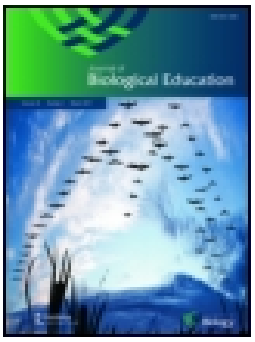

Journal of Biological Education

ISSN: 0021-9266 (Print) 2157-6009 (Online) Journal homepage: http://www.tandfonline.com/loi/rjbe20

Greek Students Research the Effects of Fire on the Soil System through Project-based Learning

Vasiliki Kioupi & Margarita Arianoutsou

To cite this article: Vasiliki Kioupi & Margarita Arianoutsou (2016): Greek Students Research the Effects of Fire on the Soil System through Project-based Learning, Journal of Biological Education, DOI: 10.1080/00219266.2015.1117509

To link to this article: http://dx.doi.org/10.1080/00219266.2015.1117509

Published online: 25 Jan 2016.

Journal of Biological Education, 2016
http://dx.doi.org/10.1080/00219266.2015.1117509

Routledge
Taylor & Francis Group

Greek Students Research the Effects of Fire on the Soil System through Project-based Learning

Vasiliki Kioupi[a,b]* and Margarita Arianoutsou[b]

[a]*Hellenic Ministry of Education, Research and Religious Affairs, Regional Directorate for Primary and Secondary Education of Attica, Directorate for Secondary Education of Piraeus, Environmental Education Office, Education and Religious Affairs, Athens, Greece;* [b]*Faculty of Biology, Department of Ecology & Systematics, National and Kapodistrian University of Athens, Athens, Greece*

This study is focused on the development, implementation and evaluation of an environmental education programme for secondary education students. The programme was entitled 'The effects of fire on the soil system' and it was implemented during the school period of 2008. Twenty-four (24) students (aged from 15 to 20) coming from Lidoriki Secondary School (Central Greece) participated in the programme, which was based on Project Method. The programme consisted of one theoretical part (achievement of cognitive and affective goals) and one experimental part (achievement of cognitive and psychomotor goals). Initial, formative and summative assessments were implemented during the course of the programme, by means of questionnaires, observation of students' teamwork and examination of their work sheets. The questionnaire analysis highlighted students' misconceptions regarding the subject, revealed positive changes in students' attitudes as a result of their participation in the programme, as well as satisfactory results concerning the acquired knowledge and skills. The experimental results were of significant scientific and educational value.

Keywords: *Environmental education programme; Fire-effects on soil; Project-based learning; Programme evaluation; Students' misconceptions*

Introduction

The origins of environmental education (EE) can be found as early as the 1970s when the International Environmental Movement had begun to take shape. A series of International Summits have contributed to forming the core of EE. An effort was made each

*Corresponding author. Hellenic Ministry of Education, Research and Religious Affairs, Regional Directorate for Primary and Secondary Education of Attica, Directorate for Secondary Education of Piraeus, Environmental Education Office, Education and Religious Affairs, Athens, Greece. Email: grperiv@dide-peiraia.att.sch.gr

time to give new and expanded context to EE in a way that it would incorporate not only environmental but social, political and economic aspects as well. During the Earth Summit of Rio (1992) and the Conference of Thessaloniki (1997) in particular, the idea of protecting the environment was connected with a new model of development which should be adopted globally and therefore EE was transformed into Education for the Environment and Sustainable Development-EESD (Scoullos 1995, 1997). As a result, EE, which at the beginning was primarily focused towards knowing, understanding and solving environmental problems, has begun to encompass critical thinking and understanding of complex natural, social and political systems and lifestyle changes (Tilbury 1995). EE has begun to promote active citizenship and highlight a new model of development that not only meets human needs, but also improves their quality of life, without compromising the environment and natural resources (Flogaiti 2006). Nowadays, EESD urges the need for students' active participation in local 'real-world' issues with a view to applying gained experience to global ideas (Barratt Hacking, Barratt & Scott, 2007a; Baumgartner and Zabin 2008; Lewis, Mansfield, and Baudains 2008). This environmentally responsible action is promoted mainly by action competence for sustainability (behaviour modification and critical reflection-adoption of standpoint), motivational factors (i.e. self-esteem, participation/belongingness) and significant life experiences (i.e. contact with nature in early childhood, interaction with positive adult role models) (Almers 2013; Schusler et al. 2009). However, there are challenges and controversies to be overcome with respect to the orientation and framework of EESD, some authors argue on the limitations, narrow reductive focus and inadequate theoretical support when reshaping EE to EESD (Kopnina 2014; Marcinkowski 2009; Strife 2010).

Fire is a disturbance frequently affecting terrestrial biomes on various scales. What is more, Mediterranean-climate ecosystems (MCEs) are known as the most fire-affected ecosystems of the world (Bond and Keeley 2005). The Mediterranean climate is characterised by an alternation of mild, humid winters with warm and dry summers. Fire regime in the Mediterranean is significantly influenced by weather conditions, however, socio-economic factors, anthropogenic pressures and intensive human influences also affect fire occurrence over time (Koutsias et al., 2012b). Forest fires during the summer of 2007 in Greece have been reported as the most severe natural disaster of the last decades at national level. The total amount of burned land was estimated to be more than 2.5 billion m^2 of which 301,302,000 m^2 were designated as protected sites of the Natura 2000 Hellenic network. This is an EUwide network of nature protection areas under the EU 1992 Habitats Directive. Apart from damaging forests and agricultural land, the fires of 2007 destroyed human settlements, rural infrastructure and claimed the lives of 67 people (WWF fire-report, 2007). Also, a shift in the burning patterns was observed with fires occurring in higher altitude and cooler areas and affecting non fire-prone ecosystems (Christopoulou et al. 2013; Koutsias et al., 2012a).

Global environmental issues, such as global warming, ozone depletion or air pollution, are only marginally incorporated in traditional science curricula at Greek schools (Dimitriou and Christidou 2007). This is also the case with the issue of forest fires which is only superficially and unsystematically addressed in secondary science education. Similarly, there is very limited discussion on the soil as a system in Biology and Chemistry lessons, under the framework of the Greek Science Education Curriculum, focused mainly on its important role in nutrient cycles that occur in natural ecosystems (Sotiriou, 2004). This lack in scientific context and its pedagogical transformation in the secondary school curriculum, could be remedied by quality EE programmes. The challenge to environmental educators then, is to provide such scientific experiences to their students so as to help them build scientific and, consequently, environmental literacy. Project-Based Learning (PBL) is a perfect methodological tool for achieving that. When participating in such projects, students must determine how to solve problems, gather and organise information, develop and test hypotheses. These practices promote ownership of knowledge and translate into critical thinking skills (Resnick and Chi 1988). The real-world experience of PBL is enhanced when students engage in group discussions and activities as peers and colleagues the same way that professional scientists do (Barab and Hay 2001).

Taking into account the contemporary aspects of EE and the fact that forest fire is a major environmental and socio-economic issue in Greece, we developed a project-based EE programme which promotes scientific inquiry but is also connected with the social, political and economic implications that indisputably arise when addressing such an issue.

Methodology

Identity, Rationale and Preparation of the EE Programme

The EE project 'Effects of fire on the soil system' was implemented in Lidoriki Secondary school during the school year of 2007–2008. Lidoriki Secondary school is located in a secluded mountainous area of central Greece. Twenty-four students participated in the project, 16 of which came from 9th grade (aged 15) and 8 came from 10th grade (aged 16). The average age of the students was 15.3 years. Teacher–students meetings were held once a week for about 2 h or more and took place mainly in the afternoon, after normal teaching hours. During the course of the programme two field trips for collecting soil samples, an environmental excursion and a presentation meeting with the local community took place. Because the importance of students' outdoor experience and contact with the local community, is proven to promote effective learning, peer socialisation and active engagement, by many authors (Barratt Hacking et al. 2007b; Brody 2005; Rickinson 2001), we chose to include fieldwork in the agenda of the EE programme.

The selection of students to participate in the programme was made taking into account three important factors: (a) students' age which determines their cognitive and psychomotor abilities, (b) their willingness to engage in the programme's activities in terms of devoting part of their leisure time and (c) students' interest in the topic and previous experience with EE programmes. What is more, several authors (Cole 2007; Duffin et al. 2004; Sobel 2008) argue that working on small, place-based and cognitive accessible environmental problems at the local level is the most appropriate way to foster a pupil's commitment to environmental behaviour.

Consequently, the subject of the EE programme was deemed appropriate for these students because:

(1) It is relevant to a real-world issue: 'forest fires', that occur almost every summer in Greece.

(2) Students were particularly sensitised to it because of the disastrous effects of 2007 forest fires.
(3) It is easy for them to collect soil samples in the surrounding area of the school.
(4) Soil is an indispensable natural resource that is not adequately protected.
(5) There is a variety of experiments and activities to carry out using soil samples that have significant scientific and educational value.
(6) It is an opportunity to promote students' interest for scientific issues and environmental conservation.

Some of the topics taken into account before developing the EE programme were:

(1) The significant impact of forest fires on the functioning of the soil system in physicochemical and biological level (Cerdà and Doerr 2008; Doerr et al. 2006; González-Pérez et al. 2004; Pausas et al. 2008.).
(2) Students' misconceptions that are relevant to concepts and processes tackled in the current EE programme (e.g. about the soil as an ecological system, forest fires, biogeochemical cycles, micro-organisms and decomposition), (Leach et al. 1992; Özay and Öztaş 2003; Sotiriou, Arianoutsou, and Kokkotas 2004).
(3) The educational objectives to be achieved by implementing the EE programme. Determining the educational objectives from the beginning is very important because it facilitates proper organisation and valid evaluation of the EE programme. We used Bloom's classification (1991) for setting educational objectives that refer to three major domains: cognitive, affective and psychomotor (Table 1).

Table 1. The educational objectives of the programme according to Bloom's classification

Cognitive	Affective	Psychomotor
The students to		
Know what soil is and what it is composed of	Accept their peers' viewpoints	Work as a team
Know the conditions that favour the occurrence of fire	Express their opinion in a democratic way	Acquire skills of collecting and characterising samples in the field
Associate nutrient cycles with the soil system	Appreciate the importance of soil to ecosystems and humans	Operate laboratory instruments and equipment
Apply scientific inquiry	Be willing to assist their teammates	Assemble simple laboratory devices to conduct experiments
Comprehend fire effects on ecosystems	Ponder about the interactions between the components of the ecosystems	Carry out organised scientific work
Collect, use, analyse and associate scientific data	Adopt values and attitudes that comply with environmental protection	Present their team's results comprehensibly
Exercise critical thinking on provided information	Reject harmful to the environment preconceptions	Compare and contrast scientific approaches to determine the validity of the results provided

Methodological Approaches and Evaluation

Students' learning during the entire EE programme was project-based. PBL is considered to be an 'umbrella method' because it embraces numerous pedagogical strategies that aim at improving students' learning, shaping attitudes and cultivating values (Trikaliti 2004). PBL enhances problem-solving, collaboration, critical thinking and meaningful learning (Barrel 2006; Jensen 1998; Resnick and Chi 1988). The pedagogical strategies we used in this project were: PowerPoint presentations and animations to illustrate basic concepts, extensive discussion with the students concerning concepts, ideas and practices of the programme, newspaper articles and video documentaries analyses and critical thinking through questionnaires, educational games, scientific inquiry and experimentation. For achieving the educational goals of the programme we promoted collaborative teaching and learning (Matsagouras 2008). The students were divided in groups of four during the activities and assumed specific roles in each group.

For evaluating the programme, we used: (1) An initial questionnaire (iq) to reveal students' preconceptions, previously acquired knowledge and expectations concerning the programme in order to develop it accordingly, (2) Observation of the groups of students during the activities and evaluation of their worksheets and other material and (3) a final questionnaire (fq) to assess the achievement of educational objectives and the results of the students' teamwork. In both the questionnaires we used five-point Likert scale questions with anchor points ranging from 'strongly disagree' to 'strongly agree' and 'never' to 'very often', as well as open-ended and closed-ended questions.

Initial and final questionnaires were divided into three sections as follows:

Section A: six questions that reveal students' attitudes with regard to the information sources they use to learn about environmental issues, 6 questions about personal actions to protect the environment and 11 questions about specific attitudes concerning concepts introduced in the programme. Section B: questions that reveal students' expectations (iq 7 questions) and the fulfilment of those expectations (fq 5 questions) and Section C: questions that reveal preconceptions (iq 13 questions) and knowledge and skills acquired during the programme (fq 12 questions). We have to mention that Sections A and B were similar in the initial and fqs but Section C was qualitatively different to compensate for newly acquired knowledge and skills by the students. Questionnaires' analysis was carried out using Microsoft Office Excel 2007 and SPSS statistics software. For Likert scale questions we estimated the number of students' responses in each question and then we defined the frequency and percentage for each one. The same applies for close-ended questions. For open-ended questions we first recorded, then grouped students' responses by taking into account similar characteristics and finally determined the frequency and percentage of each individual group. For questions that revealed students' misconceptions we compared their responses before and after their participation to the EE programme using SPSS statistics software to determine if there was a significant difference in the students' attitudes. We chose to perform Wilcoxon Signed Rank Test for this purpose. This is a non-parametric test that assesses two sets of scores that come from the same participants to find out if any change has occurred, with significant level of 0.05. The results were chosen to be reported in the form of histograms in order for them to be more visual and easily perceivable and to compare and contrast them more easily.

The Structure of the EE Programme

The programme consisted of two parts. The theoretical part, in which the students were provided with adequate information about soil and fire, were sensitisaed and discussed about forest fires, their causes and consequences for humans and ecosystems, prevention and fighting measures taken by the state to tackle with fires and post-fire management plans implemented in fire-affected areas. The second part was the experimental part which involved scientific inquiry. In this, the students applied scientific methodology by collecting and characterising soil samples, conducting experiments to research fire effects on soil, provided explanations on their data and results, discussed about the obstacles they encountered in their inquiry and tried to understand how their findings apply in 'real-world' cases of forest fires.

Activities in the Theoretical Part

Students: (1) answer the iq, are divided into groups, participate in a group-bonding game, (2) brainstorm about soil and fire, watch pictures of fire-affected areas and discuss the emotions evoked by them, (3) are introduced to key concepts about soil and fire, fill in worksheets relevant to the introduced concepts (soil Sudoku, a story about soil formation, soil chemistry-pH)–play the table game 'The fate of nitrogen in the soil', (4) elaborate on newspaper articles regarding soil erosion in the fire-affected areas of 2007. (5) Watch an educational film about fires and fill in the appropriate worksheet.

Activities in the Experimental Part

Course of activities:

(1) The students, assisted by the educator, organise and present the topic of research 'The effects of fire on soil', define the scientific questions and methodology to be answered and used, respectively, during the experimental part.
(2) They collect and characterise soil samples in the field in two sampling sites (Ag. Efthimios and Mornos Lake area) by using appropriate equipment and following a specific field protocol.
(3) They air-dry and sieve the soil samples.
(4) The soil samples of student groups 3 and 6 are placed in an oven to be heated (in order to simulate fire conditions) in 150 °C for 2 h, of groups 2 and 4 in 250 °C for 2 h as well, and of groups 1 and 5 were not heated and used as control.
(5) Students conduct Experiment 1: 'Soil density and moisture',
(6) Then, Experiment 2: 'Soil water content',
(7) After that, Experiment 3: 'Soil texture',
(8) Following, Experiments 4 and 5: 'Soil pH and nutrient content',
(9) Then, Experiment 6: 'Isolation of soil microorganisms',
(10) Finally, Experiment 7: 'Soil erosion and land use',

(11) Students process experimental data to draw conclusions and discuss them in groups and also present their results to the other groups for comparisons.
(12) Each group finally writes a report about their research.
(13) Students answer individually the fq.

Results and Discussion

Questionnaire Analysis

As far as the first part of Section A of the iq is concerned, which is relevant to the sources of environmental information, students' answers reveal that they take environmental information from watching the TV (50% of the students answer agree-strongly agree) and from their school courses (66.7% of the students answer agree-strongly agree). A similar investigation carried out in English and Mexican schools (Barraza and Cuarón 2004) revealed that out of 3742 responses, school and television were the most frequent choices (29.8% and 29.4% respectively). Kobierska, Fiertak, and Grodzinska (2007) also support that the first two sources of knowledge about the environment for the pupils are television and school. In the second part of Section A that concerns students' actions to protect the environment, analysis showed that the students' believe that they protect the environment by disposing of their waste in the proper bins (66.8% of the students answer often-very often), by recycling (66.7% of the students answer sometimes-often) and by saving energy in their everyday activities (75% of the students answer often-very often). A survey comparing environmental awareness among 1220 German and Russian youth found that adolescents in both countries were willing to participate in environmental behaviours such as recycling and conserving energy (Szagun and Pavlov 1993). In general, actions for the environment most often undertaken by pupils are those aimed at product re-use and conservation of natural resources (Kobierska, Fiertak, and Grodzinska 2007; Morris and Schagen 1996). The final part of Section A is tackling attitudes towards the subject of the EE programme. Of the 11 questions that were answered, we chose to report the three that revealed significant misconceptions. Student replies for these questions are shown in Figures 1, 2 and 3 in the form of frequencies (the bars in blue depict results of the iq, while the ones in pink the respective answers of the fq).

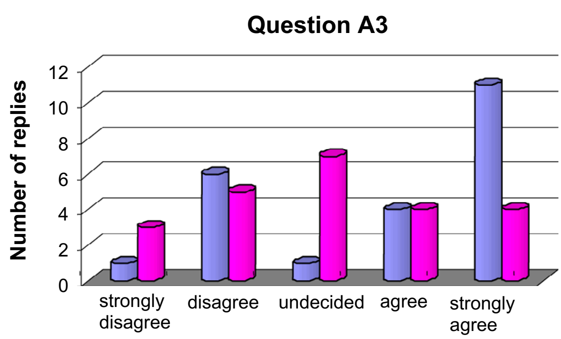

Figure 1. Students' responses to question A3 'A burned forest area should be converted into agricultural land.' (Blue colour: iq, pink colour: fq)

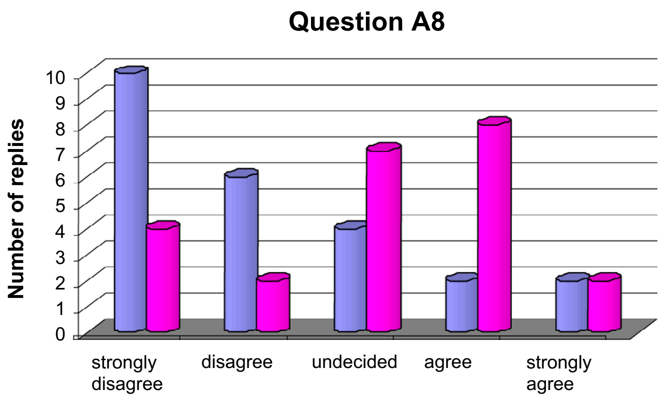

Figure 2. Students' responses to question A8 'The best way for a burned pine forest to regenerate is to be left undisturbed.' (Blue colour: iq, pink colour: fq)

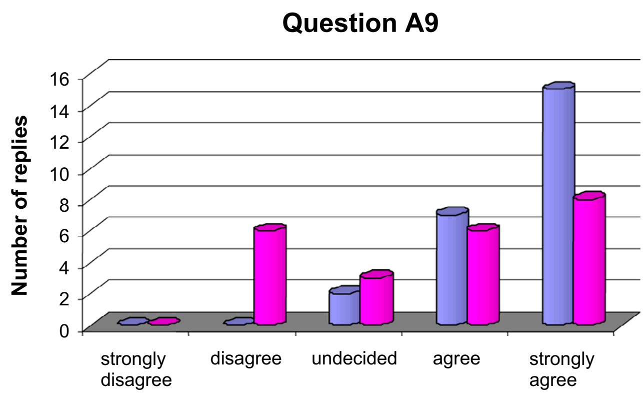

Figure 3. Students' responses to question A9 'The best way for a burned pine forest to regenerate is reforestation.' (Blue colour: iq, pink colour: fq)

Three important misconceptions were revealed through questionnaire analysis. The first concerns students' strongly positive attitude towards utilising burned forest areas as agricultural land (Figure 1-QA3). This suggests that they are in favour of a land-use change for the sake of covering the burned area with vegetation of any kind, even if it is not naturally occurring in this area. Nevertheless, after their participation in the EE programme this attitude is shifted towards more moderate opinions. This is also supported by the Wilcoxon Singed Rank Test which compares students' responses in the initial and fq. The test returned a p value of 0.000 (Table 3), which indicates that there is a significant difference between the two sets of students' responses. What is more, students appear to be less positive (Negative ranks QA3f < QA3i = 14, $N = 23$) in their opinion after their participation in the programme (Table 2). The second misconception reveals that the students support that a burned MCE (i.e. pine forest) does not have the capacity of recovering after a fire-event if left without any human assistance (Figure 2-QA8). Thus, they believe that there are no specific biological adaptations and ecological mechanisms

Table 2. Results of the Wilcoxon Signed Rank Test performed on the students' responses to questions A3, A8 and A9 (QA3, QA8, QA9) in the initial (i) and final (f) questionnaire (q)

Ranks		*N*	Mean rank	Sum of ranks
QA3f–QA3i	Negative ranks	14[a]	7.50	105.00
	Positive ranks	0[b]	0.00	0.00
	Ties	9[c]		
	Total	23		
QA8f–QA8i	Negative ranks	0[d]	0.00	0.00
	Positive ranks	17[e]	9.00	153.00
	Ties	6[f]		
	Total	23		
QA9f–QA9i	Negative ranks	15[g]	8.00	120.00
	Positive ranks	0[h]	0.00	0.00
	Ties	8[i]		
	Total	23		

[a]QA3f < QA3i.
[b]QA3f > QA3i.
[c]QA3f = QA3i.
[d]QA8f < QA8i.
[e]QA8f > QA8i.
[f]QA8f = QA8i.
[g]QA9f < QA9i.
[h]QA9f > QA9i.
[i]QA9f = QA9i.

at work in the MCE that assist its regeneration post-fire. Also, there is a strong correlation between the second and third misconceptions that reveals a commonly shared notion among students that the best way for a burned MCE (i.e. pine forest) to regenerate is artificial reforestation (Figure 3-QA9). The fq analysis shows that for these two misconceptions a positive change can be observed in students' attitudes after the completion of the EE programme because the returned p value for both questions is 0.000 (Table 3). Furthermore, for the second misconception we can see a shift in students' responses towards more positive attitudes (Positive ranks QA8f > QA8i = 17, $N = 23$) and for the third misconception there is a change to less positive attitudes (Negative ranks QA9f < QA9i = 15, $N = 23$) after their participation in the programme (Table 2). Thus, we suggest that some of the affective goals of the programme have been achieved.

Table 3. Wilcoxon Signed Rank Test Statistics–*Z* values and *p* values for questions' A3, A8 and A9 comparisons between the initial (i) and the final (f) questionnaire (q)

Test statistics[c]	QA3f–QA3i	QA8f–QA8i	QA9f–QA9i
Z	−3.494[a]	−3.739[b]	−3.578[a]
Asymp. Sig. (2-tailed)	0.000	0.000	0.000

[a]Based on positive ranks.
[b]Based on negative ranks.
[c]Wilcoxon Signed Ranks Test.

In Section B of the initial and fq that concerns previous and acquired knowledge, analysis shows that students' answers regarding questions chosen from courses taught in lower grades, according to the primary and secondary school curriculum, were adequate (25–100% correct answers). This was both in terms of understanding fire and soil concepts and of reflecting on laboratory experiment techniques. In the respective cognitive questions of the fq that investigated either newly acquired knowledge, or the same concepts as in the iq but given in a new context, the results were highly satisfactory (>91% of the students answered correctly). Consequently, the cognitive objectives of the EE programme were adequately addressed. Moreover, most students were acquainted with the laboratory experiments conducted during the programme, so they were able to answer successfully, questions regarding how the experiments were conducted, why they used the specific procedure, under which conditions a given experiment provided the best results and make comparisons between different laboratory techniques in terms of their reliability (>75% answered correctly and thoroughly). As a result, the psychomotor objectives of the EE programme were successfully achieved.

Laboratory Experiments

Reference of the laboratory results of the experimental part of the EE programme is of crucial importance, because scientific inquiry and experimentation is the key pedagogical strategy that the programme was built upon. The students used the scientific inquiry in order to formulate hypotheses and research questions, collect data, test and compare them, come up with results and plausible explanations for those results and gained the maximum educational benefit of scientific inquiry (McComas 2004; Songer, Lee, and McDonald 2003). Also, the students had the opportunity to connect their observations and conclusions about the effects of fire on the soil system, obtained under laboratory conditions, with the ones that actually occur in the natural environment. In this way they realised they were capable of doing science, felt empowered and their attitude to science was improved as well (Edelson 1998; Ødegaard et al. 2014). The experimental results were of high scientific value because they were in accordance with research results reported in published scientific literature. In Figures 4, 5 and 6 the experimental results with the highest scientific value are illustrated.

The soil's water holding capacity seems to decrease after heating at 150 °C, but it tops its original value after heating at 250 °C (Figure 4). Possibly, the changes in soil's water holding capacity are connected with changes in its hydrophobicity. After a fire incident, the combustion of the layer of organic litter results in the release of hydrophobic compounds that form water-repellent zones in the soil (Jordán et al. 2013). Perhaps above 250 °C those compounds are broken down and the soil starts to retain more water.

Soil pH slightly decreases after heating at 150 °C, while it increases after heating at 250 °C (Figure 5). After a fire, soil pH is found to either slightly increase or decrease depending on the ecological characteristics of a given area (Granged et al. 2011). In both sampling sites the initial soil nitrate content is very low. After heating the soil in 150 °C the nitrate content sharply increases, but after heating it in 250 °C the increase is only slight. Burning of the soil transforms organic nitrogen to inorganic nitrogen, thus the soil

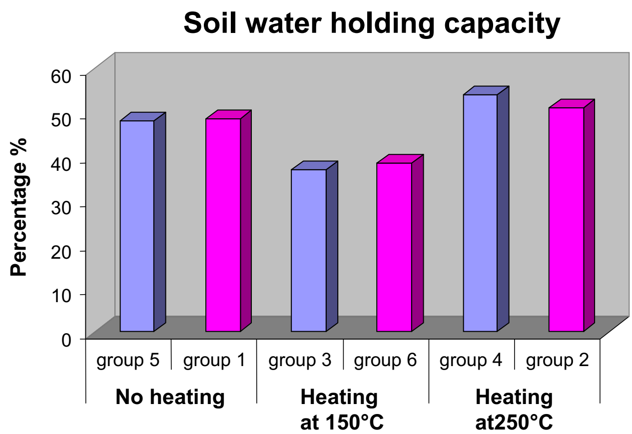

Figure 4. Soil's water holding capacity percentages depending on heating conditions. (Blue–Mornos lake area sampling site, Pink–Agios Efthimios sampling site)

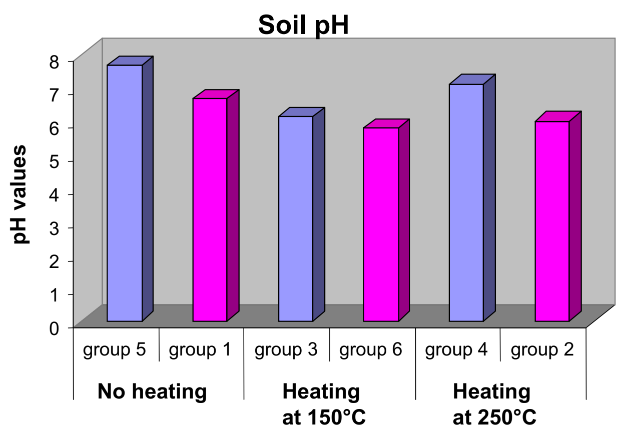

Figure 5. Soil pH values depending on heating conditions. (Blue–Mornos lake area sampling site, Pink–Agios Efthimios sampling site)

nitrate content increases (Guerrero et al. 2005). Possibly, the low nitrate content observed after heating at 250 °C has to do with the fact that nitrogen turns into gas at low temperatures. In general, after a fire the loss of total nitrogen in an ecosystem can be as high as 90% (Mataix-Solera et al. 2007). A similar pattern can be observed for potassium for both sampling sites. Phosphorus content in Agios Efthimios is found high before heating and it shows a significant decrease after heating both at 150 and 250 °C. In our study area of Mornos, soil phosphorus content is initially low, it shows a moderate increase after heating at 150 °C and a slight one after heating at 250 °C. After a fire incident that increases soil pH, phosphorus is not lost but stored in the ash that covers the soil (Stephens et al. 2004). Micro-organisms isolated from the soil samples in both areas were

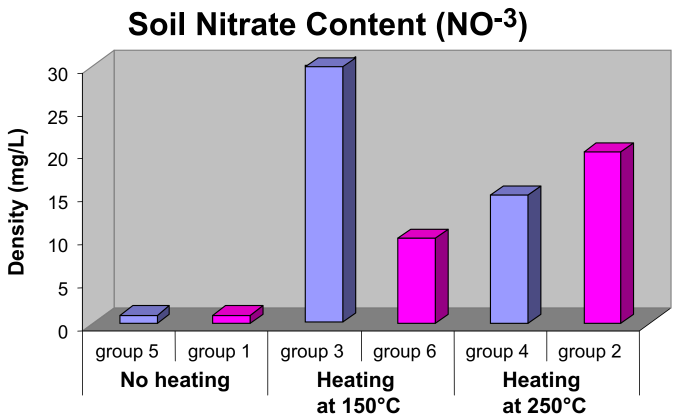

Figure 6. Soil nitrate content depending on heating conditions. (Blue–Mornos lake area sampling site, Pink–Agios Efthimios sampling site)

exclusively bacteria (spherical, rod-shaped and filamentous). Large numbers of bacteria were developed in cultures originating from unheated soil samples, whereas no micro-organism was observed in cultures taken from heated soil samples. The exception was one culture taken from a soil sample from Mornos lake area that was heated at 150 °C that developed two bacterial colonies. We can conclude that heating the soil samples at temperatures as high as 150 and 250 °C, causes the loss of its microbial community. The loss percentage of the soils' micro-organisms after a fire depends significantly on its dryness before the fire, the temperature reached in the soil during the fire and how long the micro-organisms were exposed to this temperature (D'Ascoli et al. 2005).

Educational Implications

The importance of the EE programme lies in the fact that students acquire indispensable knowledge on concepts such as forest fires, soil structure and function, biogeochemical cycles, micro-organisms etc., develop laboratory and communication skills and shape positive attitudes and values towards the prevention of forest fires and management of fire-affected areas. Fire is a very common event in the Mediterranean region and soil is a valuable natural resource. Both lack the attention of the Greek Educational System and are poorly incorporated in the secondary school curriculum. This programme is an effort to remedy the lack of educational material concerning fire and soil because it is based on effective methodology, is scientifically valid, follows interdisciplinary approach, encourages meaningful, collaborative, creative and exploratory learning and provides significant scientific and pedagogical results.

Limitations of the Study

In terms of methodology, the size of the sample was relatively small, consisting of the 24 students who participated in the EE programme. However, the Greek educational system urges educators to enrol no more than 25–30 students in their EE programmes, in order for the educational activities to be meaningful and have a positive impact on the students' skills and attitudes. In the future, this project could be replicated by other educators and schools in order to have a larger sampling size, so as to generalise the conclusions suggested in this study.

The three students' misconceptions detected, could be further investigated and more educational activities could be implemented in order for them to be disproved. Nevertheless, the duration of an EESD programme is limited to one school year and only a small number of activities could be implemented. The authors tried to include potentially effective educational activities supported by literature in PBL and everyday teaching practice. The lasting nature of the positive change in students attitudes found after the statistical analysis of the responses in the fq, could be further studied by providing a third questionnaire to the same students after a considerable period of time to assess that. This could be the objective of a new study for the same or other authors or the guideline for those educators who would wish to replicate this project in their schools.

The methodology selected to study the effects of fire on the soil as a system was the outcome of literature review and discussions between the educator and students and was limited by the available resources in terms of scientific equipment and consumables to study these complex ecological interactions and also by the level of cognitive development of the students. The main intention of the authors has been to carry out PBL and scientific inquiry with their students and assess their outcomes in realistic conditions that apply at least for Greek educational standards. Nevertheless, the authors managed to receive funding by the EU project 'Kallisto–open environmental class' in order to cover some of the expenses incurred to the school during the implementation of the programme.

Acknowledgements

The authors wish to thank the Head Teacher Maria Chantzopoulou and the colleagues of Lidoriki Secondary School for their invaluable support throughout the duration of the EE programme. Also, we wish to thank the reviewers of the Journal of Biological Education for their useful comments and helpful suggestions with regard to the improvement of the quality of this manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Almers, E. 2013. "Pathways to Action Competence for Sustainability—Six Themes." *The Journal of Environmental Education* 44 (2): 116–127.

Barab, S. A., and K. Hay. 2001. "Doing Science at the Elbows of Scientists: Issues Related to the Scientist Apprentice Camp." *Journal of Research in ScienceTeaching* 38 (1): 70–102.

Barratt Hacking, E., R. Barratt, and W. Scott. 2007a. "Engaging Children: Research Issues around Participation and Environmental Learning." *Environmental Education Research* 13 (4): 529–544.

Barratt Hacking, E., W. Scott, and R. Barratt. 2007b. "Children's Research into Their Local Environment: Stevenson's Gap, and Possibilities for the Curriculum." *Environmental Education Research* 13 (2): 225–244.

Barraza, L., and A. D. Cuarón. 2004. "How Values in Education Affect Children's Environmental Knowledge." *Journal of Biological Education* 39 (1): 18–23.
Barrel, J. 2006. *Problem-Based Learning. an Inquiry Approach*. 2nd ed. Thousand Oaks, California: Corwin Press.
Baumgartner, E., and C. J. Zabin. 2008. "A Case Study of Project-Based Instruction in the Ninth Grade: A Semester-Long Study of Intertidal Biodiversity." *Environmental Education Research* 14 (2): 97–114.
Bloom, B. S., and D. R. Krathwohl. 1991. *Educational Objectives Taxonomy*. Greek Translation A Labraki-Paganou. Thessaloniki: Kodikas Publications.
Bond, W. J., and J. E. Keeley. 2005. "Fire as a Global 'Herbivore': The Ecology and Evolution of Flammable Ecosystems." *Trends in Ecology and Evolution* 20: 387–394.
Brody, M. 2005. "Learning in Nature." *Environmental Education Research* 11 (5): 603–621.
Cerdà, A., and S. H. Doerr. 2008. "The Effect of Ash and Needle Cover on Surface Runoff and Erosion in the Immediate Post-Fire Period." *Catena* 74: 256–263.
Christopoulou, A., P. Fulé, P. Andriopoulos, D. Sarris, and M. Arianoutsou. 2013. "Dendrochronology-Based Fire History of *Pinus Nigra* Forests in Mount Taygetos, Southern Greece." *Forest Ecology and Management* 293: 132–139.
Cole, A. 2007. "Expanding the Field: Revisiting Environmental Education Principles through Multidisciplinary Frameworks." *The Journal of Environmental Education* 38 (2): 35–45.
D'Ascoli, R., F. A. Rutigliano, R. A. De Pascale, A. Gentile, and A. De Santo. 2005. "Functional Diversity of the Microbial Community in Mediterranean Maquis Soils as Affected by Fires." *International Journal of Wildland Fire* 14: 355–363.
Dimitriou, A., and V. Christidou. 2007. "Pupils' Understanding of Air Pollution." *Journal of Biological Education* 42 (1): 24–29.
Doerr, S. H., R. A. Shakesby, L. W. Dekker, and C. J. Ritsema. 2006. "Occurrence Prediction and Hydrological Effects of Water Repellency amongst Major Soil and Land-Use Types in a Humid Temperate Climate." *European Journal of Soil Science* 57: 741–754.
Duffin, M., A. Powers, G. Tremblay, and PEER Associates. 2004. *Place-Based Education Evaluation Collaborative: Report on Cross-Program Research and Other Program Evaluation Activities*. Accessed from PEER Associates, http://www.peecworks.org/PEEC/PEEC_reports.
Edelson, D. C. 1998. "Realising Authentic Science Learning through the Adaptation of Scientific Practice." In *International Handbook of Science Education*, edited by K. Tobin and B. Fraser, 317–331. Boston, MA: Kluwer.
Flogaiti, E. 2006. *Education for the Environment and Sustainability*. Athens: Ellinika Grammata.
González-Pérez, J. A., F. J. González-Vila, G. Almendros, and H. Knicker. 2004. "The Effect of Fire on Soil Organic Matter-a Review." *Environment International* 30: 855–870.
Granged, A. J. P., L. M. Zavala, A. Jordan, and G. Barcenas-Moreno. 2011. "Post-Fire Evolution of Soil Properties and Vegetation Cover in a Mediterranean Heathland after Experimental Burning: A 3-Year Study." *Geoderma* 164: 85–94.
Guerrero, C., J. Mataix-Solera, I. Gómez, F. García-Orenes, and M. M. Jordán. 2005. "Microbial Recolonization and Chemical Changes in a Soil Heated at Different Temperatures." *International Journal of Wildland Fire* 14: 385–400.
Jensen, E. 1998. *Teaching with the Brain in Mind*. Alexandria, VA: Association for Supervision and Curriculum Development.
Jordán, A., L. M. Zavala, J. Mataix- Solera, and S. H. Doerr. 2013. Soil Water Repellency: Origin, Assessment and Geomorphological Consequences. *Catena* 108: 1–5.
Kobierska, H., M. T. Fiertak, and M. J. Grodzinska. 2007. "Attitudes to Environmental Education in Poland." *Educational Research* 42 (1): 12–18.
Kopnina, H. 2014. "Future Scenarios and Environmental Education." *The Journal of Environmental Education* 45 (4): 217–231.
Koutsias, N., M. Arianoutsou, S. A. Kallimanis, G. Mallinis, J. M. Halley, and P. Dimopoulos. 2012a. "Where Did the Fires Burn in Peloponnisos, Greece the Summer of 2007? Evidence for a Synergy of Fuel and Weather." *Agricultural and Forest Meteorology* 156: 41–53.

Koutsias, N., G. Xanthopoulos, D. Founda, F. Xystrakis, F. Nioti, M. Pleniou, G. Mallinis, and M. Arianoutsou. 2012b. "On the Relationship between Forest Fires and Weather Conditions in Greece from Long-Term National Observations (1894–2010)." *International Journal of Wildland Fire* 22 (4): 493–507.

Leach, J., R. Driver, P. Scott, and C. Wood-Robinson. 1992. *Progression in Understanding of Ecological Concepts by Pupils Aged 5 to 16*. Leeds: The University of Leeds, Centre for Studies in Science and Mathematics Education.

Lewis, E., C. Mansfield, and C. Baudains. 2008. "Getting Down and Dirty: Values in Education for Sustainability." *Issues in Educational Research* 18 (2): 138–155.

Marcinkowski, T. J. 2009. "Contemporary Challenges and Opportunities in Environmental Education: Where Are We Headed and What Deserves Our Attention?" *The Journal of Environmental Education* 41 (1): 34–54.

Mataix-Solera, J., I. Gomez, J. Navaro-Pedreno, C. Guerrero, and R. Moral. 2007. "Soil Organic Matter and Aggregates Affected by Wildfire in a *Pinus Halepensis* Forest in Mediterranean Environment." *International Journal of Wildland Fire* 11: 107–111.

Matsagouras, E. 2008. *Collaborative Teaching and Learning*. Athens: Grigoris Publications.

McComas, W. 2004. "Keys to Teaching the Nature of Science." *The Science Teacher* 71 (9): 24–27.

Morris, M., and I. Schagen. 1996. *Green Attitudes or Learned Responses?* Berkshire: National Foundation for Education Research.

Ødegaard, M., B. Haug, S. M. Mork, and G. O. Sørvik. 2014. "Challenges and Support When Teaching Science through an Integrated Inquiry and Literacy Approach." *International Journal of Science Education* 36 (18): 2997–3020.

Özay, E., and H. Öztaş. 2003. "Secondary Students' Interpretations of Photosynthesis and Plant Nutrition." *Journal of Biological Education* 37 (2): 68–70.

Pausas, J. G., J. Llovet, A. Rodrigo, and R. Vallejo. 2008. "Are Wildfires a Disaster in the Mediterrenean Basin? – A Review." *International Journal of Wildland Fire* 17: 174–723.

Resnick, L. B., and M. T. H. Chi. 1988. "Cognitive Psychology and Science Learning." In *Science for the Fun of It: A Guide to Informal Science Education*, edited by M. Druger, 24–31. Washington, DC: National Science Teacher Association.

Rickinson, M. 2001. "Learners and Learning in Environmental Education: A Critical Review of the Evidence." *Environmental Education Research* 7 (3): 207–320.

Schusler, T. M., M. E. Krasny, S. J. Peters, and D. J. Decker. 2009. "Developing Citizens and Communities through Youth Environmental Action." *Environmental Education Research* 15 (1): 11–127.

Scoullos, M. 1995. "Towards an EE for Sustainable Development." Interregional Workshop on Re-orienting EE for Sustainable Development, Athens, June 26–30, 1995.

Scoullos, M. 1997. "Observation, Key Issues and Suggested Solutions Open to Comments by the Conference." Proceedings of the International Conference, Environment and Society: Educational Public Awareness for Sustainability, Organized by UNESCO and the Greek Government, 197–201. Thessaloniki, December 8–12.

Sobel, D. 2008. *Childhood and Nature: Design Principles for Educators*. York, ME: Stenhouse.

Songer, N. B., H. S. Lee, and S. McDonald. 2003. "Research towards an Expanded Understanding of Inquiry Science beyond One Idealized Standard." *Science Education* 87 (4): 490–516.

Sotiriou, E., M. Arianoutsou, and P. Kokkotas. 2004. "The opinions of 15 year old pupils about the soil system and their didactic utilisation." Proceedings of the 2nd Panhellenic Conference of E.D.I.F.E. & 2nd Symposium I.O.S.T.E. in Southern Europe "Science and Technology Didactics. The Challenges of the 21st century", Kalamata, March 18–20, 2004.

Stephens, S. L., T. Meixner, M. Poth, B. McGurk, and D. Payne. 2004. "Prescribed Fire, Soils, and Stream Water Chemistry in a Watershed in the Lake Tahoe Basin." *International Journal of Wildland Fire* 13 (1): 27–35.

Strife, S. 2010. "Reflecting on Environmental Education: Where is Our Place in the Green Movement?" *The Journal of Environmental Education* 41 (3): 179–191.

Szagun, G., and V. Pavlov. 1993. “German and Russian Adolescents’ Environmental Awareness.” Paper presented at the Biennial Meeting of the Society for Research in Child Development. New Orleans, LA, March 25–28, 1993.

Tilbury, D. 1995. “Environmental Education for Sustainability: Defining the New Focus of Environmental Education in the 1990s.” *Environmental Education Research* 1 (2): 195–212.

Trikaliti, A. 2004. *Environmental Education: Theory and Practice*. Athens: University of Athens Press.

UNESCO. 1997. “The Declaration of Thessaloniki.” Paper presented at the International Conference Environment and Society: Education and Public Awareness for Sustainability, Thessaloniki, December 8–12.

United Nations. 1992. *Earth Summit, Agenda 21, The United Nations Programme of Action from Rio de Janeiro*. Brazil: United Nations.

WWF Greece. 2007. *Fire-report The Peloponnese*. Athens: WWF Greece.