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Engineering Education: Beyond Technical Skills

Part II—Case Studies Linked to the Promotion of Specific Technical Skills

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The objective of this paper is to address the methodological process of promoting professional project management skills in Engineering Higher Education, evolving from Graduate to Postgraduate Programs. The strategy was born from a cooperative model of Project Based Learning (PBL) created with the experience of the GIE-Project, Educational Innovation Group (EIG) of the Technical University of Madrid (UPM), in collaboration with other EIG and industry stakeholders external to the university. The model has evolved and undergone various phases until being inserted in the European Space of Higher Education with the International Project Management Association (IPMA) competences. Over time GIE-Project strategy has developed into a process, an approach to designing, developing, implementing, evaluating and promoting professional Project Management skills in first (Graduate), second (Postgraduate) and third (PhD) cycle degree programmes. The results show how phasing in teaching aimed across different educational levels facilitates a gradual training in the 46 elements of professional competences required to obtain the IPMA's certification on Project Management. The educational strategy is conceived as a new teaching dimension within the framework of the EHEA, taking the course projects—Preliminary course, Final Degree Course Project and Final Master's Course Project—as an educational component suited for generating a "pre-work experience" to link teaching activity to the business and industrial environment. This paper shows the main success factors in the process that was carried out: the links between teaching-professional certification, the evaluation of professional competences, Project Based Learning, teaching subjects in connection with real-world problems, cooperative learning, mobility activities and integration and applied teaching-research.

Keywords: professional skills; Engineering; higher education; assessment and certification of professional competencies; cooperative education; project-based learning

During the last few years of teaching the subject of Graphic Engineering, traditional teaching methods have been used based on lectures and solving any problems as they arose. In the opinion of the authors, this gave a rather compartmentalised overview of engineering design. Students were assessed solely by a final exam, the final mark only being slightly influenced by the exercises set throughout the course. Being aware of this deficiency and motivated by the large number of graduates absorbed by the industrial engineering sector, two different experiences were developed built around project-based learning (PBL). It was intended to introduce a consolidated method that would bring students closer to an environment that simulated the actual working conditions in the field of engineering design. This paper describes the evolution of the methodology proposed by the authors and the results achieved. The aim of the authors is not simply to establish a methodology that will serve as an integrative component between the different degrees but as a methodology that will forge cross-links between degree subjects and enable students to develop their work more fully and endow their vocational training with a wider scope.

Keywords: project-based learning (PBL); cooperative learning; collaborative learning; engineering design

Formula Student (also known as Formula SAE) is an international competition for universities that challenges the students with a comprehensive engineering problem. Most of the participant universities and all the companies involved in the organization of the competition have identified this event as the most suitable tool for hard and soft skills development. This paper evaluates this development by means of two different objective assessments in the frame of a specific team, identifying the potential of the competition and showing a particular approach to enhance soft skills development.

Keywords: soft skills; scoring rubric; E-Delphi; Formula Student; practical case study

A project-based learning approach is proposed and tested in this study to explore its feasibility and the effectiveness of such a pedagogical framework to guide instructors and learners in an interdisciplinary learning context. Objective data from summative evaluations were collected to understand students' performance and attitude in their project-based learning experiences, as well as to explore whether the interdisciplinary project-based learning approach improves students' abilities to perform project work. The results of this study showed that students did improve their ability to work on group projects through the engagement and experience of this interdisciplinary PBL. Also, students performed well on their final projects, for the instructors were satisfied with

their group project performances. Students also expressed positive attitudes toward the interdisciplinary PBL approach as an effective instructional strategy. Based on the findings of this study, discussion and recommendations are provided on future issues in engineering education, both for practical application as well as research.

Keywords: interdisciplinary learning; engineering education; project-based learning; smart living technology

Transversal skills are known to be often forgotten in the engineering studies plans or relegated to the will of the professors. The nuclear engineering subjects at the Universidad Politécnica de Madrid are taught in the last courses of the degree or at master and doctorate levels. Therefore, the alumni are expected to be almost ready for the working period of their lives. Throughout the last years, due to the Bologna process, some transversal skills evaluation initiatives have been implemented. Those initiatives were mainly based on doing an additional project, individually or in group, during the semester, and presenting it in public at the end of the semester. Thanks to those initiatives, noticeable lacks were identified in several transversal skills such as oral and written communication, creative thinking and team work. For example, some alumni confessed that it was the first time they had to expose a technical work in public. Those lacks in the transversal skills were also identified by engineering companies. Motivated by those issues, a new project to develop the mentioned skills in nuclear engineering subjects was raised. In the first phase during the courses 2011–2012 and 2012–2013, two subjects were selected as pilot: Nuclear Power Plants (4th course in degree) and Reliability and Risk Analysis (Master in Nuclear Science and Technology). They were chosen by the different level of knowledge, the numbers of students and their origins. The training has been improved during the second phase with the lessons learned of the first phase. In conclusion, following the alumni polls and evaluated results, the training was very effective and the alumni have a positive feedback on it. They think they have developed their transversal skills in a way they feel better prepared for their careers.

Keywords: transversal skills; nuclear engineering; project-based learning

Recently, new syllabuses are being implemented accordingly to the European Higher Education Area (EHEA) in Spain. This paper describes the methodology and assessment strategy applied in the subject "Digital Circuits and Systems" (CSD) in the third semester course in the Telecommunications Engineering degree at the Castelldefels School of Telecommunications and Aerospace Engineering (EETAC) of the Universitat Politècnica de Catalunya (UPC). The course's main learning objective is that students be able to analyse and design simple combinational and sequential circuits by means of hardware description languages for programmable devices and program applications using microcontrollers and C language.

Small groups of two or three students work in cooperation using PBL techniques to solve design-oriented assignments, while instructors act more as mediators than lecturers in order to facilitate project development and knowledge acquisition. The experience we describe corresponds to the spring term of 2011, a period in which this methodology was applied to 46 students.

This work compares statistically the influence of the students' background on their academic performance in our subject. A significant correlation has been detected between test marks and the final grade, based on continuous assessment. Students' opinions have been obtained by means of a survey at the end of the course. Although the high workload and involvement, because this methodology requires constancy and commitment from the students, most of them have positive opinions on the development of the subject, due to the fact that they realise that they have put into practice several competences or cross-curricular skills, while acquiring the course content, and furthermore, most of them have passed the course, even with higher grades than the ones from other subjects in the same semester.

Keywords: collaborative work; circuit simulation; digital systems; competences

A teaching-learning experience focused on the promotion of specific transversal competencies (self-learning, efficient oral and written communication and team working) integrated into the curriculum of Bachelor in Industrial Engineering (BIE) is presented. With the aim of reinforcing some traditional lacking aspects in old engineering curricula, some core subjects linked to project-based learning activities have been included in the new curriculum of BIE given by the School of Engineering of Barcelona (UPC). The current curriculum includes two mandatory subjects aimed to the acquisition of professional competencies. Students can choose from a list of fifteen available projects. An example of the type of projects offered on the course is given here. It is an interdisciplinary project combining Mechanics of Materials, Statistics and Engineering Project disciplines. Teaching learning methodology and benefits of the approach followed for promoting professional skills are presented. The final section summarises the main results provided by the experience against conventional activities.

Keywords: interdisciplinary project; engineering; professional competencies; problem-based learning

In the light of increasing demands on engineering curricula to integrate the development of professional skills in engineering education, this paper focuses on characteristics of effective educational environments and experiences for preparing students for future challenges by exploring ways in which professional learning is encouraged. The study is empirically grounded in a 3-day annual workshop that brings together students from all areas in the building sector including industry exponents to engage collaboratively in the processes of design and construction of a new building. The workshop is based on the principles of Building Information Modeling (BIM), which facilitate the coordination and collaboration between parties of a building design and construction team, and in this process, essential communication and interpersonal skills are mobilized and developed. Data about the students' learning outcome are collected through observation, interviews and online questionnaires. The present investigation points at the dual effect of experiential learning in problem-based, interdisciplinary environments with regard to both actualizing core knowledge, skills and competences through solving complex real life problems and having to employ and thereby develop professional skills in the process of solving these problems.

Keywords: collaboration skills; interdisciplinary teams; digitally supported collaboration environment; problem based learning

Educational institutions face many challenges in closing the gap between what is currently offered through academic engineering curricula and what is expected by society in general and industry in particular. There are many aspects to these challenges and here we address needs that are specific to global professionals by investigating the knowledge, skills and abilities needed for mediating and using Collaborative Technologies (CT) in an Open Ended Group Project (OEGP) within a global setting. We discuss these needs as framed by relevant theoretical frameworks for collaboration and learning (including Collaborative knowledge building and Collaborative Technology Fit), mapped using empirical data from a course setting involving global collaboration between two Universities (one in the United States and one in Sweden). The paper concludes with a commentary on competencies beyond discipline specific technical skills and presents recommendations, based upon this research, for developing students' proficiency in both mediating and using CTs in OEGP courses. These recommendations are followed by an outline of key areas for future research.

Keywords: collaborative technologies; professional competencies; open ended group projects, global collaboration, engineering education research

Interdisciplinary learning is often limited to student groups which already have significant overlap in either their curricular content or whose day-to-day duties entail regular interactions. This is not generally the case for engineers and clinicians, and almost never the case for students of engineering and medicine. In this feasibility study, interdisciplinary learning outcomes were assessed in six teams comprising undergraduate engineering and medical students at a major Irish university. Three key factors differentiated the current study from complimentary approaches; (i) the module places undergraduate medical and engineering students in interdisciplinary teams, (ii) students are educated in a systematic methodology (TRIZ) of design and innovation, which is then applied to a clinical challenge and (iii) the present study places student learning outcomes as the primary mission of the module, rather than the project deliverables. Feedback from both students and clinical mentors was assessed using focus groups and individual interviews. The learning outcomes were convincingly imparted as evidenced by feedback, which was overwhelmingly positive from both students and clinicians. As an added benefit, the tangible outputs (e.g., prototype or software tool) from each of the 6 teams represented a worthy proof-of-concept, in some cases suitable for future research or commercial exploitation. This initial feasibility study highlights the potential benefits of a new structured methodology in to solving clinical problems in the context of interdisciplinary learning.

Keywords: interdisciplinary learning; medical education; biomedical design; TRIZ, theory of inventive problem solving; TIPS

This article explains the results of more than three years working in collaborative engineering learning development, at the master's degree level, in the school of industrial engineers of the UNED, distance university of Spain. The fundamental approach is based on the "distance methodology" and "continuous evaluation" of the students' work and periodic reviews. The need for a teamwork aptitude is assumed an implicit requirement and, therefore, there is a specific methodology for the project. The work is supported by data and statistics that show better results than those obtained in other subjects of the same master's where the teamwork option is not applied, or in other master's and degree subjects in the engineering field or other technical areas. The result is success in the response and participation of the students and a new methodology that could be transferred to other subjects that do not have a specific teamwork requirement, but could use this methodology to improve the results.

Keywords: teamwork; collaborative engineering; concurrent engineering; design; design engineering

Building Information Modeling (BIM) is changing the way projects are constructed. This emerging practice requires new mind-sets and technological know-how in order to achieve significant improvements in building efficiency. Universities must focus on the strategy of using BIM as an innovative technology to allow the acquisition of new skills by students and prepare them for their future activity in a more competitive world. Based on this perspective, the text presents some educational measures on offer at the Technical University of Lisbon. It focuses on the importance of teaching BIM: the involvement of students in research projects, PhD theses and MSc dissertations, and the dissemination of BIM through professional short courses and workshops addressed to the AEC community outside the school. Some of these have already been carried out in the school; others are presently being proposed or currently in progress. It is clear from this paper that school is an important driver for the growth of BIM knowledge and practice through the preparation of new and existing professionals.

Keywords: education; BIM; concept; curriculum

The spatial skills are an active field of research, especially in the engineering area. Several authors connect high levels of spatial kills with the success in technical careers. One of the components of spatial skills is spatial orientation. Many studies show that providing the appropriate material may develop spatial skills. However, a plan aiming for the development of spatial orientation skills in formal teaching is still missing. This paper presents an innovation in the teaching strategies through a Geographic Information Technologies workshop which aim is development of the spatial orientation. The workshop's study was completed during four academic courses with 248 university engineering students involved. A control group was created with 35 students using conventional teaching methods for determining if the increase in the spatial orientation skill is due to the effect of this workshop. The result shows significant statistical gains over the spatial orientation skill of 19.21 degrees. The results from the control group confirm that students who have not undertaken specific training didn't develop their spatial orientation skill.

Keywords: geographic information technologies; infrastructure for spatial information in Europe; spatial orientation; spatial skill

Engineers are required to have good levels of spatial skills in order to operate in a professional environment. Consequently, we may state that spatial skills are a professional skill which engineers must acquire. In this work, a methodology based on 3D virtual technologies and tools have been implemented in terms of the curriculum of the subject of Engineering Graphics. The experimental study has been carried out with different groups of students from several engineering degrees who studied that subject, using different 3D virtual technologies. Once the subject is completed, the results indicate that there is a significant difference between the spatial ability levels acquired by the groups which had 3D technology support compared with those which didn't. Regardless of the technology used, the improvement is quite similar over both groups, without any significant differences. The academic performance of the students is much better on the part of those groups using these technologies compared with those who complete the course following traditional methods.

Keywords: spatial skills; virtual reality; augmented reality; PDF3D, engineering education; professional skills; professional competencies

An interactive workshop has been developed that is intended to increase the integration of the creative process across engineering curricula. The workshop introduces participants to key findings from the research on creativity and the creative process including effectiveness of instruction on creative performance and assessment of creativity. A key goal of the workshop is helping instructors to see the strong parallels between the creative process and the processes used to address novel, complex problems in engineering design, analysis, and experimentation. The outcomes of the first two workshops were quite positive and indicate that it is effective in increasing knowledge about the creative process and in helping engineering instructors begin to design activities for integrating the creative process, or elements of it, into their courses. However, the outcomes also point to opportunities to improve future versions of the workshop.

Keywords: creativity; creative process; design; analysis; laboratory

An online open access test (CREAX self-assessment) has been used in this work so that students from degrees in engineering in the Universidad Politécnica of Madrid (UPM) could self-assess their creative competence after several classroom activities. Different groups from the first year course have been statistically compared using data from their assessment. These first year students had different professors in the subject 'Technical Drawing' and belonged to several degrees in the UPM. They were as well compared regarding sex and a group of first year students was also compared to another last year group of the degree so as to observe possible differences in the achievement of this competence. Only one difference was detected concerning sex in one of the degrees. Among degrees, the higher marks obtained by students who had done specific exercises for the development of creativity in class is highlighted. Finally, a significantly high mark was observed in students during their last year of degree with respect to first year students. The tool CREAX has become very useful in the assessment of this competence in the UPM degrees in which it has been implemented.

Keywords: engineering creativity; engineering education; CREAX test; e-tool for self-assessment; technical drawing; generic competence; soft skills

Creativity is one of the skills of our graduates most demanded by working companies, which is directly linked to problem-solving, innovation, and the creation of new businesses ideas or the patents development. The demand for the creativity skill is ever increasing and appears among the five skills most valued by employers at times when resources are most limited. During the last three years, a set of initiatives has been performing at the Industrial Technologies Degree course, at the Universidad Politécnica of Madrid, to enhance creativity as one of the most relevant skills. The goal is clearly to improve the creative skill of the engineers in the industrial field, having focused the activities carried out on the two major players in the educational process, i.e. the teaching staff and the students. The paper describes the process followed to gradually bring on board an ever increasing number of teachers committed to developing their student's creativity.

Keywords: creativity; skills; industrial engineers; educational process; competencies

This research presents an innovative and formal educational initiative that is aimed at enhancing the development of engineering students' specific competencies when studying Engineering Project Management subject. The framework of the experience combines theoretical concepts, the development of a real-case project carried out by multidisciplinary groups of three different universities, the use of software web 2.0 tools, and group and individual assignments of students that play different roles (project managers and team members). Under this scenario, this paper focuses on monitoring the communication competence in the ever growing Project Management virtual environment. Factors such as corporal language, technical means, stage, and management specific vocabulary among others have been considered in order to assess the students' performance on this issue. As a main contribution, the paper introduces an ad-hoc rubric that, based on previous investigations, has been adapted and tested to this specific context. Additionally, the research conducted has provided some interesting findings that suggest further actions to improve and better define future rubrics, oriented to communication or even other competencies. As specific Project Management subject concerns, it has been detected that students playing the role of Project Managers strengthen their competencies more than those ones that play the role of Team Members. It has also been detected that students have more difficulty assimilating concepts related to risk and quality management. However those concepts related with areas of knowledge like scope, time or cost have been better assimilated by the students.

Keywords: competency development; communication skills; communication rubrics; virtual learning experience; multidisciplinary learning

The paper focuses on the education of communication competent engineers. The comparison of engineers (student-future engineers, active engineers, and active engineers specialized for energy efficiency of electric drives) with other professional groups, and between subgroups mutually, and the comparison of the participants included in a communicology course or training and without it, are the topics of the paper. Interaction involvement scale and Rahim Organizational Conflict Inventory II are used. The sample consists of 166 participants (university students of engineering, engineers in the engineering field, especially in the field of energy efficiency of electric drives, teachers of engineering courses). The results indicated that engineers and teachers of engineering courses have manifested moderate level of interaction involvement and mostly chosen integrative conflict resolving style; however, some of them who finished communicology courses have significantly higher level of these competencies. It is necessary to strengthen communication competence in a systematic way by organizing suitable training for active engineers as well as for students–future engineers during their initial education.

Keywords: engineer's communication competency; communication education; interaction involvement; conflict management style

The importance and the levels of foreign language communication skills of engineering students, prospective engineers, in the fields of agronomy and food technology are analyzed in the paper. The models of communicative competence and communicative language ability are illustrated. Communicative language ability was measured by applying the instrument Communicative language ability scale. The sample consists of 60 engineering students in the fields of agronomy and food technology, studying English as a foreign language at the Faculty of Agronomy, University of Kragujevac, Serbia. The obtained results indicate moderate level of communicative language ability within the sample. The levels of all elements of communicative language ability of engineering students of biotechnical sciences are influenced by the teaching/learning approach applied, particularly by communication-oriented approach.

Keywords: engineering profession; communication skills; communicative language ability; foreign language

Ability to write for disciplinary publication is a hallmark of disciplinary expertise. This article reports on the pedagogical strategies used in a semester-long graduate course offered to facilitate engineering students' production of a manuscript ready, or near ready, for submission to a peer-reviewed engineering journal at semester's end. Strategies of structure oriented students to the foundational components of a journal manuscript. Strategies of evaluation oriented students to self- and peer-evaluation, in preparation for the broader peer-review process that occurs upon manuscript submission. Each strategy presented was identified as

instrumental in developing students' disciplinary writing skills and knowledge. However, each strategy appeared to have a window of heightened effectiveness, depending upon the level of a student's previous writing experience. This article describes pedagogical strategies that support disciplinary writing development and considers the effect of initial differences in writing ability in terms of the use and timing of these strategies.

Keywords: academic writing; civil engineering; pedagogical writing strategies; graduate students

This article describes a project in which writing assignments were embedded into a 100-level course entitled Chemistry for Engineers. The authors discuss a workplace-oriented writing assignment that involved group work, problem solving, and sensitivity to rhetorical and genre considerations. Through an analysis of student work, the authors illustrate how seemingly small instructional decisions can significantly impact student performance. Based on this analysis, the authors recommend teaching practices that support engineering students' writing development. They conclude by discussing factors that aid in the integration of writing instruction into unique locations in the engineering curriculum.

Keywords: engineering communication; communication instruction; writing; interdisciplinary collaboration

The development of interpersonal skills during a student's undergraduate course is critical because the more developed the social skills the more chances to satisfactorily deal with the demands of different environments and interlocutors. That being the case the university should include interpersonal development as part of its academic goals. Some universities try to achieve those objectives through "junior" enterprises, continuing education programs, university-industry outreach programs and so on. Therefore, this paper describes a successful experience conducted in the university for developing engineering students' interpersonal skills. Two different strategies were adopted to promote the Engineering students' development of interpersonal skills: the PRODIP (Interpersonal Professional Development Program) and academic disciplines focusing on social skills and leadership. The PRODIP program had the participation of 41 engineering students in one of its four consecutive annual editions. The students' social skills were assessed before, during, and after the end of the program, and also three months after (follow-up). The program, which lasted four months, was composed of 15 weekly sessions that included intervention and theoretical aspects related to the practical training of successful social interactions. The participants in PRODIP improved their social skills after the program was implemented and this improvement continued over time (follow-up). The social skills course was applied in two ways, the first one, a brief format, was offered to 29 students, with three four-hour meetings each and addressed topics such as communication, assertiveness and working skills. The second one in a larger format, was offered to 40 students, it consisted of 15 lessons of two hours each. The participants reported the importance of social skills as a prerequisite for teamwork and internship programs, which constitutes the transition from student to the professional workplace. The need to plan strategies in order to promote the students' interpersonal development is discussed.

Keywords: engineering education; interpersonal development; leadership; social skills

This paper presents the Professional Social Responsibility Development Model, which is a framework to help understand the development of personal and professional social responsibility in engineers. Social responsibility is seen as a foundational disposition that informs how engineers relate to many professional skills valued in engineering including ethics and the impacts of engineering on society. This framework is rooted in the Ethic of Care philosophy, and uses three realms to describe the development of social responsibility: the development of personal social awareness, the development of professional skills and how they relate to social considerations, and the connection between personal and professional views of obligation or responsibility. Qualitative data from interviews with engineering students are used to exemplify development in each realm. This conceptual framework is intended as a blueprint for developing studies and assessment instruments which examine the development or identification of social responsibility in engineers or other professionals. Results from one such tool are presented to exemplify one way in which this framework could be used.

Keywords: social responsibility; ethics; Ethic of Care; professional skills; developmental framework

STEM leadership education as a formal discipline is not present in the majority of higher institutions. Similar is the case with ethics in engineering schools. Although ethics is recognized as a crucial aspect in developing the professional identity of engineers, it is still not required as a mandatory course in all engineering curricula. This study introduces a project that simulates a real-world engineering application and uses this task to examine how the assignment objectives influence employment of students' leadership skills and social responsibility awarness. The participants were from three different groups – (1) learning communities, (2) traditional sections, and (3) international sections. It was hypothesized that there would be different outcomes of the students teams projects considering the three different missions of the groups. Results corroborated the hypothesis. The learning community teams proposed projects that best addressed the assignment objectives and enhanced professional skills in the utilization of the course project compared to the traditional and international sections. Outcomes are discussed in terms of underlying links in assignment objectives and the enhancement of professional skills in engineering instruction.

Keywords: engineering leadership; ethics; engineering education; project-based approach

Today's engineering graduates face an evolution of global priorities that places a greater emphasis upon sustainability, community, and well being. Overcoming the complex challenges of this shift will require engineers to display agility, resilience, intrinsic drive, and an ability to continually grow and develop—capacities that are currently underemphasized in engineering degree programs. Despite a growing recognition of the importance of socially responsible technological development, many engineering programs continue to prioritize decontextualized technical content learning over broad competency development. As a result, students may have difficulty identifying either personal or societal value in their engineering activities. We suggest that the integration of engineering and humanities perspectives can help students situate their technical studies within the larger human system while simultaneously offering measurable improvements in students' motivations and lifelong learning skills. In this paper, we report findings from an investigation of the effects of disciplinary integration on student motivation and learning engagement in introductory materials science courses. The quantitative results show that integrating materials science with humanities through a project-based course effectively supports increased student motivation and engagement in self-regulated learning strategies. Compared to students in non-integrated project-based courses, students in integrated project-based courses show higher intrinsic motivation and task value. Students in the integrated materials science-history course also report significantly higher use of critical thinking strategies in their project work, indicating that an emphasis on societal context may help students cognitively engage in their engineering studies. Findings also indicate that disciplinary integration offers particular benefits to women engineering

students. Compared with the non-integrated course, women in the integrated course report more significant motivational and self-regulated learning gains. This research suggests that putting human contexts at the center of engineering learning can help all engineering students, and especially women engineering students, build a sense of societal relatedness that promotes better learning.
Keywords: motivation; self-regulated learning; lifelong learning; project-based learning; disciplinary integration; self-directed learning