Chemistry Education Research and Practice

Biogeochemical cycles for combining chemical knowledge and ESD issues in Greek secondary schools

Part I: Designing the didactic materials

Sophia KOUTALIDI and Michael SCOULLOS

Environmental Chemistry Laboratory and UNESCO Chair & Network on Sustainable Development Management and Education in the Mediterranean;
National and Kapodistrian University of Athens; Department of Chemistry

Panepistimiopolis 15771 Athens Greece; scoullos@chem.uoa.gr

ABSTRACT: Biogeochemical cycles support all anthropogenic activities and are affected by them, therefore they are intricately interlinked with global environmental and socioeconomic issues. Elements of these cycles that are already included in the science/chemical curriculum and textbooks intended for formal education in Greek secondary schools were thoroughly reviewed and on the basis of the gaps and needs identified new didactic materials were produced. The didactic materials were designed in order to enhance comprehension of the biogeochemical cycles (of water, carbon, nitrogen, phosphorus and sulphur) and include educational content and guidance to achieve ESD goals including strengthening of students' environment-friendly attitudes and commitment towards sustainability. The materials clarify the function of the cycles supplementing chemical knowledge and scientific information relevant to the real world phenomena and conditions (e.g. climate change, ocean acidification, eutrophication) that learners could experience, connecting them with sustainable development issues (sustainable consumption and production, renewable energies etc). The materials were assessed as successful by educators and students through experimental implementation in 16 Greek secondary schools. The present article (Part I of the research) focuses on the aim, content and design of the didactic materials while in Part II, assessment of their impact on the knowledge and attitudes of students is presented.

KEYWORDS: *Education for Sustainable Development (ESD), biogeochemical cycles, didactic material, students' knowledge and attitudes.*

Introduction

Biogeochemical cycles are integral part of our "*natural capital*" which is the most fundamental of the core forms of capital (i.e., manufactured, human, social and natural) since it provides the basic conditions for human existence (EEA, 2015). A large number of human activities such as agriculture, transport, industry, tourism and urban sprawl increasingly influence biogeochemical cycles (Vitousek et al., 1997; Rojstaczer et al., 2001) and degrade a series of natural processes linked with them at local and global scale. For the first time in history, most of the human population lives in urban areas (UN, 2014) where biogeochemical cycles are controlled by complex interactions between society and the environment (Kaye et al., 1996; Pataki et al., 2013), while the impacts are visible in the increase of climate variability and change, loss of biodiversity and decline in ecosystem services (Schlesinger & Bernhardt, 2013). Biogeochemical cycles are as a rule included in the curriculla of natural sciences but they may become valuable vehicles for the introduction of sustainable development issues in secondary schools.

Traditionally, in the Greek schooling system the method of descriptive chemistry was followed (Tsaparlis & Angelopoulos, 1993; Tsaparlis, 1994), however in a series of newer programmes and textbooks a more practically oriented *Science*, *Technology, Environment, and Society (STES)* approach (Tsaparlis, 2000; and references there in) seems to be followed and, promoted by several individual educators.

Despite some progress, the references to the biogeochemical cycles in the textbooks used by the Greek secondary schooling system, are poorly analysed and scattered (as it will be further explained under the section "*initiation*" of the present paper), not allowing the teachers to fully comprehend the chemistry involved and the great importance of the cycles, to properly prepare their lectures. This weakness was identified during the preparatory phase of the present research by many educators of different disciplines who suggested that some additional supporting didactic material on the issue could have been very useful.

All major Environmental Education (EE) and Education for Sustainable Development (ESD) documents and International Conferences from Tbilisi (1977) to Nagoya (2014) recognize explicitly and/or implicitly the importance of knowledge and understanding of general ecological principles and biogeochemical cycles in order to comprehend the interlinkages with production and consumption patterns, as well as with the overall environmental problems, their causes and solutions, at local and global level (UNESCO, 1978; Negev et al., 2010).

To effectively combine teaching of chemistry and science, in general, to the messages of sustainable development is not an easy task. Practitioners working in secondary schools, in countries like Greece, face major difficulties because of lack of provisions and available time for ESD within the syllabus and limited knowledge, transdisciplinary experience, understanding and access of educators to global issues, despite some promising developments (e.g. the operation of approximately 50 centres on EE & ESD) in the country.

The production of the specific didactic materials, attempts to enhance the knowledge on major biogeochemical cycles and fill the abovementioned gap by introducing learners, not only to the environmental pillar but also to all the other pillars or rather "*facets*" and aspects of sustainable development (Scoullos, 2010). This multi and inter-disciplinary approach of the biogeochemical cycles is intended to provide an attractive, innovative and potentially efficient way to introduce ESD through science, and particularly chemistry, while contributing to chemical education research. The latter does not only contribute in understanding and improving chemistry learning by studying variables relating to chemistry content but it involves the complex interplay between the more global perspective of the social sciences (i.e., the process of learning) and the analytical perspective of the natural sciences (i.e., the content) (Herron & Nurrenburg, 1999).

The present article focuses on the design and content of didactic materials, for students and teachers, largely based on chemistry and aiming at expanding educators and learners' knowledge and understanding of natural phenomena and global problems and their environmental socioeconomic implications, in an effort to mobilize them for more sustainable futures. The materials were produced in Greek. The details of the implementation of the didactic materials and the assessment part of the research programme providing the results on its impact on knowledge and attitudes of students, are presented in Part II (*Koutalidi et al, submitted).*

Didactic materials development

Didactic materials were always used in education. They are indispensable in the teaching process, since they are, in addition to the teacher's direct explanation and other learning activities, an important and easily accessible source for students (Mazgon & Stefanc, 2012).

The materials and particularly textbooks, are important links of connection between the teacher and student. They also allow the better understanding between what is called the purpose and effect, as they seek to translate the principles of a proposed curriculum - which represents the more general goals of education and a vision of science and technology - into content and activities that can be assimilated by students (Borges, 2000).

Modern didactic materials should serve a dual goal: enhancing understanding of scientific issues, (for instance biogeochemical cycles) and deepening the commitment of learners for sustainable development (UNECE, 2005; UNECE, 2009).

The UN Decade of ESD (2005-2014) and all relevant global and regional frameworks on ESD (UNECE, 2005; UNECE, 2019; UNECE 2011) have raised the awareness of educators and education administrations on the need to link education with sustainable development issues by addressing existing and emerging global and local problems and challenges in a coherent, constructive and effective way. Teaching and didactic materials used should be able to inspire and facilitate learners to become better persons for a better, more sustainable world by enhancing their competences to know through *learning to learn*, *learning to be and work with others* (UNESCO, 1996). Also by developing behaviors, attitudes and skills to act accordingly for the benefit of themselves, the communities within they live, as well as for the society and the environment.

A didactic material should in principle be permeated by a coherent viewpoint about the potential and objectives of ESD itself. Currently, there is still an ongoing dispute between different EE/ESD approaches, namely the instrumental one according to which EE/ESD should serve particular ends and the more pluralistic or emancipatory one, privileging transactional and dialogical forms of decisions making characterized by indeterminism and co-creation (Kopnina, 2015). The combination of ESD with science privileges, to a certain extend, the instrumental approach. However, in preparing didactic material the authors, apart from understanding the principles of knowledge construction (Schunk, 2012) need to consider not only their own views about the deeper objectives of ESD teaching and learning but also the potentially different perceptions and approaches of the educators who will use it. The student-centered teaching and learning approaches should guide knowledge information, as well as activities and tools included in the material. Undoubtedly, educators involved in ESD should try to obtain the relevant competences (UNECE, 2008).

The development of didactic material for secondary schools requires the support of a development methodology and a high-quality authoring environment (Padron et al., 2005). It should be scientifically sound including also the most important recent findings and interpretations on the issues in question and prepared in a comprehensive and simple style. It should help the teacher in planning and carrying out the teaching process and the students with their independent learning, that is, gaining, revising, reflecting on, valuing and using knowledge (Mazgon & Stefanc, 2012). In this respect contextualization is important, and practical examples must be included in an appropriate way, in teaching – learning texts so that can be easily understood by students (Cardoso DC et al., 2009).

A series of important factors suggested by Kopper (2000) for deciding the suitability of available didactic materials in the teaching process, including: (a) the objectives and goals of instruction, (b) the characteristics of educational contents, (c) the intended didactic strategies, (d) the characteristics of the social environment, (e) the characteristics of students and teachers, and (f) the characteristics of the materials themselves were taken into account in preparing didactic material (Koutalidi, 2015).

Design and production of the didactic materials on biogeochemical cycles

The new didactic materials on biogeochemical cycles were designed to provide not only chemical knowledge and scientific information relevant to the real world conditions that learners could experience, but also include educational content and guidance to achieve the specific goals of ESD.

The didactic materials intended for both students and teachers were designed, prepared and validated through a PhD research carried out in the UNESCO Chair & Network on Sustainable Development Management and Education in the Mediterranean and the Laboratory of Environmental Chemistry, Department of Chemistry of the University of Athens (Koutalidi, 2015).

The specific objectives of the materials are to: (a) help educators to enrich their "*disciplinary*" chemistry and science teaching related to biogeochemical cycles and introduce through them some wider aspects of sustainable development and (b) enhance learners' knowledge, influence their attitudes and stimulate their action towards the protection of the environment and sustainable development. Through this process "*bridges*" are expected to be built between chemistry/science and other school subjects, respecting also the basic aims of the Education for All.

For the design, experimental implementation and assessment of the materials a series of steps was followed:

(i) **Initiation:** A review of the provisions of the curricula (GG, 2003a; GG, 2003b) and the content of the relevant textbooks which are common throughout the country was carried out. It is noteworthy that all textbooks are under the full responsibility of the Ministry of the Education, prescribed, selected and approved by the Institute of Educational Policy. The textbooks are written by consortia of authors responding to public calls for tender, produced and disseminated by a public agency *gratis* to all students.

The textbooks examined included the following: a) for the lower secondary school "*Biology*", "*Chemistry*", "*Physics*" and "*Domestic Economy*"; b) for the upper secondary school "*Biology*", "*Chemistry*", "*Physics*", "*Management of Natural Resources*" "*Principles of Environmental Sciences*". It is noteworthy that the last two are textbooks supporting the relevant "*optional*" subjects followed only by certain students with particular interests on these issues. The results of the review demonstrated that in some of the above mentioned textbooks there are no references to the biogeochemical cycles, while in other there are several references to the cycles of chemical elements (C, N, P, and S) as well as to the hydrological one. The latter is the only cycle which is also included in the curricula of elementary schools but its importance and complexity was considered by the Ministry of Education as such that requires further elaboration and study at secondary school level to allow learners to fully understand its function and significance (GG, 2003a; GG, 2003b). The relevant issues were found scattered in a fragmented way in various chapters of chemistry, biology, physics etc. not comprehensively explained and lacking the necessary analysis and connection to practical matters. A number of misconceptions were identified (such as a confusion between the "*greenhouse effect*" and the climate change "*per se*"). Furthermore, there is lack of connection between disruptions of the cycles and the environmental pollution, either as a cause or as a result of such phenomena. In conclusion, learners are not facilitated to fully understand neither the intra-disciplinary nature of the cycles, nor the critical interlinkages among them or between the cycles and sustainable development issues, (e.g. on production and consumption patterns, ecosystem services etc.), despite some efforts made in the past through relevant research projects (e.g. Dikaiakos, 2009). Furthermore, nowhere in the curricula, systematic interdisciplinary didactic approaches were identified (GG, 2003a; GG, 2003b).

(ii) **Identification of educators needs:** A consultation including interview was carried out involving secondary school educators of different disciplines responsible for teaching chemistry and other sciences in order to identify the areas where support is needed, considering also their difficulties in dealing with multi- and interdisciplinary approaches. In general, educators had serious problems in fully understanding the connection among the different cycles. There are no such explanations available in the textbooks and most of them have knowledge gaps in chemical processes. Since most of the cycles are dealt with under biology lessons, biogeochemical cycles are frequently considered by the educators as the most difficult part of their teaching. Finally, the majority of them were not able to easily provide to their students appropriate examples from the everyday life.

(iii) **Identification of students needs:** A construction, use and evaluation of a questionnaire addressed to students in order to identify their knowledge gaps and misconceptions on biogeochemical cycles and their overall awareness on environmental and sustainable development issues. The questions were formulated on the basis of a thorough investigation of bibliography, previous research carried out in our laboratory (Papadopoulos, 2005; Dikaiakos, 2009; Roussos, 2010) as well as the conditions prevailing in the Greek schools.

(iv) **Design and production of the materials' content/activities:** The design and selection of the specific activities of the didactic materials**,** considering international and Greek literature and the principles and practices of ESD (UNECE, 2005; UNECE, 2011). Many of the activities were invented for the needs of this programme, while others derive from the combination or amendments of activities from previous surveys (Papadopoulos, 2005; Dikaiakos, 2009; Roussos, 2010) or other didactic materials (Scoullos et al. 2003; Scoullos et al. 2007; Scoullos et al. 2008; Scoullos et al. 2010).

(v) **Design of the Teacher Guidebook/Toolkit:** This design was based on international and Greek literature and previous experience of the group in producing similar didactic material (Scoullos et al., 2003; Scoullos & Malotidi, 2004, UNECE, 2005; Scoullos et al., 2007; Scoullos et al., 2008; Ceulemans & De Prins, 2009; Cardoso et al., 2009; Scoullos et al., 2010; Granados, 2011; UNECE, 2011; Madsen, 2013; Dumitrescu et al., 2014). It contains a compilation of examples of PowerPoint presentations concerning biogeochemical cycles, principles and practices of ESD as well as a comprehensive list of useful links.

The content of (v) and (iv) above is examined in the next chapter.

(vi) **The implementation of the didactic material:** The didactic material developed was classified as an "*Environmental and SD Education Program*" suitable to be used under the newly introduced compulsory school subject called "*school project*" (GG, 2011). It was experimentally applied, during the school year 2011-12, in classes of year one of upper secondary school pupils (15-16 yrs) in sixteen (16) schools voluntarily participating located in urban and suburban areas of south east and central Greece (see Part II, Koutalidi et al., submitted).

(vii) **The Assessment of the didactic materials:** The effectiveness and suitability of the didactic materials was assessed in three complimentary ways:

(a) by employing the pre- and the post-control method using the questionnaire described under step (iii) above addressed to both the experimental and control groups (Wiersma, 2000; Bieger & Gerlach 1996; Cohen et al., 1997). The detailed results of the assessment are presented elsewhere (Koutalidi et al., 2013; Koutalidi, 2015), indicating a positive impact on students' knowledge about biogeochemical cycles and their link to sustainable development as well as on students' attitudes about the environment and sustainability.

(b) by collecting the views of the learners participating in the experimental implementation through a questionnaire on the following: the structure of the material, its attractiveness, comprehensibility, opportunities it offered to work together and develop initiatives. The results of the assessment were very positive (Koutalidi, 2015).

(c) by considering the opinion of the educators involved in the implementation of the programme, by using an anonymous questionnaire and interviews. The results of the assessment were very positive (Koutalidi & Scoullos, 2015).

The whole research project including the survey, the pedagogical module and the implementation of the didactic materials in the schools was approved by the Greek Ministry of Education, as well as by the Teacher Council of each school based on strict scientific, pedagogical and ethical criteria, including the requirement for prior information of the students and their parents about the project. It is noteworthy that the instrument of the research (questionnaire) was anonymous.

Description of the components and content of the didactic materials

From the two didactic materials produced, the first one entitled "*Guidebook of Educational Activities on Biogeochemical Cycles"* intended for both students and teachers, while the second entitled "*Teacher Guidebook/Toolkit*" is addressed to educators.

The first didactic material consists of six parts: five "*vertical*" and one "*horizontal*". The "*vertical*" ones are "*cycle-specific*" and refer respectively to the biogeochemical cycles of Carbon, Nitrogen, Phosphorus, Sulfur as well as the Hydrological cycle. For each cycle/part a series of activities has been developed, clustered under two major thematic questions: (a) what are the fundamental biogeochemical processes of the cycles and how they are linked to the knowledge already included in the standard textbooks and curriculum and (b) what are the natural and anthropogenic causes and key underpinning drivers for the destruction of the cycles as well as the impacts of their disturbance on environmental, socioeconomic and geopolitical aspects of our life and the potential for future development. Table 1 indicates in a summarised way some connections among the biogeochemical cycles, major natural phenomena as they are experienced/known by students and a series of important sustainable development issues. The material is available to learners providing them with the necessary background for their study, preparation etc. while the educator could use it to elaborate his lectures and, raise the awareness and interest of students, expanding their knowledge and critical thinking and stimulating the needed behavioral changes and mobilization for action.

The structure and content of each one of the vertical components is similar. It offers a menu of activities from which the educator may choose according to the needs of the class and his/her specific background/competences.

Indicatively, the part/component referring to the nitrogen cycle includes activities such as: (a) bibliographic research, (b) brainstorming and conceptual mapping, (c) exercise with "*crossword*" & "*wordsearch*", helping students to get acquainted and assimilate difficult terms such as "*nitrification*", "*denitrification*" etc., (d) appropriate experiments in the school laboratory or in the field which facilitate students to comprehend basic processes of the nitrogen cycle, impact of application of nitrogen containing products etc. More specifically, within this cluster of activities the following are included: calculation of the actual fertilization needs of certain cultivations; identification of the content/components of fertilizers; observation of the impact of fertilizers in the growth of selected plants; production and use of compost from solid wastes; examining the contributions of nitrogen oxides to the generation of acid rain; observation of eutrophicated waters etc. Apart from the above, the material provides guidance for dramatisation/role playing, where pupils represent specific sectors dealing with the production and use of important nitrogen products having environmental consequences (e.g. fertilizers, detergents) contributing on the one hand to water pollution and on the other to food safety or healthcare, respectively. Further, tips are provided for visiting fertilizers' factories, farms etc. (see Appentices 1 & 2).

The sixth, "*horizontal*" part is not "*cycle specific*" and provides material and examples of applications for the support of the educational interventions of all five "*vertical*" parts. Indicatively this part includes extracts from important Conventions related to protection of the environment (e.g. the Climate Change, Biodiversity Conventions etc.), general environmental awareness activities in the classroom, instructions for field visits/studies, various constructions, artistic activities, photography, video making, organization of exhibitions, interviews with experts etc.(see example on photographic exhibition, Appendix 3). In addition some interventions are suggested to encourage students to come together, stimulate their engagement, enhance their ownership and undertake individual responsibilities according to the principles and practical applications of ESD (Scoullos & Malotidi, 2004; Scoullos, 2007a; Scoullos, 2007b; Eilam & Trop, 2010).

Every activity included and described in the six parts has a similar structure summarised in its "*identity card*", consisting of: (a) the title, (b) the didactic objectives of the material according to the Bloom taxonomy (Bloom et al., 1956; Kratthwohl et al, 1999; Bloom & Kratthwohl, 2000): cognitive, emotional, psychomotor, (c) the indicative duration of the activity, which depends on the age, abilities and psychology of the students, as well as the experience, commitment and personality of the teachers and the available material-technical infrastructure and conditions prevailing, (d) the school rank it addresses (lower or upper secondary school), (e) the relevant school subjects (curriculum subject in which the biogeochemical cycles and the ESD problematic could be integrated), (f) the needed materials and instruments for carrying out the activity, (g) the indicative course of the activity where all the steps of the process are described in detail and (h) tips and emphasis on certain points that should be taken into account during the conduct of the activity.

The themes of the didactic materials allow for the integration of specific information, issues and concepts to the relevant parts of school subjects not only of chemistry and biology, but also of physics, geography and even non-science subjects such as history, art and religion.

Most activities were accompanied by a **worksheet for students** which aims at helping them to record their observations, eliminate/reduce misconceptions by answering specific questions, foster the knowledge they have acquired by expanding it to other cognitive areas and draw conclusions. It also enables them to have second thoughts about the protection of the environment and sustainable development as well as to create positive attitudes and put them into action.

The modular structure of the activities allows the teacher to use them in a flexible way according to the students' experiences, their age, the classrooms' possibilities and the circumstances that prevail in each occasion, and mainly according to the aim of the programme. The teachers have the possibility to choose the themes and activities they prefer, draw ideas and approach them in a creative way by supplementing them and/or by adding new ones. The knowledge and the experience of the teachers in issues directly related to the students such as the local traditions, the biodiversity and the geomorphology of the neighboring areas, major local challenges and opportunities (e.g. accidents, pollution incidences, vicinity to natural resources, protected areas), can enrich their teaching and help the students to find a linkage between school subjects and everyday life.

Through the "*Teacher Guidebook/Toolkit*" which is in a digital form, educators are facilitated for their better understanding and improvement of their performance on theory development about SD and ESD, while they are provided with visual supporting material e.g. pictures from related phenomena, models in digital form etc. to better prepare their lectures (see example in Appendix 4).The Toolkit contains PowerPoint examples of the basic biogeochemical processes/steps of each cycle, the causes of their disruption as well as their connection with major phenomena and sustainable development related issues. For instance: for the nitrogen cycle the processes of N-fixation, nitrification, denitrification etc. are described; for the carbon cycle: photosynthesis, aerobic and anaerobic decomposition etc.; similarly processes of all the other cycles are included. Presentations from related phenomena such as the "*greenhouse effect*", "*eutrophication*", "*acid rain*" etc. are provided through hyperlinks. Finally, visual material such as images (e.g. of rhizobium bacteria on the roots of legumes, eutrophicated waters, various sources of air pollution etc.) as well as short videos on digital models of the cycles are included in order to enhance the teaching/learning procedure and help the learners to connect the cycles with everyday life. The above aim to enhance educators' competences which, in turn, are linked to the competences we wish to be developed, through ESD, by learners (UNECE, 2008; UNECE, 2011).

Conclusions

This article reports the development process of new didactic materials on the biogeochemical cycles of carbon, nitrogen, phosphorus, sulphur and water, designed for the specific needs and conditions of the Greek secondary schools. The materials were experimentally applied for one semester, to sixteen schools from various parts of the country, in the framework of the new compulsory school subject, the so called "*school project*".

Although it was originally destined to be used in conjunction with standard textbooks complimenting them and facilitating the introduction of critical ESD issues related to them, the result could be considered as an autonomous didactic material. Its innovative character is based on the fact that it simultaneously strengthens the chemical and overall scientific knowledge linked to the cycles, while it demonstrates their multiple connections to burning socioeconomic, cultural and geopolitical aspects. Its modular structure and the adjacent to it "*Teachers Guidebook/Toolkit*" offer a flexible tool in the hands of educators allowing them to put emphasis on important and/or emerging issues of relevance for the local and global society and economy.

The analysis of the results of the experimental application (Koutalidi et al., submitted) indicate its value through the positive impact on students' knowledge. Learners were able to minimize misconceptions, understand better the cycles and comprehend their connection to various aspects of sustainable development, including e.g. the links between climate change and disruption of the water cycle, overpopulation and famine issues linked to needs for agricultural production, use of fertilizers connected to the nitrogen and phosphorus cycles etc. Furthermore, the results indicated that certain components of the students' attitudes were also impacted positively through the application of the didactic material.

As it concerns the ESD message, the material does not explicitly side with any particular position in the dispute between the instrumental and the more pluralistic/emancipatory approach. This allows educators to make their own choices and interpretations eventually in an eclectic way (Fien, 2002), depending on the nature and specific issues raised. Nevertheless, the science background of the material emanates the respect for the "*intrinsic value of nature*" and the moral obligation of humans to ensure the undisturbed functioning of the biogeochemical cycles in nature, balancing human and natural worlds. In this way, the material implicitly supports those who expect ESD to address successfully even the "*paradox*" mentioned by Kopnina (2015), namely the pluralistic perspectives (e.g. Ohman, 2006; Wals, 2010), combined with behaviours and attitudes safeguarding environmentally benign and functioning natural cycles. After all, ESD is about reconciling, balancing and combining without losing the irreplaceable and without moving to irreversible. In this way the material follows the paradigm suggested by Sterling (2010) reconciling instrumental and intrinsic educational traditions, informed and infused by the resilience theory and social learning.

In conclusion, the use of the didactic materials described in this paper, for Greek secondary schools, utilising the biogeochemical cycles in order to combine chemical knowledge with sustainable development issues are useful and powerful tools, in the hands of educators. Through them learners' knowledge of chemistry and understanding of sustainable development issues are enhanced, while ESD could effectively be introduced through chemistry and science, into the formal education system of the country.

Address for correspondence: Michael SCOULLOS, *Environmental Chemistry Laboratory and UNESCO Chair & Network on Sustainable Development Management and Education in the Mediterranean, Department of Chemistry National and Kapodistrian University of Athens. Panepistimiopolis 15771 Athens Greece; fax: 0030 210 7274432; e-mail: scoullos@chem.uoa.gr*

REFERENCES

Bieger, R.G., & Gerlach, J.G. (1996). *Educational Research: A practical approach.* New York: Delmar Publishers.

Borges, G.L.A. (2000). *Training teachers of biology, teaching materials and school knowledge.* Ph.D. in Education. University of Campinas, Campinas. http://libdigi.unicamp.br/document/?code=vtls000220007

Bloom, B. S., & Englehatt, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives:Handbook I Cognitive domain.* New York: Willey.

Bloom, B., & Kratthwohl, D. (2000). *Taxonomy of educational objectives:Handbook I Cognitive domain (in Greek)*. Thessaloniki: Kodikas.

Cardoso, DC., Cristiano, MP., & Arent, CO. (2009). Development of New Didactic Materials for Teaching Science and Biology: The Importance of the New Education Practices. *OnLine Journal of Biological Sciences*, *9(1):* 1-5, ISSN 1608-4217. Science Publications.

Ceulemans, K., & De Prins, M. (2009). Teacher's manual and method for SD integration in curricula. *Journal of Cleaner Production, doi: 10.1016/jclepro.2009.09.014.*

Cohen, L., & Manion, L. (1997). *Methodology of educational research (in Greek).* Athens: Ekfrasi.

Dikaiakos, D. (2009). *Application of Educational material for the sustainable development and the environment on issues regarding energy. PhD Thesis, Department of Chemistry, National and Kapodistrian University of Athens,* Athens.

Dumitrescu, C., Draghicescu, L., Oltenau, RL. & Suduc, AM. (2014). Key Competences for Sustainable Development - Aspects Related with SUSTAIN Project Activity. Procedia - *Social and Behavioral Sciences 141, 1101-1105.*

EEA, (2015). European Environmental Agency. The European Environmental State and Outlook 2015: Synthesis Report EEA, Copenhagen 2015, pp. 204, ISBN 978-92-9213-522-5.

Eilam, E., & Trop, T. (2010). ESD Pedagogy: A Guide for the Perplexed. *The Journal of Environmental Education*, 42(1), 43-64

Fien, J. (2002). Advancing sustainability in higher education: Issues and opportunities for research. *International Journal of Sustainability in Higher Education*, 3(3), 243-53

GG, (2003a). Government Gazette. FEK 303B/13.03.2003.

GG, (2003b). Government Gazette. FEK 304B/13/03/2003.

GG, (2011). Greek Ministry of Education. Circular N^{o} 97364/Γ2/30.8.2011. Directions for the teaching of "school project" of A' & B' class of Senior High school for the school year 2012-13.

Granados, J. (2011). Teaching Geography for a Sustainable World: A Case Study of a Secondary School in Spain. *Review of International Geographical Education Online, 1(2).*ISSN:2146-0353.

Herron, J.D. & Nurrenburg, S.C. (1999). Chemical Education Research: Improving chemists by learning. *Journal of Chemical Education*, 76. 1354-1361.

Kaye, J., Groffman, P., Grimm, N., Baker, L., & Pouyat, R. (2006). *A distinct urban biogeochemistry? Trends in Ecology and Evolution*, 21,(4), 192-199.

Koper, R. (2000). From change to renewal Educational technology foundations of electronic learning Environments. Retrieved from DSpace OUNL site http://hdl.handle.net/1820/38.

Kopnina, H. (2015). Education for sustainable development (ESD): the turn away from "environment" in environmental education? *Environmental Education Research*, 18 (5), 699-712.

Koutalidi, S., Psallidas, B., & Scoullos, M., (2013). *Comprehehending global Environmental and Sustainability Problems through biogeochemical cycles in secondary schools: Experience of three years of implementation in South Greece.* World Environmental Education Congress (7th WEEC). Marrakech, Morocco, 2013, 9-14 June.

Koutalidi, S. (2015). *Investigation and Integration of important environmental biogeochemical processes in secondary school programs. Unpublished PhD Thesis, Department of Chemistry, National and Kapodistrian University of Athens, Athens.*

Koutalidi, S., & Scoullos. M. (2015). Assessing Educators' opinion for the implementation of ESD didactic material in school project using bio-geochemical cycles as entry points. 8th WEEC, Planet and People-how can they develop together? Gothenburg. *Proceedings in Press* Kratthwohl, D., Bloom, B., & Bertram, B. (1999). *Taxonomy of educational objectives:Handbook II Emotional domain (in Greek).* Thessaloniki: Kodikas.

Madsen, KD. (2013). Unfolding Education for Sustainable Development as Didactic Thinking and Practice. *Sustainability, 5(9) 3771-3782.*

Mazgon, J. & Stefanc, D. (2012). Importance of the Various Characteristics of Educational Materials: Different Opinions, Different Perspectives. *TOJET: The Turkish Online Journal of Educational Technology*, 11(3).

Negev, M., Garb, Y., Biller, R., Sagy, G. & Tal, A. (2009). Environmental Problems, Causes, and Solutions: An Open Question. *The journal of environmental education*,41(2),101-115.Ohman, J. (2006). Pluralism and criticism in environmental education and education for sustainable development: A practical understanding. Environmental Education Research, *12(2), 149-63.*

Padrón, C., Dodero, J., Díaz, P., & Aedo, I. (2005). The collaborative development of didactic materials. *Computer Science and Information Systems,* 2(2), 1-21.

Papadopoulos, D. (2005). *Development, Implementation and Evaluation of Environmental Educational programme on waste management (in greek). PhD Thesis, Department of Chemistry, National and Kapodiatrian University of Athens.* Athens.

Pataki, D., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., Pouyat, R. V., Whitlow, T. H., & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions and misconceptions. *Special Issue of Frontiers in Ecology and the Environment*, 9(1), 27–36.

Rojstaczer, S., Sterling, S., & Moore, N., (2001). Human appropriation of photosynthesis products. *Science,* 294(5551), 2549–52.

Roussos, G. (2010). *Mediterranean and Diet: Educational material for Sustainable Development emphassing on the chemical approach of the Mediterranean Diet (in Greek). PhD Thesis, Department of Chemistry of National and Kapodistrian University of Athen.* Athens.

Schlesinger, W., & Bernhardt, E. (2013). *Biogeochemistry: An Analysis of Global Change (3rd ed.).* USA: Academic Press.

Schunk, D. H. (2012). *Learning theories: An educational perspective (6th ed)*. Boston: Pearson.

Scoullos, M., Alampei, A., Malotidi, B., Vazaiou, S. & Boulouxi, A. (2003). *"The water in Mediterranean", Educational Material.* Athens: MIO ECSDE & GWP-Med.

Scoullos, M. & Malotidi, V., (2004). *Handbook on Methods used in Environmental Education and Education for Sustainable Development*. Athens: MIO-ECSDE.

Scoullos M., Papadopoulos D., Alampei A., & Malotidi V. (2007). *"Waste in our life", Educational material – Learner's book.* Athens: MIO-ECSDE.

Scoullos, M. (2007a). Eclectic relationship between Environmental Education and Education for Sustainable Development: evolution, relevance and further questions. *4th International Conference on Environmental Education.* 24-28 November 2007, Ahmedabad, India.

Scoullos, M. (2007b). Evolution and principles of the Education for Sustainable Development, Thalo, Vol I, *"Education and Sustainability",* July 2007 (in Greek).

Scoullos M., Alampei A., Kouroutos V., Malotidi V., Mantzara M., & Psalidas V. (2008). *"Environmental Education and Education for Sustainable Development in Protected Areas" Educational Material.* Athens: MIO-ECSDE.

Scoullos, M. (2010). Education for Sustainable Development: The Concept and Its Connection to Tolerance and Democracy. In A. A. Nikolopoulou, *Education for Sustainable Development, Challenges, Strategies and Practices in a Globalizing World.* California, USA: SAGE Publications INC.

Scoullos, M., Malotidi, V., Alampei, A., Vlachogianni, Th., Toli, K., Trikaliti, A., & Psalidas, V. (2010). *"The Gift of Rain", (2nd Ed.). Educational Material for Education and Sustainable Development.* Athens: MIO-ECSDE.

Sterling, (2010). Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education *Environmental Education Research*, 16(5–6), 511–528.

Tsaparlis, G., & Angelopoulos, V. (1993). The hierarchical method of teaching descriptive chemistry: An experimental study and the attitude of students. In: Bargellini, A., & Todesco, P.E. (eds.), *Proceedings of the 2nd ECRICE, 3511-356.* Pisa, Italy: Universita degli Studi di Pisa.

Tsaparlis, G. (1994). Hierarchical organisation of descriptive chemistry. *La Chimica nella Scuola,* Anno XVI (2), 47-49.

Tsaparlis, G. (2000). The states-of-matter approach (SOMA) to introductory chemistry. *Chemistry Education Research and Practice*, 1(1), 161-168.

UNESCO, (1978). Tbilisi Declaration. Final report of intergovernmental conference of environmental education.Organized by UNESCO in co-operation with UNEP. Tbilisi (USSR), 14-26 October 1977. Paris: UNESCO.

UNESCO, (1996).Learning: The treasure within. Report to UNESCO of the International Commission on Education for the Twenty-first Century. Paris.

UNECE, (2005). *UNECE Strategy for Education for Sustainable Development CEP/AC-13/2005/3/Rev.1*. Vilnius.

UNECE, (2008). Competencies for ESD (Education for Sustainable Development) teachers. A framework to integrate ESD in the curriculum of teacher training institutes. Brussels.

UNECE, (2009). Learning from each other. The UNECE Strategy for Education for Sustainable Development. New York and Geneva. ECE/CEP/159.

UNECE, (2011). Learning for the future. Competences in Education for Sustainable Development; ECE/CEP/AC.13/2011/6.

UNESCO, (2014). *Aichi-Nagoya Declaration on Education for the Sustainable Development. World Conference Aichi-Nagoya (Japan) 10-12 November 2014.*

UN (United Nations), (2014). World urbanization prospects: the 2009 revision. New York, NY: UN Department of Economic and Social Affairs, Population

Vitousek, P., Aber J., Howarth, R., Likens, G., Matson, P., Schindler, D., Schlesinger, W., & Tilman, D., (1997). Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications*, 7(3),737–750.

Wals, A.E.J. (2010). Between knowing what is right and knowing that is it wrong to tell others what is right: On relativism, uncertainty and democracy in environmental and sustainability education. *Environmental Education Research*, 16(1), 143-51.

Wiersma, W. (2000). *Research Methods in Education: an Introduction (7th ed.).* Boston: Allyn and Bacon.

TABLE 1: Indicative thematic connections between Biogeochemical Processes, major Phenomena and possible links with SD related Issues

Cycles	Biogeochemical Processes	Phenomena	SD related Issues
1 Carbon	Photosynthesis; aerobic and anaerobic decomposition; production of greenhouse gases	greenhouse effect; climate variability and change; atmospheric pollution; ocean acidification	Links to: unsustainable modes of production and consumption; increasing CO_2 emissions; scarcity of energy recourses; geopolitical implications; poverty; renewable energy; non carbon economy
2 Nitrogen	N-fixation; N-reduction; nitrification; denitrification; N-assimilation	eutrophication; nitrates in ground waters; greenhouse effect of gaseous species of nitrogen; acid rain	Links to: pollution of water recourses destined to produce potable water; role and use of fertilizers; detergents; sewage treatment; alternative nitrogen sources; food safety
3 Phosphorus	ortho-phosphates; conversion to various forms of phosphorus; introduction to the food chain; phosphate minerals	eutrophication; self purification of natural waters employing ecosystem services	Links to: scarcity of phosphorus minerals; fertilizers; food safety; alternative sources from waste water treatment: struvite; circular and green economy

4	Sulfur	mineralization of organic sulfur into inorganic forms; oxidation of hydrogen sulfide, sulfide and elemental sulfur to sulfate	acid rain; anaerobic transformations in natural waters	Links to: different types of air pollution from industrial activities/use of fossil fuels; desulfurization; transborder pollution
5	Hydrological cycle	Evapotranspiration, condensation and precipitation, run off, water as universal solvent,	Washing and transfering of pollution from the atmosphere to surface and groundwater bodies, soil salinization through salt water intrusion, desertification	Links to: water scarcity; floods and droughts; transborder conflicts over water; health impacts through water induced diseases; poverty; non conventional water recourses

LIST OF APPENDICES

APPENDIX 1:"Simulation Model of the "greenhouse effect", translated extracts from the "Activity 5" of the original material concerning the Carbon Cycle (*original in Greek*).

APPENDIX 2:"Dramatization/Playing role the use of fertilizers", translation of the "Activity 8", of the original material concerning the Nitrogen Cycle (*original in Greek*).

APPENDIX 3:"Photography exhibition", translation of an indicative horizontal activity of artistic nature ("Activity 7"), of the original material relevant for all biogeochemical cycles (*original in Greek*).

In all the above activities the didactic objectives are indicated according to the Bloom Taxonomy, as referred in the text, (C: Cognitive, E:Emotional, P:Psychomotor).

APPENDIX 4: Indicative example from ppt included in the Educator Guidebook/Toolkit concerning the evolution of SD and the connection between biogeochemical cycles and sustainable development pyramid (*original in Greek*).

ACTIVITY 5

A simulation model of the "Greenhouse effect"

Didactic objectives

Students (after the intervention) should be in a position to:

- comprehend the "greenhouse effect" as a natural phenomenon (C)
- describe the "greenhouse effect" (C,P)
- construct simple simulation models (P)
- identify the similarities (analogies) between the model and the natural system (C)
- measure, treat and present data collected from the model, extrapolating them to the natural system (C,P)
- enhance their own awareness as well as raise the awareness of others on the important positive and negative effects of the "greenhouse effect" (C,E)

Indicative duration

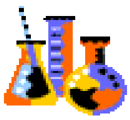
3 didactic hours

School rank

Lower/Upper Secondary School

Relevant school subjects

Biology, Chemistry, Principles of Environmental Sciences, Domestic Economy, Management of Natural Resources, Geography, Computer Science



Materials & Instruments

- 3 containers of adequate size, one with a transparent and one with opaque lids
- three small thermometers (range -20° to +50° C)
- soil from the school yard
- a sheet of paper
- timer
- PC (M.S Office programme)

Instructions

1. Construct a funnel with the sheet of paper and use it to place soil inside the containers.
2. Place the thermometers inside the containers.
3. Close the first and second container with the transparent and opaque lids, respectively.
4. Place all three containers near a window, in order to be exposed to the sun.
5. Record the readings of the three thermometers for 30 minutes, in 5 min intervals.
6. Open the lids of the containers and allow them to stay under the same conditions for 10 min. Record the indications of the thermometers every 2 min for 30 min.
7. Depict the results manually on a graph using different color pencils for each container. Alternatively, you may use a PC in order to make the relevant graphs.
8. Discuss the results and correlate them with natural conditions, including cases of the past "*paleoenvironment*" as well as of recent disturbances of the carbon and nitrogen cycles related to increase of CO_2, N_2O and other greenhouse gases (GHGs).
9. Identify and briefly describe recent anthropogenic activities that enhance the "greenhouse effect". Examine which of them could be replaced by non destructive activities.
10. Explain both the difference and the connection between the "greenhouse effect" and the climate change

If you wish to make the simulation model more realistic you may include in the containers a small glass of water and a small plant. You may use seeds of legumes to obtain a small flora by preparing the model 1 or 2 weeks in advance.

ACTIVITY 7

Photography exhibition

Didactic objectives

Students (after the intervention) should be in a position to:

- present in a coherent visual way an environmental problem (P)
- exhibit characteristic components of the problem and associate them with the root causes (C)
- acquire competences in organizing exhibitions (P)
- acquire competences in the collecting and combining information/data (C,P)
- develop team spirit and work in groups (P)
- become familiar with the use of ICT (P)

Indicative Duration

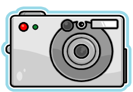
1 school year

School rank

Lower/Upper Secondary school

Relevant school subjects

Biology, Chemistry, Principles of Environmental Sciences, Art, Management of Natural Resources



Materials & Instruments

- camera
- PC, Internet connection

Instructions

Organize a contest and a photo exhibition on an environmental/sustainable development theme, for instance "*Eutrophication of lakes and/or coastal areas* ", "*Atmospheric pollution*" etc. Each photo to be included in the exhibition related to the illustration of the relevant phenomenon will be accompanied by a short explanatory text. For the interpretation you may ask, if needed, the help of your teacher or an expert.

Remember…..!

A picture equals to a thousand words!

ACTIVITY 8

Role playing/Dramatisation for the use of fertilizers

Didactic objectives

Students (after the intervention) should be in a position to:

- playing roles through which the rights, interests, intentions, behavior and attitudes of others are better understood in trying to reach a consensus (E,P)
- present arguments and suggest related solutions (C,P)

More specifically:

- present the reasons for the need of rational use of fertilizers (C)
- juxtaposing advantages and disadvantages of their use (C)
- relate the consequences of unsustainable use of fertilizers resulting to disturbance of the nitrogen cycle, for instance through eutrophication, increase of nitrates in groundwater etc. (C)

Indicative duration

1 month

School rank

Lower/Upper Secondary School

Relevant school subjects

Biology, Chemistry, Principles of Environmental Sciences, History, Domestic Economy, Management of Natural Resources, Civic Education.

Materials & Instruments

Paper & pencil, tape-recorder, camera

Instructions

Following a documentary presentation (e.g. from the National Geographic on eutrophication) or a TV emission/debate on a critical phenomenon caused by the disturbance of the nitrogen cycle connecting with unsustainable use of fertilizers, students are asked to organize a debate under a round-table format, where the topic will be discussed. Roles will be distributed after a detailed discussion between the students and their teacher.

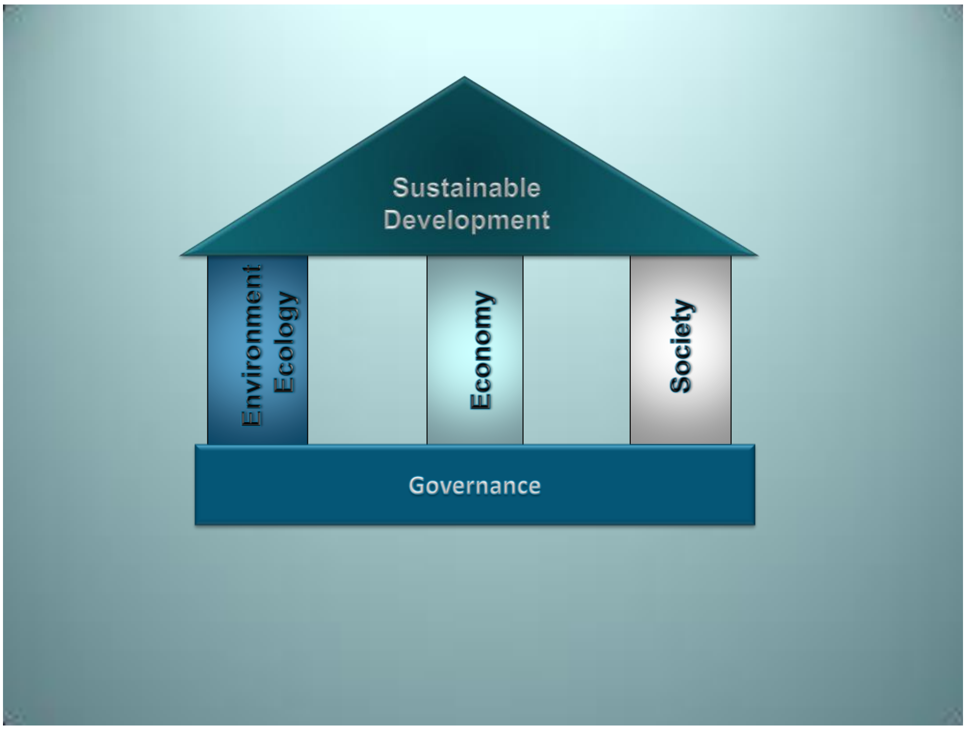
The roles suggested include:

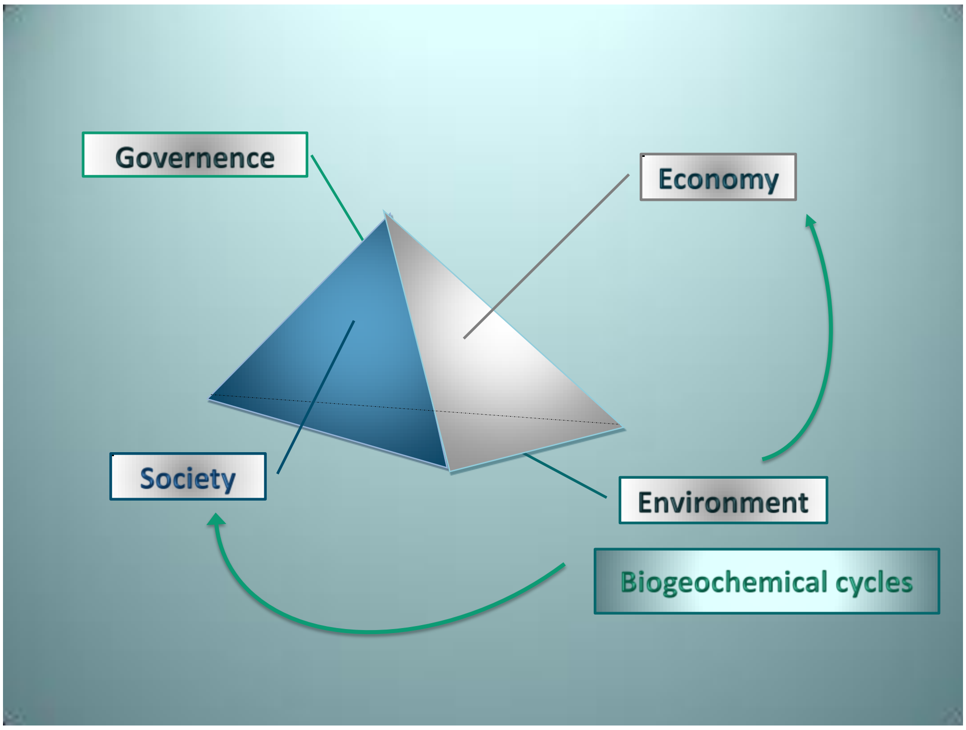
- **Journalist**: Coordinates the discussion making, eventually, provocative questions.
- **Farmer 1:** Supports the excessive use of fertilizers. In order to increase his production and citing his experience considers that there is no need for special precautions for himself or the environment. More often he does not consult the specialist for the dosage and type of the fertilizer.
- **Farmer 2:** Faces long-term health problems due to inhaled chemicals.
- **Fisherman:** Faces serious economic problems resulting from eutrophication caused by runoff contaminated by fertilizers.
- **Agriculturist:** Promotes the reasonable use of fertilizers, considering the time, dosage and type that is necessary depending on the crop and the necessary precautions.
- **Ecologist:** Strongly supports the exclusion of the use of chemical fertilizers and their substitution by organic fertilization. He emphasizes the problems caused by the disturbance of the nitrogen cycle in the environment and he calls for ban of chemical fertilizers.
- **Chemist:** Promotes the movement of green chemistry as a tool for sustainable development. Supports the selective and combined use of chemical and organic fertilizers. He presents the problems but also advantages in tackling the problem of hunger and malnutrition, achieving social cohesion etc.
- **Ordinary citizens:** All other students in the group will be the audience of this debate. As consumers of the produced agricultural products, are suspicious for the chemicals found in the food chain but also for the higher cost and the "certification mechanisms" of organic products. Also they can submit via the Journalist-coordinator questions to the participants.

Remenber…..!

Participation in the role-playing game should not result in adoption by the students of the positions express through the role.

APPENDIX 4


Sustainable
Development
Environment
Ecology
Economy
Society
Governance


Governence
Economy
Society
Environment
Biogeochemical cycles