In the Greek schooling system ESD introduction is considered as a strategic goal of the multi annual work programme of the Ministry of Education and it is supposed to be obtained through alternative approaches that have been reviewed as background of the present work by Koutalidi (2015). Based on this mapping and analysis, appropriate interventions were designed, including the production of didactic materials (Koutalidi & Scoullos, 2015a), which were applied experimentally in 569 students of 16 secondary schools. The present article focuses on the implementation and assessment of impact part of the research programme, on the knowledge and attitudes of students while the design and production of the didactic materials, have been presented, in Article/Part I; (Koutalidi & Scoullos, submitted).

The guiding idea of this work is that good understanding of these cycles is essential from a scientific point of view, but also because it could enhance learners' knowledge and environmentally friendly attitudes in linking these cycles with their everyday life.

One of the major problems in introducing sustainable development issues in school curricula is the identification of suitable "frameworks" for developing the concepts as well as knowledge, critical thinking and action opportunities for learners. The "framing" issue is closely linked to whether, when, where and how the issues will be presented, taking also into account the overloaded "standard" curriculum which, in the case of Greece, is applied uniformly throughout the country. The limited available time and the "crowded" students' programmes are interlinked. In many schooling systems, "new" knowledge is simply "added" to existing programmes in a rather superficial way, or "replaces" knowledge which in some cases is done at the expence of those more "general" elements and conditions necessary for the gradual development of knowledge and values by the learners through critical and systemic thinking.

If ESD has something important to offer is not so much "new" information but higher "quality in the interpretation" which could lead to balanced knowledge of higher value. In

this respect, through the present research, we wanted to associate our intervention to "value added" to knowledge already provided to students through the standard curriculum, without overloading their programme.

The options examined for Greece were either to introduce ESD as an individual "integrated" and "interpretive" lesson, or to modify and enrich existing well established subjects using them as "carriers" of ESD and SD messages. Both options have "pros" and "cons".

Greece has a long tradition in E.E. Every year many hundreds of EE/ESD projects are carried out throughout the country where 50 Centres for EE/ESD operate in nearly all Prefectures (UNESCO, 2014). The UNECE Strategy for ESD (UNECE, 2005), was endorsed and formally introduced in the Greek educational system, since 2006. Despite the above, there are no specific provisions and time allocation in secondary school curricula for a dedicated and structure ESD approach. Teachers are encouraged to act independently by introducing SD themes to their regular teaching. Since the academic year 2011-12, a new "opportunity" is offered through the introduction of a new "compulsory" subject, the so called, "school project" (GG, 2011), which has as main aim the enhancement of "interdisciplinary". The Teacher Council of each school decides on a number of potential themes for "school projects" covering four thematic directions or a combination of them which apparently is proffered by many educators. The four themes are: a) Humanities and Social Sciences, b) Art and Culture, c) Mathematics, Science and Technology, d) Environment and Sustainable Development. The thematic proposals are presented to the students who, through guided discussion, choose the specific theme for project and in many cases propose their own amendments to it. According to their choices they are grouped and "follow" the specific project for either the first or the second semester for each school year at the first year of junior secondary school/high school (ages 15-16 years old), (Greek Ministry of Education, 2011).This approach offers flexibility for ESD initiatives and combinations with other subjects, though many teachers feel that they are left on their own, largely "unguided" to identify the most appropriate themes to be used, as well as, tools and methods for the design and implementation of ESD interventions.

In view of the above, after careful review of the content of the formal curriculum lessons and textbooks and the methods employed and through consultations with a group of active educators of different disciplines we concluded that the inherent multi- and intra-disciplinary character of the biogeochemical cycles may offer an attractive and potentially efficient way to combine chemistry and science in general with ESD thus responding to

themes (c) and (d), mentioned already, of the compulsory "school programme". Biogeochemical cycles were identified as of "particularly high importance" by many educators and, also, as an area where many of them felt that additional guidance and support was needed. The theme, offers also an opportunity for directly sharing experiences on ESD among educators (including in-service training and informal), of different scientific origin and background.

Research methodology

The research questions

The questions that guided the present research are:

- What is the students' knowledge, understanding and possible misconceptions related to the hydrological cycle and biogeochemical cycles of carbon, nitrogen, phosphorus and sulphur?
- What are the prevailing students' attitudes about the environment and sustainable development and what are the main factors shaping them?

Designing of the intervention

The educational intervention required the construction and implementation of suitable didactic materials assessed directly by educators and students and through assessment of their impact on the basis of the pre- and post- control method by employing a questionnaire, on experimental and control groups (Wiersma, 1995; Bieger & Gerlach, 1996; Cohen & Manion, 1997). The experimental group was subjected to the intervention while the control group was not.

The construction of the questionnaire

A two part prototype questionnaire was designed. The first part included demographic characteristics of the student while the second, knowledge and attitude questions (see Appendices 1 & 2a,b). Knowledge was assessed through sixteen four option "Multiple choice" and nine "True-False" questions. The attitudes were assessed through twenty nine self responding behaviour questions in four expressions of commitment; "Action commitment", "Verbal commitment", "Efficacy perception of personal action" and "Sustainable orientation of the positive attitude towards the environment". The latter was introduced to identify/clarify the nature of commitment and distinguish the "motives" behind it (e.g. those responding to economic incentives from those based purely on ethical principles). For assessment of attitudes the five point Likert scale was employed in two

formats: (1 never, 2 seldom, 3 sometimes, 4 often, 5 always & 1 I disagree totally, 2 I rather disagree, 3 I am not certain, 4 I tend to agree, 5 I fully agree) (Likert, 1974).

The questions were formulated considering the principles of ESD, the provisions of the national curriculum and the content of the standard textbooks, which are common in all schools throughout the country. Some of the questions were invented for the needs of this research, while others derive from previous surveys of our research team (Papadopoulos, 2005; Dikaiakos, 2009; Roussos, 2010).

The construction of the questionnaire followed a number of steps: (a) it was presented to a team of peer reviewers for face and content validity (approval with a >70% agreement); (b) it was slightly amended through a consultation with the supervisor and a small team of experts and (c) it was presented to students to assess the comprehensibility and suitability of its format and (d) it was applied to 205 secondary school students and the results were used for evaluating the reliability of the instrument and its finalisation. The results were statistically treated by using SPSS 13. The questions finally selected and included in the questionnaire had values of the Cronbach Alpha reliability coefficient 0,737 for the multiple choice questions and 0,607 for the "True-False" ones while for the attitudes the coefficient value was 0,829. These values fulfil the criteria according to the relevant literature, indicating reliability and internal consistency of a test/scale/questionnaire (Cronbach, 1984; Anastasi, 1988; Litwin, 1995; Cohen et al., 1996; Tavakol & Dennick, 2011). In addition, the Cronbach Alpha values with one question removed from the test at a time, in order to assess the acceptability of the individual questions and to omit from the questionnaire any problematic questions are given in Appendices 3 & 4a,b. It is clear that, if each question is omitted, the remaining questions have Cronbach's a values less than the above mentioned values for each category of questions, respectively and, therefore, the set of questions helps the internal consistency of the scale. The same goes for the scale mean and variance of the questions.

The design of the didactic materials

The didactic materials were designed and produced by using current, state-of-the-art methodology including the identified through the questionnaire knowledge gaps and misconceptions of students, examination of the relevant literature, consideration of the needs of educators involved in teaching of science, EE and ESD, and the specificities of the Greek schooling system, as described in Part I (Koutalidi & Scoullos, submitted).

The intervention

The intervention was carried out during the school year 2011-12 and lasted for one semester and more specifically for three hours per week for thirteen weeks. At the beginning of the intervention the questionnaire was filled by the students subject to the intervention as well as the control group to allow the evaluation of the programme at the end of it.

One of the features of this research was the effort to capture "real conditions". The intervention was made in sixteen (16) schools selected from urban and suburban areas of south east and central Greece. Apart from obtaining a fair, statistically sound geographical distribution, the specific schools were chosen randomly. The participating educators were of different age, gender, level of teaching experience and they were involved in the project because they were available at the given time and willing to participate. Their scientific background varied considerably from chemistry, physics and agricultural science, to mathematics, informatics, engineering and, even, law. Obviously their overall and specific expertise, experience and competences on ESD as well as their teaching style and performance differed considerably, despite the guidance, mentoring and assistance by the research team. This is why the intecomparisons among the participating schools were not attempted, considering all the 22 educators involved as one group and the sum of all 569 students also as another single group, both samples reasonably representative of the entire Greek schooling system. In this respect the assessment of the impact of the didactic material and intervention on learners could be considered as independent of the specific educational environment and conditions of each schools and it does not reflect specific skills and competences of individual educators. The schools' participation in the research was voluntary and based on an agreement reached between on the one hand, the University of Athens, and on the other the Teacher's Council and the Headmaster of each participating school, who have thoroughly examined the scientific, educational and ethical aspects of the project based on strict criteria, similar to those included in the CERP ethical considerations (Taber; 2014). Furthermore the students were fully informed in advance for the research character of the project, taking into account all relevant principles, allowing them to make their own choice for participation in this particular programme.

The teaching methods employed for the intervention, included activities in the classroom such as brainstorming, conceptual mapping, experiments, use of simulations and models, various constructions, dramatisation etc. and also field activities in urban environments and specially designated areas (Scoullos et al., 2008). Apart from the "core" activities, several "peripheral" ones were organized to encourage students to come together,

create engagement, enhance ownership and undertake individual responsibilities, according to the principles and practices of ESD (Scoullos & Malotidi, 2004; Eilam & Trop, 2010).

Following the intervention the students were invited to fill in the questionnaire which was also completed for a second time by the control group.

Statistical analysis for the assessment of the impact

The answers of the students were treated statistically in order to evaluate the impact of the intervention. Descriptive statistics for the characteristics of the study population, by group and overall, are given, for categorical variables, as absolute (N) and relative (%) frequencies within two-way tables. For continuous variables, including scores, the respective distributions are summarized through their median and interquartile range (IQR). For easier comparisons, scores are presented in a transformed 0-100% scale (i.e. the highest theoretically possible score corresponds to 100 and the lowest to 0). P-values in the tables with the descriptive statistics are based on the chi-square and Mann-Whitney U-tests.

Formal inference and derivation of various estimates (e.g. average pre- to post-test change in scores within a group, difference of changes between groups) are based on appropriate models for repeated measurements data. More specifically the fractional logistic model for proportions (Papke & Wooldridge, 1996) was used in order to take into account the restricted range of theoretically possible values in each specific score. Potential correlations between initial and final scores of the same student were taken into account by assuming a marginal model for longitudinal data with an unstructured variance-covariance matrix for the residuals. Estimation of models parameters was based on the generalized estimating equation–GEE methodology (Zeger et al., 1988). Models were initially unadjusted and included only the group and time effects along with their interaction but additional covariates were included in multivariable models (when statistically significant or marginally significant), in order to adjust for potential confounding effects.

All analyses and data treatment have been performed using Stata 10 (Stata Corp. TX USA) and SPSS 13 (SPSS Inc. Chicago); p-values<0.05 have been considered as indicating statistical significance.

Results

Demographic and other relevant characteristics of the study population, according to group assignment (i.e. experimental or control), are summarized in Table 1. Differences in the distribution of these characteristics, between groups, were not significant and rather small. The only noteworthy exception concerned students who had participated in an

EE/ESD program before the present study. Their proportion in the control group was higher (p=0.001), (~54%) compared to the experimental one (~40%).

The distribution of the various scores (i.e. " True-False", "Multiple choices", "Action commitment", "Verbal commitment", "Efficacy perception of personal action", "Sustainable orientation of the positive attitude towards the environment") by group and occasion (i.e. at baseline and at the end of the study period) is summarized in Table 2. All scores have been transformed into a common 0-100% scale. As shown in this table, the evolution of the scores, from the baseline to the final test, in the control group, suggests, as expected, stability or a rather small decrease. On the other hand, scores from students belonging to the experimental group were, in most cases, higher at the end of the study compared to the respective initial levels.

Table 3 summarizes results from a multivariable model for the evolution of scores related to the knowledge of students. The results of the scores of "True-False" type knowledge questions, adjusted for gender and grade, indicate that students in the experimental group scored slightly higher (p=0.002) at baseline compared to students in the control group. After the intervention, scores in the experimental group increased significantly (p<0.001) whereas the respective scores in the control group remained practically stable (p=0.113). The estimated changes between the final and the baseline tests correspond to an average (95% Confidence Interval-CI) increase of 4.13 (2.15, 6.11) units, in the 0-100 scale, in the experimental group and simultaneously an average (95% CI) decrease of 2.16 (-0.54, 4.86) units in the control group providing a statistically significant (p<0.001) difference between these two changes. Better performance (higher grades in school lessons) were associated with both higher scores at baseline (p<0.001) and more pronounced increases due to the intervention (p=0.035). Finally, girls tended to have higher scores compared to boys both at baseline and at the final test (p=0.043).

Regarding the "Multiple choices" type knowledge questions, the results follow the same trends. The two groups started from similar score levels (p=0.516) but students in the control group showed a small but significant decrease at the final test (p=0.018) whereas students in the experimental group had a substantial increase (p<0.001). Estimated changes correspond to an average (95% CI) decrease of 4.21 (0.71, 7.71) units for the control group and an average (95% CI) increase of 22.53 (18.95, 26.10) units for the experimental group with highly statistically significant difference (p<0.001) between the two groups. Higher grades were again associated with higher scores (p<0.001). Girls had a slight disadvantage at baseline (p=0.043) but they reached comparable levels with boys at the final test. In both

types of knowledge achievements, previous participation of students in EE/ESD programs did not have any significant effect neither at the baseline nor at the final test levels.

Results from a multivariable model for the evolution of attitudes related scores are given in Table 4 "Action commitment" scores were comparable at baseline (p=0.202) for both groups but while the control group showed a small tendency for decreasing scores (p=0.077), students in the experimental group had a clear improvement (p<0.001). The estimated average (95% CI) changes from baseline to the final test were -1.45 (-3.06, 0.16) and 4.59 (2.80, 6.39) units, respectively, in the 0-100 scale for the control and experimental group, and the difference between the two groups was statistically significant (p<0.001). As in previous cases, higher school lessons grades and female gender were associated with higher scores at both tests (p<0.001 and p=0.015, respectively). Moreover, in this case, previous participation in EE/ESD programs was associated with higher overall scores (p=0.013).

Considering the scores for "Verbal commitment" there were significant differences between the two groups with initial scores being higher in the experimental groups (p=0.001). However, students in the experimental group practically retained their initial levels till the end (estimated change 0.20 units; 95% CI: -1.42, 1.83; p=0.804) whereas students in the control group had significantly decreased levels at the final test (estimated change -2.14 units; 95% CI: -3.88, -0.39; p=0.017). The differences between the two groups were rather non-significant (p=0.065). Similarly to other scores, previously analyzed, higher grades in school lessons (p=0.005) and female sex (p<0.001) were both associated with higher scores.

The results from the last two multivariable models, of scores on "Efficacy perception of personal action" and "Sustainable orientation of the positive attitude towards the environment", are summarized in Table 5. As in most previous cases, students in the experimental group scored slightly higher at baseline (p=0.012 and p=0.104 for the two scores, respectively) but, while those in the control group had decreased scores at the final test (p<0.001 for both scores), those in the experimental one achieved increased scores after the intervention (p=0.040 and p=0.077 for the two scores, respectively). The estimated (95% CI) changes for the "Efficacy perception of personal action" score were -2.98 (-4.64, -1.33) and 1.64 (0.08, 3.21) units of the 0-100 scale for the control and experimental group, respectively. The corresponding estimates for the "Sustainable orientation of the positive attitude towards the environment" score were -3.88 (-5.52, -2.24) and 1.38 (-0.15, 2.92), respectively. In both scores, the difference between the two groups in terms of changes from

baseline to final examination were highly significant ($p<0.001$). Similarly to previous cases girls and those with higher average grades in school lessons scored significantly higher ($p\leq0.001$ in all cases). It was found that, the higher educational level of the students' fathers was significantly associated only with one attribute the higher "Sustainable orientation of the positive attitude towards the environment" ($p=0.001$). Finally, participation in a EE/ESD program before the current study had no effects on the initial scores nor in their changes from the baseline to the final test.

As it concerns the overall character of the intervention, we observed that students appreciated much more the hands-on activities (such as experiments, constructions of models and work in the field) versus the traditional teaching in the classroom. The impact of these activities was recognized by both students and educators through additional evaluation questionnaires and interviews (Koutalidi & Scoullos, 2015b; Koutalidi, 2015).

Discussion

When we decided to undertake the present research we were aware that in Greece, as is the case also in many other countries, chemistry was perceived by students as being a difficult subject (Johnstone, 2000; MacCarthy & Widansky, 2009) and the biogeochemical cycles were considered by many Greek educators as some of the most difficult issues. To choose, therefore, this genuinely difficult and complex subject as the "carrier" for sustainable development issues, including socioeconomic and geopolitical aspects, was both a challenge and a risk. Several of educators involved had openly expressed their fears.

However, the results show clearly that the intervention was very successful and has influenced positively the knowledge of students at many levels while it has also a noticeable impact on many components of attitudes. Positive results have been reported previously by other workers using comparable educational interventions linking chemistry to EE, on environmental pollution issues (Mangas et al., 1997; Vasilopoulou, 1998; Morgil et al., 2004). Those interventions were particularly successful as it concerns enhancement of knowledge. Literature shows that the impact of educational interventions on attitudes may not be so obvious, if at all observed (Kortland, 1997; Smith-Sebasto & Semrau, 2004; Papadopoulos, 2005).

The impact of the intervention in our case, as indicated by the results, was positive for both knowledge and attitudes. It has reduced misconceptions (e.g. in distinguishing between the "greenhouse effect" and climate change) and has made the link between the biogeochemical cycles and critical sustainable development issues (e.g. production and

consumption patterns, environmental pollution, ecosystem services) much more visible. The intervention was more effective on better students (those who performed better/obtained higher grades) in general school subjects, a finding which is in agreement with results of other surveys carried out in Greece and elsewhere (Trikaliti, 1995; Yilmaz et al. 2004; Papadopoulos, 2005). The impact of the intervention was also higher on girls who (judging from the degree of change in their attitudes) seem to be more readily sensitized than boys on environmental and sustainable development issues. The better environmental performance of girls has been demonstrated by other researchers too (Trikaliti, 1995; Mogensen & Nielsen, 2001; Yilmaz et al. 2004; Tuncer et al. 2005; Papadopoulos, 2005). This could be, at least partly, explained by the fact that the percentage of "good" students is higher among girls. The fact that the correlation between knowledge and certain of the components of attitudes was not always very significant may be attributed to the fact that attitudes are shaped to a large extend, by emotions and not so much by intellect. In the present approach the use of biogeochemical cycles as a "vehicle" attempts to shape attitudes by developing critical and systemic thinking, relying heavily on science. The new message coming out through our intervention, is that visible and invisible aspects of the biogeochemical cycles are interlinked and interrelated, directly and indirectly, with socioeconomic and cultural impacts, health effects and value systems, all of which are critical for the achievement (or not) of sustainable development. The above explain why the approach chosen, which "speaks" more to the mind than directly to the heart of students, has more profound impact on those who "function" better using their intellect, therefore better students, and apparently the more "mature" ones, among which we find more girls than boys of the age of 15-16 years old.

According to the results of the survey, no correlation was found concerning students' knowledge and attitudes with previous participation in EE/ESD programs except from the component of "Action commitment". This result could be linked, to some extent, to the demographic information of Table 1, showing that most of those who have participated in previous EE/ESD interventions had not selected "biogeochemical cycles" as project theme. This could be attributed either to the fact that some of these students didn't associate in their mind directly the cycles with the environment or, eventually, because some others felt that they had already "enough" on the environment and wanted to explore other fields. The lack of correlation may seem, at first approximation, at odds with other surveys that have been carried out in Greece in the past, according to which students who have participated in environmental programs develop more friendly attitudes towards the environment (Trikaliti,

1995; Papadopoulos, 2005). However, in the above mentioned, purely EE surveys, the intervention was a straight-forward information and sensitization process on environmental changes and solid wastes, respectively, and the attitude change was a direct response of the students towards "protecting the environment". Under such circumstances students could easily recall similar messages from their previous EE experiences, many of which generate emotional reactions. Comprehension of sustainable development issues dealing with complexity and systemic approaches, where attitude changes are the secondary result of subsequent transformation of information to knowledge, is a far more complex intellectual process which primarily requires fresh and alert minds, able to concentrate, imagine, combine and assimilate in short period of time difficult and abstract notions. In such a process previous experiences may or may not matter, because memory and impact of previous experiences may vary significantly and, though important, come second, as a support process to the genuine capacity of the student to "learn and know". It is not a coincidence that the survey of Dikaiakos (2009), which focused on sustainable development issues linked with energy consumption and climate change, carried out in Greek schools at 1st year of upper secondary school classes, (viz having exactly the same age target group with the present research), concluded that previous participation of students in EE/ESD programmes had no impact on the "Action commitment" and "Verbal commitment" of attitudes and resulted only in reinforcement of the "Efficacy perception of personal action". Again the latter was related to the conviction developed by learners about their role in obtaining energy efficiency (a concrete result), if they acted accordingly. Such message was rather absent or more defused in the biogeochemical cycles approach, which however enhanced specifically the "Action commitment" component of attitude more among the students who have been exposed previously to EE/ESD interventions, in comparison to the rest.

While it is frequently reported in the EE literature that students with better educated parents tend to have (a) higher ability to assimilate knowledge (Trikaliti, 1995; Gambro & Switsky, 1999; Makki et al., 2003; Papadopoulos, 2005), and (b) more environmental sensitivities, more positive attitudes and, in particular, "Verbal commitment", the results of the present research concluded that the parents' educational background had no impact on neither the knowledge nor the majority of the components of the attitudes, except of the "sustainable orientation of the positive attitude towards the environment". Research on students of the same age (Dikaiakos, 2009) came up with similar results, where it was observed in particular that the parents' educational level had no impact on components of

attitudes such as "Efficacy perception of personal action" and "Action commitment". The potential explanation of the reported differences may be attributed to a number of reasons or rather a combination of them. In many countries, particularly in previous decades, the educational background was, to some extend either the result of a genuine, very strong drive of individuals for knowledge and personal development and to a large extend closely related to prosperity. Better off families secured better and higher education for their children. The relationship between environmental awareness and living standards is well documented for the 1970's and the 1980's, as is also the correlation between prosperity and the level of education obtained, particularly in countries where higher education is not free. In highly stratified societies, the percentage of people with higher education degrees, who better understand environmental, and particularly SD issues and have, at least, high "Verbal commitment" attitude towards the environment is directly proportional to the socioeconomic status. Therefore, and for the first decades of environmental awareness, clear correlations are more visible.

In countries like Greece where education, including higher education, is totally free and particularly in the last decades, the percentage of people with higher education degree is extremely high: In the study sample 60.2% for fathers and 59,1% for mothers with children of average age of sixteen (see Table 1), whereas those with secondary education diploma represent 28% of fathers and 31.6% of mothers indicating weak influence on educational background and lack of direct correlation between prosperity and level of education. If the recent economic crisis, which has affected vertically the Greek society, is added to the above picture, we may be able to explain, at least partly, the findings, while the fact that SD issues are considered new, rapidly evolving and complex for all adds to the equation.

Conclusions

In the present work we report the results of our research in addressing a series of the most common problems of both ESD and chemical/science education, namely the appropriate practical ways and tools in order to fulfil their mission by enhancing meaningful knowledge and facilitate learners to learn how to incorporate new information to existing knowledge developing their own "body of knowledge", which extends beyond a single subject through critical and systemic thinking into better understanding multi-disciplinary and intra-disciplinary issues and into formulating opinions and positive attitudes towards the environment and sustainable development. To do so we, examined alternative educational

options of the Greek schooling system, and excluded the option of a new "separate lesson" on ESD.

Our approach was based on real conditions and pragmatic/feasible approaches exploiting fully the "window of opportunity" offered by the newly introduced compulsory "school project". We focused on the hydrological cycle and the biogeochemical cycles of basic chemical elements namely of Carbon, Nitrogen, Phosphorus, Sulphur, which are extremely important for the environment, natural resources and human societies, as a suitable vehicle for introducing SD principles, notions and practices.

Following a survey described in Part I (Koutalidi & Scoullos, submitted), through which knowledge gaps, teaching difficulties (Koutalidi & Scoullos, 2015b) and lack of connection with current socioeconomic issues were identified, we designed, produced and validated new didactic materials for students and teachers, which were applied to 569 students of 16 schools from various parts of Greece, through an intervention lasting for one semester by their educators, assisted/guided by the principal researcher. Experimental and control groups were used throughout the research.

The impact of the material was assessed through pre- and post- intervention questionnaires and the results were analysed statistically. A clear positive impact of the intervention on students' knowledge was found. Learners were able to minimize misconceptions understand better the biogeochemical cycles and comprehend their connection to various aspects of sustainable development, including e.g. the links between climate change and serious disturbance of the water cycle, overpopulation and famine issues linked to need for agricultural production and use of traditional and non-conventional water resources and fertilizers linked to the N and P cycles etc..

Many components of the student's attitudes were clearly impacted positively whereas this was not so clear for others. Neither the educational background of students' parents nor their previous participation in EE/ESD programmes had any noticeable impact.

Furthermore hands–on activities seem to have more impact on students than traditional teaching. The above mentioned results, in combination with interviews of the educators involved indicate that the use of the biogeochemical cycles as a vehicle for the introduction, at secondary school level, of knowledge related to sustainable development, was very successful. The initial fears and hesitation of some educators before the intervention, related to difficulties linked to the complexity of the natural processes involved, were not confirmed.

Therefore, we suggest that apart from the use of the materials presented in this article the relationship of biogeochemical cycles with SD issues should be elaborated and, included in the curricula and the textbooks of specific relevant subjects of science (e.g. chemistry, biology etc), in combination with increase of the didactic hours devoted in the curricula on the issues mentioned above.

The results also demonstrated that the learners who benefited more were those who had a better overall performance/the better students and, in relative terms, the participating girls, the learning capacity and critical thinking of whom was apparently more readily developed through the materials and the overall intervention described. As it concerns the "weaker students" it should be clarified that in this article they are confined to those with relatively low mean average grade in the entire set of subjects examined. In a further stage of this research we may need to examine the correlation between the impact of the material with the performance of students only in selected, relevant subjects. As a general observation, weaker students benefit more from the hands-on activities which allow them to concentrate and participate more actively. The role of the participating educators needs also to be studied in greater depth, by analyzing, comparing and correlating their competences to the performance of their students as it concerns both knowledge and attitudes. Such an analysis may indicate common knowledge gaps where further training of educators might be needed.

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Table 1. Characteristics of the study population by group and overall

	Group			
	Control N=285 N (%)	**Experimental N=284 N (%)**	**Overall N=569 N (%)**	**p-value**
Gender				0.737
Male	153 (53.7)	148 (52.1)	301 (52.9)	
Female	132 (46.3)	136 (47.9)	268 (47.1)	
Father's Educational level				0.060
Not finishing primary school	1 (0.4)	2 (0.7)	3 (0.5)	
Primary graduate	16 (5.6)	9 (3.2)	25 (4.4)	
Junior High school graduate	24 (8.5)	15 (5.3)	39 (6.9)	
Senior High school graduate	83 (29.2)	76 (26.8)	159 (28.0)	
Technical school graduate	41 (14.4)	65 (22.9)	106 (18.7)	
University graduate	119 (41.9)	117 (41.2)	236 (41.5)	
Mother's Educational level				0.879
Not finishing primary school	2 (0.7)	1 (0.4)	3 (0.5)	
Primary graduate	11 (3.9)	8 (2.8)	19 (3.3)	
Junior High school graduate	16 (5.6)	15 (5.3)	31 (5.4)	
Senior High school graduate	94 (33.0)	86 (30.3)	180 (31.6)	
Technical school graduate	47 (16.5)	54 (19.0)	101 (17.8)	
University graduate	115 (40.4)	120 (42.3)	235 (41.3)	
Previous participation in EE/ESD program(s)				0.001
Yes	155 (54.4)	115 (40.5)	270 (47.5)	
No	130 (45.6)	169 (59.5)	299 (52.5)	
	Median (IQR[1])	**Median (IQR[1])**	**Median (IQR[1])**	**p-value**
Average grade in school lessons (0-20)	17.2 (15.4, 18.7)	17.0 (15.2, 18.5)	17.1 (15.3, 18.6)	0.286

[1] Interquartile range

Table 2. Distribution of scores by group and occasion. All figures are Median (Interquartile Range). Scores are given as percent (%) of the maximum theoretically achievable score

	Group					
	Control *Occasion*		Experimental *Occasion*		Overall *Occasion*	
	Baseline	***Final***	***Baseline***	***Final***	***Baseline***	***Final***
Type of Score						
"True-False"	88.9 (77.8, 100.0)	88.9 (77.8, 100.0)	88.9 (77.8, 100.0)	100.0 (88.9, 100.0)	88.9 (77.8, 100.0)	100.0 (77.8, 100.0)
"Multiple choices"	50.0 (33.3, 75.0)	50.0 (33.3, 75.0)	58.3 (41.7, 66.7)	83.3 (66.7, 100.0)	50.0 (33.3, 66.7)	66.7 (41.7, 91.7)
"Action commitment"	76.0 (64.0, 88.0)	72.0 (64.0, 88.0)	80.0 (64.0, 88.0)	84.0 (72.0, 94.0)	80.0 (64.0, 88.0)	80.0 (68.0, 92.0)
"Verbal commitment"	73.3 (63.3, 80.0)	70.0 (60.0, 80.0)	76.7 (66.7, 86.7)	76.7 (66.7, 86.7)	73.3 (66.7, 83.3)	73.3 (63.3, 83.3)
"Efficacy perception of personal action"	76.7 (63.3, 86.7)	73.3 (60.0, 83.3)	76.7 (70.0, 86.7)	80.0 (70.0, 90.0)	76.7 (66.7, 86.7)	76.7 (63.3, 86.7)
"Sustainable orientation of the positive attitude towards the environment"	82.2 (73.3, 88.9)	80.0 (68.9, 88.9)	84.4 (75.6, 91.1)	86.7 (74.4, 93.3)	82.2 (73.3, 91.1)	82.2 (71.1, 91.1)

Table 3. Results from multivariable models for the evolution of a) "True-False" type and b) "Multiple choices" type knowledge questions scores.

	"" type knowledge's questions score			"Multiple choices" type knowledge's questions score		
Factor	**Coef.**[1]	**95% C.I.**[2]	**p-value**	**Coef.**[1]	**95% C.I.**[2]	**p-value**
Baselinevalue - Controlgroup	1.697	(1.516, 1.878)	<0.001	0.210	(0.084, 0.337)	0.001
Group						
Experimental *vs.* Control group difference at baseline	0.359	(0.134, 0.584)	0.002	0.044	(-0.090, 0.179)	0.516
Time						
Final *vs.* baseline change in score Control group	-0.156	(-0.349, 0.037)	0.113	-0.169	(-0.310, -0.029)	0.018
Group X Time Interaction						
Experimental *vs.* Control group difference in score's change (final *vs.* baseline)	0.654	(0.340, 0.969)	<0.001	1.231	(1.035, 1.428)	<0.001
Grade						
Overall difference in score per 1 unit increase in grade	0.118	(0.066, 0.169)	<0.001	0.202	(0.169, 0.235)	<0.001
Grades X Time Interaction						
Difference in score's change per 1 unit increase in grade	0.075	(0.005, 0.145)	0.035			
Sex						
Overall difference in score for girls *vs.* boys	0.224	(0.007, 0.440)	0.043	-0.143	(-0.281, -0.004)	0.043
Sex X Time Interaction						
Difference in score's change Girls vs. boys				0.171	(-0.015, 0.356)	0.071

[1]Estimated coefficients refer to logit transformed score values (rescaled to a 0-1 range); [2] 95% Confidence Interval

Grey shaded areas denote factors which were not statistically significant and were not included in the model

TABLE 4. Results from multivariable models for the evolution of a) "Action commitment" and b) "Verbal commitment" scores

	"Action commitment" score			"Verbal commitment" score		
Factor	**Coef.**[1]	**95% C.I.**[2]	**p-value**	**Coef.**[1]	**95% C.I.**[2]	**p-value**
Baselinevalue - Controlgroup	0.955	(0.826, 1.084)	<0.001	0.824	(0.733, 0.915)	<0.001
Group						
Experimental *vs.* Control group difference at baseline	0.094	(-0.051, 0.240)	0.202	0.187	(0.072, 0.302)	0.001
Time						
Final *vs.* baseline change in score Control group	-0.071	(-0.150, 0.008)	0.077	-0.099	(-0.180, -0.018)	0.017
Group X Time Interaction						
Experimental *vs.* Control group difference in score's change (final *vs.* baseline)	0.326	(0.200, 0.453)	<0.001	0.109	(-0.007, 0.225)	0.065
Grade						
Overall difference in score per 1 unit increase in grade	0.077	(0.046, 0.108)	<0.001	0.036	(0.011, 0.060)	0.005
Sex						
Overall difference in score for girls *vs.* boys	0.164	(0.031, 0.296)	0.015	0.225	(0.124, 0.325)	<0.001
Previous participation in EE/ESD program(s)						
Overall difference in score Participation *vs.* "no" participation	0.171	(0.035, 0.306)	0.013			

[1]Estimated coefficients refer to logit transformed score values (rescaled to a 0-1 range); [2] 95% Confidence Interval

Grey shaded areas denote factors which were not statistically significant and were not included in the model

TABLE 5: Results from a multivariable model for the evolution of a) "Efficacy perception of personal action" and b) "Sustainable orientation of the positive attitude towards the environment" scores

	"Efficacy perception of personal action" score			"Sustainable orientation of the positive attitude towards the environment" score		
Factor	**Coef.**[1]	**95% C.I.**[2]	**p-value**	**Coef.**[1]	**95% C.I.**[2]	**p-value**
Baselinevalue - Controlgroup	0.977	(0.887, 1.067)	<0.001	1.255	(1.128, 1.382)	<0.001
Group						
Experimental *vs.* Control group difference at baseline	0.144	(0.032, 0.257)	0.012	0.103	(-0.021, 0.228)	0.104
Time						
Final *vs.* baseline change in score Control group	-0.146	(-0.226, -0.065)	<0.001	-0.212	(-0.301, -0.123)	<0.001
Group X Time Interaction						
Experimental *vs.* Control group difference in score's change (final *vs.*baseline)	0.236	(0.118, 0.354)	<0.001	0.299	(0.168, 0.431)	<0.001
Grade						
Overall difference in score per 1 unit increase in grade	0.057	(0.033, 0.080)	<0.001	0.094	(0.066, 0.123)	<0.001
Sex						
Overall difference in score for girls *vs.* boys	0.215	(0.111, 0.318)	<0.001	0.203	(0.087, 0.320)	0.001
Father's education						
Overall difference in score Superior*vs.*higher				0.192	(0.077, 0.308)	0.001

[1]Estimated coefficients refer to logit transformed score values (rescaled to a 0-1 range); [2] 95% Confidence Interval

Grey shaded areas denote factors which were not statistically significant and were not included in the model

APPENDIX 1: ATTITUDE QUESTIONS (Indicative sample)*

		NEVER	SELDOM	SOMETIMES	OFTEN	ALWAYS
1.	In the evenings when I'm at home I switch the lights off, except those in the room where I stay.	**1**	**2**	**3**	**4**	**5**

		I DISAGREE TOTALLY	I RATHER DISAGREE	IAM NOT CERTAIN	I TEND TO AGREE	I FULLY AGREE
2.	It's pointless to save small amounts of energy, when huge amounts are wasted in industrial units.	**1**	**2**	**3**	**4**	**5**
3.	I don't mind if I work in an enterprise which does not respect environmental regulations.	**1**	**2**	**3**	**4**	**5**
4.	I will use public transport, if available, to go to my work even if I have a car.	**1**	**2**	**3**	**4**	**5**
5.	Economic development could be combined with lower emissions of greenhouse gases.	**1**	**2**	**3**	**4**	**5**
6.	I contribute to the reduction of solid waste by choosing products with reduced packaging.	**1**	**2**	**3**	**4**	**5**
7.	Education for the population of poor areas could not contribute to the improvement of their quality of their life.	**1**	**2**	**3**	**4**	**5**

* *Translated from Greek*

APPENDIX 2a: KNOWLEDGE QUESTIONS (True-False type)*

1. Water pollution does not contribute to the spread of serious diseases.
2. Global warming alters the environment and threatens many species of animals and plants.
3. Areas that do not have pollution sources do not address the problem of acid rain.
4. Through forest cutting humans intervene in the carbon cycle.
5. The nitrogen cycle is afected through the introduction of nitrogen fertilizers in agricultural ecosystems in order to increase their productivity.
6. Population growth has no effect on the change of land use and deforestation.
7. Over-consumerism leads to buying useless products, resulting in more wastes reaching the environment.
8. The increase of human population led to the overexploitation of fossil fuels.
9. The uncontrolled urbanization entails severe atmospheric pollution due to transport, central heating and operations of factories.

* *Translated from Greek*

APPENDIX 2b: KNOWLEDGE QUESTIONS (Indicative sample of Multiple Choice type)*

1. Solar energy is captured by producers organisms and transforms into:

a. thermal energy
b. dynamic energy
b. chemical energy
d. kinetic energy

2. Sulphur dioxide and nitrogen oxides cause:

a. the greenhouse effect
b. eutrophication
c. the decrease of the ozone layer
d. acid rain

3. The water of the atmosphere enters in aquatic and terrestrial ecosystems through:

a. evaporation
b. transpiration
c. atmospheric precipitation
d. agricultural practices

4. Carbon dioxide is released in the atmosphere through:

a. denitrification
b. cellular respiration
c. photosynthesis
d. nitrification

5. The impact of the greenhouse effect is:

a. local
b. continental
c. planetary/global
d. national

* *Translated from Greek*

APPENDIX 3: STATISTICAL DATA (Attitudes questions)

Item	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
1	103,64	209,233	,249	,827
2	102,95	200,646	,404	,821
3	103,36	198,024	,451	,819
4	104,90	207,529	,291	,826
5	104,16	205,820	,308	,825
6	103,39	203,417	,317	,825
7	104,02	200,099	,409	,821
8	102,45	206,952	,406	,823
9	102,70	201,399	,403	,822
10	103,37	205,145	,308	,825
11	102,77	204,555	,360	,823
12	102,98	201,990	,370	,823
13	102,91	204,210	,373	,823
14	102,42	206,571	,439	,822
15	103,33	201,501	,402	,822
16	103,42	204,888	,305	,825
17	103,05	210,790	,227	,827
18	102,90	202,307	,353	,824
19	102,21	208,514	,396	,823
20	103,17	203,906	,395	,822
21	103,10	204,440	,331	,824
22	103,52	208,568	,269	,826
23	102,60	206,272	,369	,823
24	102,92	206,023	,248	,828
25	102,30	205,142	,433	,821
26	103,00	205,173	,357	,823
27	102,94	205,066	,281	,827
28	102,45	208,694	,284	,826
29	102,46	206,220	,374	,823

Scale Statistics	**Mean**	106,76
	Std.Deviation	218,498
Reliability Statistics	**Cronbach's Alpha**	0,829
	N of Items	29

APPENDIX 4a: STATISTICAL DATA ("True-False"questions)

Item	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
1	6,59	2,321	,227	,594
2	6,53	2,349	,334	,575
3	6,79	2,101	,256	,594
4	6,72	2,153	,250	,593
5	6,62	2,266	,243	,591
6	6,62	2,060	,449	,536
7	6,54	2,397	,231	,592
8	6,63	2,205	,289	,579
9	6,63	2,076	,409	,546

Scale Statistics	**Mean**	7,46
	Std.Deviation	2,671
Reliability Statistics	**Cronbach's Alpha**	0,607
	N of Items	9

APPENDIX 4b: STATISTICAL DATA (Multiple Choice questions)

Item	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
1	7,63	10,215	,428	,715
2	7,45	10,484	,300	,728
3	7,52	10,280	,372	,720
4	7,40	10,535	,285	,729
5	7,08	10,939	,286	,729
6	7,39	10,032	,453	,712
7	7,58	10,393	,346	,723
8	7,52	10,555	,281	,730
9	7,44	10,718	,225	,735
10	7,20	10,128	,505	,709
11	7,63	10,714	,256	,732
12	7,62	10,580	,296	,728
13	7,59	10,724	,238	,734
14	7,21	10,451	,372	,721
15	7,46	10,289	,363	,721
16	7,49	10,486	,300	,728

	Mean	7,95
Scale Statistics	**Std.Deviation**	11,708
Reliability Statistics	**Cronbach's Alpha**	0,737
	N of Items	16