Adoption of a project approach in engineering education for cultural heritage protection

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Abstract

Engineering education for cultural heritage protection involves a multi-level process, from youth awareness to postgraduate courses, supporting relevant professional profiles. Direction B' "Conservation Interventions: Techniques and Materials" of National Technical University of Athens Postgraduate Course "Protection of monuments, sites and complexes" provides advanced education to engineers and scientists in the relevant field. Interdisciplinarity, hands-on experience and dealing with real cases are key characteristics. Project approach is adopted, based on ongoing research projects. Students, working in small teams, are gradually led to the final outcome, which is presented to their lecturers and is graded accordingly. Students are exercised in creative thinking, problem solving, teamwork and actual research results serve as valuable educational tools. Having acquired this knowledge and skills, the majority of graduates are absorbed at various cultural heritage related positions (research sector - continuation of studies at University; public sector, such as Ministries; private sector, such as industries and technical offices).

Keywords: project approach; cultural heritage protection; engineering education.

1. Introduction

In engineering education, technical solutions to problems must be complemented by societal aspects, ensuring that graduates become competent professionals at both levels (Nélson Rodrigues da Silva, 2010). Engineers must be educated with a focus on technology development, taking into consideration its positive and negative impacts on society (Lehmann et al., 2008).

In order to face the current demanding challenges of modern society, engineering education had to adapt accordingly, replacing the traditional educational approaches. Within traditional education, theoretical lectures represented the core of the curriculum, with the lecturer standing in the "centre" of the learning process (Weenk & Van der Blij, 2011). Recent experience has demonstrated that better results are achieved within a contemporary educational framework – "opposite" to the traditional model and when "learning" of students becomes the central point. This contemporary educational model is increasingly been adopted in engineering education (Mills & Treagust, 2003), aiming at the achievement of active participation of students in the learning process, and of finding solutions to problems arising from contemporary life and real cases (Powell, 1999).

Engineering education has to adjust to the homogenization of the educational system, and to the requirements set by a common accreditation structure. Within this approach, emphasis is given to "what is being learned" instead of the tradition "what is being taught". Actively linked with the dynamically changing professional profiles of engineers, engineering programs are now required to demonstrate that their graduates are achieving a set of specified learning outcomes.

2. Project - based learning approach

Among the various educational approaches adopted to achieve the above goals, the project - based learning approach supports the characteristics demanded nowadays, focusing on the learning procedure, giving the opportunity to the trainer to transmit a broad range of knowledge and skills, helping students to set goals, reinforcing their active participation, supporting cooperation and teamwork. Project - based learning concerns a pedagogical approach inspired by John Dewey, who supported "hands - on experience" or "learning by doing" (Khair et al., 2011). The starting point of the method is a project, which concerns assigning certain tasks to be carried out at a given time-framework and which will result in the development of a final product, such as a design, a model, a device, or a computer simulation. The output of the project usually refers to a written and / or oral report summarizing the procedure used to produce the product and the final product itself (Prince & Felder, 2006). Project - based learning

allows investigation of a subject / thematic area / problem in-depth, instead of making use of a rigid theoretic lecture which directs the student to a certain path of learning outcomes or objectives (Helm & Katz, 2001). The approach focuses on the application of the acquired knowledge for the production of the final product, involving in the whole procedure equipment, software, laboratory work, and demanding the proper preparation and time for its accomplishment (Khair et al., 2011).

Project - based learning approach presents significant value for engineers, who are expected to work on projects in the real world, ensuring that these projects meet customers' and society's needs, requirements and expectations (Khair et al., 2011). The method focuses on the application of the acquired knowledge by students in a self - directed way for the production of a final product, working in teams. It presents similarities with problem - based learning, cooperative learning, active learning and project management theory (Lowenthal, 2006). It should be noted that project - based learning differs from problem - based learning in that it does not involve acquiring of knowledge without previous theoretic lecturing, nor focuses on the solution of a problem making use of the already existing knowledge of students (Khair et al., 2011). Through project - based approach, students are connected with real world tasks and are expected to improve learning by working on projects met in practice (Vilela et al., 2011). Working on a project enables the development of team work collaboration skills, as students are expected to reach project accomplishment working effectively in groups (Hattum - Janssen, 2007).

3. Engineering education for cultural heritage protection

The cognitive domain of built cultural heritage protection possesses the key elements of a valuable interdisciplinary, scientific and technical sector that can contribute significantly in engineering education, involving utilization of advanced diagnostics, environmental impact assessment, strategic planning and compatibility assessment regarding materials and conservation interventions, environmental management for the sustainable preservation of Cultural Heritage (Konstanti, 2013; Moropoulou et al., 2006). Education in the field of cultural heritage protection is a multi-level process, from awareness and active participation of youth to specialised postgraduate courses (Master level, PhD), which support the relevant professional profiles (Moropoulou et al., 2008).

National Technical University of Athens (NTUA) offers, since 1998, the interdepartmental postgraduate course "Protection of monuments, sites and complexes" with two directions: A' "Conservation and restoration of historic buildings and sites", and B' "Conservation interventions: Techniques and materials". The Course responds to the socio-economically important for Greece needs for (a) advanced training of specialized professionals that will be employed in the field of restoration, preservation and management of built cultural heritage, and (b) to update the educational system with the most modern educational approaches, on an interdisciplinary basis and by connecting societal needs with recent technological achievements (Moropoulou & Konstanti, 2010).

One of the basic characteristics of the Course concerns its interdisciplinary character, made apparent through the educational background of students, the origin of lecturers and the Course syllabus (Figures 1,2), (Table 1):

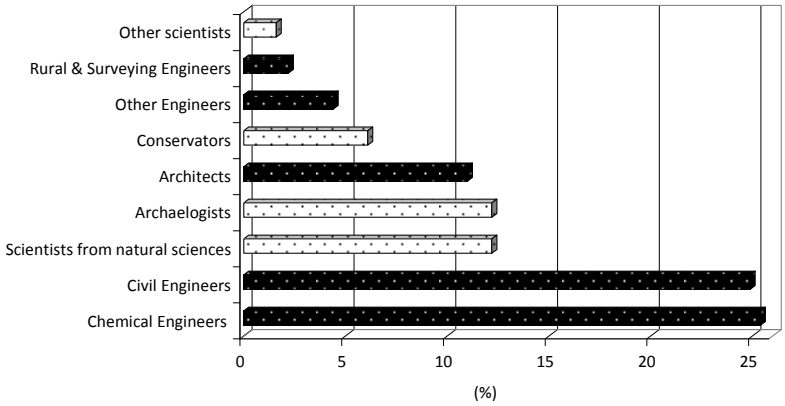

Figure 1: Interdisciplinary character of the Course expressed in students' educational background (dark colored bars indicate engineering education)

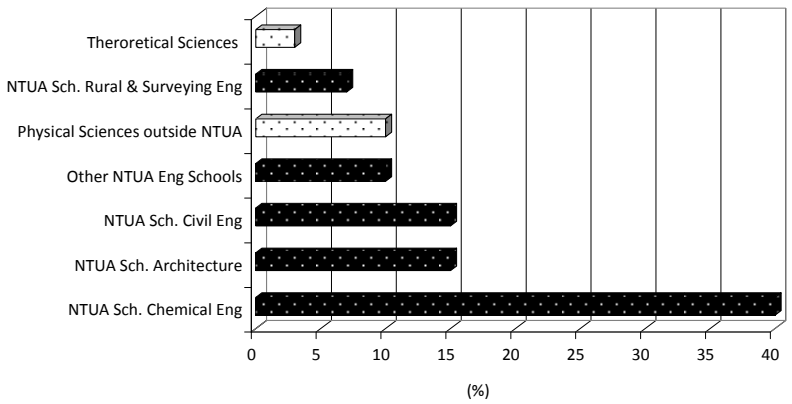

Figure 2: Interdisciplinary character of the Course expressed in lecturers' origin

Table 1: Course syllabus of Dir. B' "Conservation interventions: Techniques and materials" - NTUA Postgraduate Course "Protection of monuments, sites and complexes"

Course code	Title
1. Mandatory core courses (common to both directions)	
1.1	Theory and history of restoration
1.2	Introduction to the pathology and restoration of monuments and materials
1.3	Institutional framework for the protection and management of cultural heritage
2. Mandatory courses for direction B "Conservation interventions, materials and techniques"	
2.1	Science and engineering of building materials and materials of architectural surfaces
2.2	Science and engineering of materials and conservation – restoration – protection interventions
2.3	Environmental management for the preservation of monuments
3. Optional courses for direction B "Conservation interventions, materials and techniques" regarding specific issues, techniques and technologies (choice of three out of eight offered)	
3.1	Corrosion and conservation of metal works and structures
3.2	Specific techniques of materials and conservation – protection interventions with emphasis on earthquake protection of monuments
3.3	Pilot applications of conservation interventions on monuments
3.4	Special issues on environmental management for the protection of monuments
3.5	Special issues on environmental management for the protection of museum exhibits
3.6	Special techniques and conservation – preservation technologies for cultural heritage works
3.7	Archaeometry
3.8	Materials characterization and diagnostic methodologies of pictorial cultural heritage
4A. Thematic areas of laboratory exercises and technical projects	
4.1	Techniques and methods of diagnosis
4.2	Techniques and methods of cleaning on laboratory and monument scales
4.3	Techniques and methods of consolidation – protection on laboratory and building / monument scales
4.4	Study of the behaviour of building materials to humidity transport phenomena
4.5	Characterization of historic mortars
4.6	Characterization and synthesis of restoration mortars
4.7	Study and assessment of the behaviour of historic structures under static and dynamic stresses
4.8	Management of monument – environment data
4B. Field studies – Technical visits (Educational visits)	
5. Dissertation Thesis	

4. Project - based learning approach applied for cultural heritage protection

The Direction B' of the Postgraduate Program "Protection of monuments, sites and complexes" exploits the benefits of project – based learning approach. The basic characteristics of this approach are:

- **Hands - on experience**: Students are asked to apply the gained knowledge through the Mandatory and Optional Courses taught at theoretic level, making use of hands - on experience and of high measuring technology, including non destructive techniques for in situ measurements and analytical techniques for laboratory work. Through project assignment, students are encouraged to utilize the theoretic knowledge and basic principles for solving real problems and producing a final and unique product. Active and cooperative learning, teamwork and critical analysis for solving problems are promoted, setting students at the "centre" of the learning process.
- **Interdisciplinary character:** The cognitive field of built Cultural Heritage protection involves engineering disciplines, combined with other disciplines such as archaeology, history and art, and is characterized by strong inter-disciplinary character. The problems that built cultural heritage is facing are complex, demanding complex solutions, as well. Due to the inherent uncertainty involved in studying built Cultural Heritage, for which, limited information is typically available regarding the original materials and the construction technologies used and the effect of the environmental factors acting on the structure over time, and within the limitations imposed by the sensitivity for the artistic and historic values of built CH and the reversibility of any implemented interventions, Engineers involved in CH protection must be capable to "obtain" and "convey" useful knowledge to other scientists and personnel, working together as an integrated team.
- **Facing real cases**: Innovation is emphasised for merging traditional knowledge with state-of-the-art technologies in order to solve pressing contemporary issues such as those faced by built cultural heritage. Readjustment mechanisms are established and scientists are preparing for entering the job market through their occupation with real, complicate, engineering problems.

Project – based learning is applied in core parts of the Course, and specifically in **laboratory** and **in situ field studies** representing 400 hrs of the whole program duration and 15 credit units, and in **dissertation thesis** 300 hrs and 30 credit units (total: 45 out of 105 credit units of the whole program):

- **Laboratory exercises:** Students conduct a series of laboratory experiments, in the framework of which they are assigned certain projects and are asked to prepare a laboratory project report, summing up 15 credit units. Laboratory exercises are designed such that the students are initially provided with the basic theory and capabilities of each examined method or technique, but thereafter hands-on experience is encouraged, where, after some basic training on how to use the equipment, and under the supervision of the instructors, the actual measurements on real samples/case studies are performed by the students themselves. Sampling strategies, sample preparation, acquisition of data, data handling and data calculations are all performed by the students themselves, under the supervision of the instructors and aim to teach the students the principles, the use and the applicability of each method through a project - based approach; in this case, how to obtain useful information from real samples/structures. The corresponding laboratory reports are then prepared in the form of a short project report, describing all the steps involved, and responding to questionnaires specially designed to support creative thinking, deduction of information and experience with data management. These reports are typically assigned to teams, with each team member contributing according to their scientific background, capabilities and interests.
- **In situ field studies** at selected monuments, historic buildings, archaeological sites and complexes. The in-situ investigation campaigns and field trips in historic buildings/monuments, historic sites and cities, provide the basis for the vast majority of the Theses assigned to the students of the Program. The selection of the case studies is focusing on their educational attributes and the availability of ongoing research projects from the participating faculty/researchers that support the activities of the program, as well as the needs and cooperation of CH authorities and social carriers. The in-situ investigations and field trips are structured as short projects. Specifically, upon completion of the laboratory exercises, where the students have accumulated basic hands - on experience with the techniques and equipment used for CH protection, in - situ investigations and field trips are organized, partially with support from ongoing research programs of NTUA, and in cooperation with local Authorities, on case studies that act as open labs for applying the acquired knowledge into practice. During these in-situ investigations / field trips, students encounter firsthand the real problems faced by built CH, such as the decay of the architectural surfaces from environmental factors, the structural damage sustained due to earthquakes, the management issues involved in attempting to integrate built CH with socioeconomic activities of modern society, etc. However, these field visits are not limited only to present the prevailing issues threatening built CH, but rather are the means for applying all the theoretical knowledge obtained in classroom. Specifically, under the supervision of their instructors, and with the aid of appropriate scientific equipment, students are assigned tasks, according to their scientific background, ranging from documentation (e.g. history of the monument, photographic, architectural, survey documentation, mapping of materials), sampling of materials and their decay products, non-destructive

measurements on the architectural surfaces and the structural system of the building/monument to assess its preservation state, identification and documentation of environmental factors acting on the monument (e.g. sampling of precipitations for further chemical analyses, documentation of sources of pollution), identification of issues related to management of the site/building (e.g. accessibility to tourism). The students also interact actively with the representatives of the local authorities or the management body responsible for the ownership and maintenance of the site/building, obtaining useful information for theses' preparation.

- **Dissertation thesis**, covering a wide spectrum of subjects taught during the theoretic lectures. Typically, Theses are assigned in the framework of 2-3 Case Studies or ongoing Research Programs, supported by the participating Schools. Within each case study, Theses are assigned to students based on their scientific background (e.g. architects, civil engineers, chemical engineers, etc), their expertise, their interests, and the potential for future applications (e.g. public employees originating from Ministries / Ephorates can be assigned tasks similar to those they will be assigned once they return to their position). The Theses are also assigned such that, collectively, they cover all the issues relating to each Case Study, ranging from documentation, diagnosis of decay, preservation / protection interventions, to environmental management. Therefore, active cooperation between students of different and complementary scientific background is encouraged, so that all comprehend different aspects of each specific case study, despite focusing on more specific assignments for their personal Thesis. For example, chemical engineers' Theses that evaluate the effectiveness of conservation interventions for a specific historic building, involve data from the related work of chemical engineers' Theses focusing on decay diagnosis, and civil engineers' Theses focusing on documentation of the structural system; themselves, in turn, requiring data from archaeologist's Theses focusing on historic documentation of past interventions. All these, could, for example, be integrated within the scope of architect's Theses focusing on strategic planning of conservation interventions for the specific Case Study. The Research achievements and the Innovation developed in the framework of the more than 180 Dissertation Theses have been further exploited, and in particular, 35% of the students pursued a PhD degree, 30% of the research has been published in International Journals and Scientific Books, 47% is published in Greek and International Conferences and 53% regards Research and Applied Projects, justifying their research character and their value of application.

During the 15-year function of the postgraduate program, in situ-investigations and related Theses have been organized, among others, in the following selected Case Studies:

- Medieval City of Rhodes *[materials characterization, decay diagnosis, design and pilot application of compatible consolidation materials and treatments]*
- Hagia Sophia Basilica and Byzantine Monuments in Istanbul *[preparation of compatible repair mortars for earthquake protection of the structure; application of non-destructive techniques for assessment of the preservation state of mosaics, and for revealing plastered mosaic areas)*
- Historic buildings in Athens: Neoclassical buildings of the National Bank of Greece, Athens Academy, National Library of Greece, National Archaeological Museum, Byzantine and Christian Museum of Athens, Greek Parliament, Klonaridi Vila, Dourouti Estate, Benaki Museum, Nursery of the Municipality of Athens in Plaka *[decay diagnosis, assessment of effectiveness of cleaning interventions, strategic planning of conservation interventions]*
- Historic buildings in Greece: Kapodistrian Orphanage in Aigina, Kallithea Spa in Rhodes, Archaeological Museums in Heraklion, Rethymno and Olympia, Municipal Market of Pyrgos, traditional settlement of Oitylo *[architectural, survey, materials documentation, diagnosis of decay, planning of conservation interventions]*
- Archaeological Sites: Sarantapicho, Erimokastro and Agia Agathi archaeological sites in Rhodes, archaeological site of Delos *[architectural, survey and materials documentation of the sites, diagnosis of decay, strategic planning of conservation interventions, organization of cultural paths]*
- Sites and complexes of industrial architectural heritage in Greece: e.g. Industrial complex EMAGE in Kea island, Water Mill of Veroia *[diagnosis of decay, planning of preservation interventions]*
- Monasteries and Church buildings in Greece: e.g. Dafni Monastery in Athens, St Prodromos Bell Tower in Symi island, Agia Paraskevi Chalkidas in Evia, Paraportiani in Mykonos, Virgin Mary of the Rock in Corinth, Parigoritissa in Arta, etc *[diagnosis of decay, assessment of preservation state, mosaics and frescoes conservation, design of compatible restoration materials and techniques]*
- Monasteries and Church buildings in foreign countries: e.g. Church of the Holy Sepulchre in Jerusalem, Monasteries in Serbia *[diagnosis of decay, assessment of preservation state, mosaics and frescoes conservation, design of compatible restoration materials and techniques]*

5. Example of project - based learning approach for cultural heritage protection

An example of application of project - based learning approach organised in the framework of the Postgraduate Program is presented. It concerns a project for the implementation of an integrated diagnostic study performed at Klonaridi Vila in Athens. The project's structure involved:

Selection of project theme: The project assigned to students deals with the integrated diagnostic study at Klonaridi Vila in Athens. This is a historic building (1902) of the industrial era in Greece, built in three phases, which belongs to the Municipality of Athens and has been abandoned, but there exist plans for its rehabilitation as cultural centre or small museum. Due to the lack of architectural and historical data, an integrated technical proposal was required and through the cooperation of the Postgraduate Program and the Municipality of Athens this proposal will be the outcome of the project - based learning approach.

Setting concrete goals: The Municipality of Athens requires a technical proposal that provides information about the current state of the building (decay of materials and pathology of the structure), the restoration materials that will be used (plasters, mortars, stones, bricks), and structural strengthening measures that need to be taken, fulfilling contemporary building codes and standards. The general goals of the Postgraduate Course concern getting students acquainted with their local cultural heritage, engaging them in an integrated, interdisciplinary, hands-on, problem-based engineering approach for cultural heritage protection, cultivating effective teamwork, creativeness and critical thinking. The specific goals concern rendering students capable of identifying the basic building materials encountered in "monuments" at local scale, identifying the basic decay types encountered in "monuments" at local scales and correlating them with probable causes, making use of high measuring non destructive technology and carrying out the basic stages of an the integrated diagnostic study.

Review of relevant theory – documentation: Students are encouraged to study themselves about the specific project theme at the University library, search at the web for the specific historic buildings (e.g. Municipality of Athens) and review the theoretical lectures they have been taught regarding the integrated diagnostic study. Additionally, the first step of the integrated diagnostic study is performed concerned the documentation (historic, architectural, surveying, materials, previous interventions for conservation / protection / preservation, previous uses etc.) for the selected historic buildings for field work.

Division of students in teams – distribution of roles: Students are divided into small teams (~3-5 persons) and undertake certain roles and responsibilities, in order to apply the theoretic knowledge they have been taught. As an example, civil engineers and survey engineers are assigned the identification of the current state of the structure, using either in situ non destructive instrumentation (georadar, ultrasonics, photogrammetry, laser scanning) or analytical tools (finite element modelling, structural analysis). Chemical engineers are focusing on identifying the decay of materials and the pathology of the structure using in situ non destructive instrumentation (fibre optics microscopy, ultrasonics, infrared thermography, digital image processing) or analytical techniques (optical - electron microscopy, porosimetry, XRD etc.).

In situ work at "monument" scale: The in situ work involves working at two levels: (a) documentation of the materials and the structure (identification of the different materials and building technologies of the three phases, update of the architectural plans), (b) mapping the current state of the building (decay of materials, mapping of the cracks, pathology of the structure). In order to accomplish these two levels, the teams work simultaneously, providing relevant information to each other as needed. The in situ work utilised integrated diagnostic protocols, which enable more effective, organised work, assuring repeatability (Moropoulou at al, 2012; Kioussi, 2013).

Validation of results at laboratory scale: A sampling campaign, designed and implemented by students, provided samples of the building materials from the three phases and the encountered forms of decay, subsequently analysed in laboratory regarding their chemical composition, microstructure, mechanical and physical properties, and provided the necessary input for structural analytical models, verifying the observed buildings' pathology.

Synthesis of teams' work – presentation of final report: An integrated technical proposal is composed based on the synthesis of the teams' students work in the framework of the requirements of the Program regarding their Thesis, their in situ field studies and laboratory exercises. All teams work together for the development of the final product (report of the integrated diagnostic study) and present it to their lecturers. Within this approach, students realise that they are part of a bigger team that is capable of accomplishing a project of such a complex nature.

Evaluation of students and of the whole project: Evaluation of the students' gain and of the whole project takes place through questionnaires of perception concerning the knowledge gained by students, as well as evaluation questionnaires comprising students' impressions, problems encountered throughout project implementation, recommendations for the improvement of the project - based learning approach.

Figure 3: a. Klonaridi Vila; b. The three phases of the building; c. Assignments to teams; d. In situ measurements; e. Elaboration of results for the final "product" (e.g. results from Ground Penetrating Radar)

6. Conclusions

Education for cultural heritage protection, as engineering education in general, needs innovative approaches in order to respond to contemporary needs and expectations of youth and society in general. Direction B "Conservation Interventions: Techniques and Materials" of NTUA Interdepartmental Postgraduate Course "Protection of Monuments, Sites and Complexes" applies the project - based learning approach at core parts, such as laboratory exercises, in situ fieldwork, dissertation thesis. Interdisciplinarity, hands - on experience, use of high measuring up-to-date technology and dealing with real cases met in everyday practice compose the basic characteristics of the applied approach. Postgraduate students find these parts of the Course extremely useful and interesting, learn to work effectively in teams, cultivate critical thinking and problem solving skills, indispensable for their future careers in the respective field. All these skills are indispensable for graduates regarding their future careers. The relevant results are extremely encouraging, as the majority is absorbed in positions dealing with protection of monuments in general, a fact which evidences the usefulness and success of project - based learning approach. More specifically, 26% of the Course graduates continue their studies for a PhD in the relevant field and / or are employed at research programs carried out at University level, 46% are employed at relevant positions of public sector (i.e. Ministries), 27% are employed at relevant positions of private sector (i.e. industries, technical offices) and only 1% of graduates are employed at irrelevant - with their specialized studies - positions. In order to face contemporary world crisis encountered at multiple levels, it is essential to intensify the efforts for providing all the required skills, knowledge and expertise to young professionals for problem solving and facing real cases through engineering education, as they are considered the key players for the gradual turnover of this awkward situation.

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References

Hattum - Janssen, N.V. (2007). Project led education in engineering courses: competences to include. International Conference on Engineering Education ICEE 2007, Coimbra, Portugal.

Helm, J.H., & Katz, L.G. (2001). Young investigators: The project approach in the early years. New York, Teachers College Press.

Khair, N.M., Nabil, MD. N.A., Dayana, F.A., & Safarin, N.M. (2011). Problem - based learning (PBL) and project - based learning (PjBL) in engineering education: a comparison. Proceedings of the IETEC '11 Conference, Kuala Lumpur, Malaysia.

Kioussi, A. (2013). Standard methodology for the documentation of materials and conservation interventions with emphasis in the European Cultural Heritage identity. Phd Thesis (in progress), Scientific supervisor: Prof. A. Moropoulou, National Technical University of Athens.

Konstanti, A. (2013). Educational approach in the protection of monuments. PhD Thesis (in progress), Scientific supervisor: Prof. A. Moropoulou, National Technical University of Athens.

Lehmann, M., Christensen, P., Du, X., & Thrane, M. (2008). Problem – oriented and project – based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. European Journal of Engineering Education, Vol. 33 (3), 283 – 295.

Lowenthal, J.N. (2006). Project - based learning and new venture creation. NCIIA 10th Annual Meeting, Oregon Museum of Science and Industry, Oregon.

Mills, J.E., &Tregust, D.F. (2003). Engineering education - Is problem-based or project-based learning the answer?. Australasian Journal of Engineering Education (http://www.aaee.com.au/journal/2003/mills_treagust03.pdf).

Moropoulou, A., Konstanti, A., & Kokkinos, Ch. (2006). Education and training in cultural heritage protection: the Greek experience. International Conference Heritage Protection: construction aspects, Dubrovnik Croatia.

Moropoulou, A., Lampropoulou, A., Konstanti, A. & Kioussi, A. (2008). European Master level education on protection of cultural heritage: national experiences and European perspectives. 8th EC Conference on Sustaining Europe's Cultural Heritage - CHRESP, Ljubljana, Slovenia.

Moropoulou, A., & Konstanti, A. (2010). Master level education on protection of cultural heritage: national experiences and European perspectives. The 5th International Conference on interdisciplinarity in education - ICIE '10, Tallinn, Estonia.

Moropoulou, A., Kioussi, A., Karoglou, M., Bakolas, A., Georgousopoulos, G., & Chronopoulos, M. (2012). Innovative protocols for integrated diagnostics on historic materials and structures. Structural Faults & Repair-2012, Edinburgh - Scotland.

Nélson Rodrigues da Silva, A. (2010). A Problem-project-practice based learning approach for transportation planning education. PBL 2010 International Conference, São Paulo, Brazil.

Powell, P.C. (1999). From classical to project-led education. Project based learning: project-led education and group learning. A.S. Pouzada (ed) Universidade do Minho, Guimarães Portugal 1999, ISBN 9729810311, 11 - 40.

Prince, M.J., & Felder, R.M. (2006). Inductive teaching and learning methods: definitions, comparisons, and research bases. Journal of Engineering Education, 95(2), 123 - 138.

Vilela, L.M.C., Speranza Neto, M., Almeida, N.N., & Campos, R. (2011). From the hands-on methodology to problem-based learning: experiences and perspectives of a non-conventional introduction to engineering course. PAEE International Symposium on Project Approaches in Engineering Education - Aligning Engineering Education with Engineering Challenges, Lisbon.

Weenk, W., & Van der Blij, M. (2011). Tutors and teachers in project-led engineering education - a plea for PLEE tutor training. PAEE International Symposium on Project Approaches in Engineering Education - Aligning Engineering Education with Engineering Challenges, Lisbon.