INTEGRATING SUSTAINABILITY IN ACADEMIC CDIO SUBJECTS: A REVIEW AFTER THREE YEARS OF EXPERIENCE

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ABSTRACT

We present in this study the results and reflections about the implementation of a specific teaching-learning methodology that has been designed to incorporate sustainability aspects in “INGENIA” projects. These 12 ECTS-compulsory subjects are taught following the CDIO standards, according to which the students must develop a somehow innovative product or service from the conception and design to the implementation and operation. After three academic periods, the study discusses how our strategy has been quite satisfactory for students to strengthen their competences related to sustainability. Results firstly show that the students value positively the experience, having gained a greater awareness on sustainability issues and expanded its vision on the complexity of engineering activity. Secondly, from the point of view of the instructors, the designed methodology successfully meets the objectives previously defined. Thirdly, some difficulties encountered during the action-research period have led to the implementation to some modifications in the methodology, mainly oriented to a better adaptation to very different and heterogeneous projects. In conclusion, it is highlighted that the integration of sustainability in CDIO subjects is a complex task, which needs to overcome some difficulties, those specifically related to the intrinsic particularities of the development of each project and the coordination of multidisciplinary teams of professors.

KEYWORDS

Sustainability, Social Responsibility, Professional Responsibility, Ethics, Project-based courses, Standards 2, 3, 6, 7, 9, 11

INTRODUCTION

Engineering programs are increasingly recognizing the understanding of the responsibilities of the professional engineer in society, and the ability to analyse ethical, societal and environmental aspects of engineering activities as important goals to ensure in graduate students' profile (ABET, 2015; CEAB, 2017). The CDIO Syllabus 2.0 already includes ethical and social responsibility aspects and sustainability criteria for each one of the lifecycle stages (CDIO, 2011) and, recently, Malmqvist et al. (2017) included *sustainable development* as an optional CDIO standard in their proposal presented at the last International CDIO Conference.

In the last decade, many authors have explained their experiences about the integration of sustainability (Binder et al., 2017; Enelund et al., 2012; Hussmann et al., 2010; Silja et al., 2011; Wedel et al., 2008) or ethics (Augusto et al., 2012; Lundqvist, 2016; Palm & Törnqvist, 2015) into the context of CDIO engineering education. In the same line, Miñano et al. (2016) and Borge et al. (2017) presented in past CDIO Conferences the work developed in the Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid (ETSII-UPM).

In accordance with the mission of the ETSII-UPM, it is essential that its students become ethical, professionally aware and responsible for the implications of their activity, promoting sustainable development (ETSII-UPM, 2016). To achieve this goal, the work on transversal competences has been strengthened and the number of subjects that promote sustainability issues has been increased in the curricula. ETSII is accredited by the Accreditation Board for Engineering and Technology (ABET), which includes three learning outcomes that are directly related to sustainability: c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; f) an understanding of professional and ethical responsibility; and h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (ABET, 2015).

Using this competency framework, some project-based learning (PBL) innovations began to follow the CDIO methodology (Díaz Lantada et al., 2014) and become a reference to blend ABET and CDIO proposals. The new master's Degree in Industrial Engineering is the program in which the above outcomes were outlined as one of the main priorities of the overall curricula including a new innovative set of PBL courses denominated "INGENIA", whose name comes from "ingeniar" (to provide ingenious solutions) and "ingeniero" (engineer). All INGENIA courses have an analogous structure; primarily aiming at the acquisition of professional outcomes not only related to sustainability but also with the ability to design, implement and operate engineering systems, as well as creativity, teamwork and communication skills. Every subject is directly linked to the different ETSII-UPM majors (Lumbreras et al., 2015).

The teaching-learning strategy adopted fits to CDIO standards, such as the intensive use of supporting software, prototyping technologies and testing facilities at different labs, enabling the instructors to fulfil adequately all the CDIO steps, from the conception and design, to the implementation and operation.

In this paper we discuss the most relevant results of the implementation of the methodology after three years of experience and the new challenges to cope by the instructors for future INGENIA courses. Our conclusions are based on the annual students' assessment of the learning outcomes and the teachers' reflections about their work.

METHODOLOGY

The context: INGENIA/CDIO Courses

INGENIA courses are compulsory in the master's Degree in Industrial Engineering Program These subjects are 12 European Credit Transfer System (ECTS) equivalent, which correspond to a student workload between 300 to 360 hours, distributed along two semesters with the following structure: 120 hours of class work plus 180-240 hours of personal student work usually organized in teamwork. Class work of the subjects is structured in three modules:

- Module A (Technical): 30 hours dedicated to adapting basic theoretical knowledge derived from other subjects to those directly related with the project, and a second set of 60 hours is devoted to practical work in the lab, with professor supervised sessions.
- Module B (Transversal skills): 15 hours for workshops on teamwork, communication and creativity skills and techniques.
- Module C (Sustainability): 15h for lectures and workshops about social responsibility issues such as environmental and social impact, ethics and professional responsibility, health & safety, intellectual property, etc.

Table 1. INGENIA learning outcomes correlated with CDIO Syllabus 2.0.

	INGENIA learning outcomes		
CDIO Syllabus 2.0	Module A (Technical) ABET (b) (c)	Module B (Skills) ABET (d) (g) + Creativity	Module C (Sustainability) ABET(c) (f) (h)
2.2 Experimentation, Investigation and Knowledge Discovery			
2.3 System Thinking			
2.4.3 Creative Thinking			
2.5 Ethics, Equity and Other Responsibilities			
3.1 Teamwork			
3.2 Communications			
4.1 External, Societal and Environmental Context			
4.2 Enterprise and Business Context			
4.3 Conceiving, Systems Engineering and Management			
Environmental needs. Ethical, social, environmental, legal and regulatory influences. Risks and alternatives			
4.4 Designing			
4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives			
4.5 Implementing			
4.5.1 Designing a Sustainable Implementation Process.			
4.6 Operating			
4.6.1 Designing and Optimizing Sustainable and Safe Operations			

	Strong correlation, according to CDIO-ABET correlation (CDIO, 2011)
	Good correlation, according to CDIO-ABET correlation (CDIO, 2011)
	Strong correlation (own criterion)

These lectures, practical sessions, seminars and workshops, are distributed along the 28 weeks of the two semesters of the first year, resulting in 5 hours per week of lectures or practical sessions in the regular schedule of students. The relation of each module with the CDIO Syllabus can be seen in the above Table 1.

Research Design

To carry out the research on the integration of sustainability competencies in the INGENIA/CDIO subjects, we have opted for an action-research methodology that allows to plan, act, observe and reflect more carefully, systematically and rigorously than we usually do in everyday teaching work (Cohen et al., 2011). Based on the previous bibliographic research work, the results obtained in previous experiences and a joint reflection with the team of professors of the sustainability module, a first work proposal was elaborated, which was implemented in the 2014-15 academic year. Since then, the process has been iterated for three years.

For this purpose, various evaluation questionnaires (pre and post) were designed, which allowed to obtain relevant information (quantitative and qualitative) on the progress of the students in the acquisition of competences and on the teaching-learning process itself. Throughout each course, the team of professors had regular meetings in order to share the evolution of the course, reflect on it and work on the improvements to be implemented. Likewise, specific sessions were held at the end of each course to assess the results of the evaluations and plan the next course.

Teaching Methodology

Sustainability is a key aspect that INGENIA students must carefully consider throughout the four CDIO steps. In this sense the initiative requires a comprehensive methodology to be systematically used in all the projects, but flexible enough to be adapted and oriented to the specific social, environmental, economic, strategic and ethical aspects of each of them. The CDIO practical approach enables to consider those issues by a systematic exploration of all lifecycle phases. It provides a holistic view needed to avoid environmental bias and to deal with complexity (Cheah, 2014). Furthermore, we intend to send to our students the message, supported by several authors (Palm & Törnqvist, 2015, Crawley et al., 2008), that integrating ethical assessment, emphatic design, and social and environmental criteria strengthen the final product.

Our conceptual model considers the three classical dimensions of sustainability (economic, environmental and social), emphasizing the essential fact that these dimensions must be deeply grounded on the ethical and professional responsibility issues that may be relevant to each specific project. We add a strategic dimension that must always be considered in every phase of the project, by means of identifying its basic “why/what for”, their main differentiation characteristics, or how the long-term shared-value creation will be created in its development. These aspects cannot be studied separately, that’s why our framework also includes the relationships with the different stakeholders that may be affected by the technology/service/artefact developed in the project. These are the foundations of our methodology, characterized in Figure 1 (Miñano et al., 2016).

At the beginning of the course, an opening lecture is given to all the INGENIA courses’ students together. We introduce our conceptual model, revise the concept of sustainability, the principles of engineering ethics, and present briefly some categories of both social and environmental impacts. Throughout the two semesters, different workshops and tutorials (12 hours) for each INGENIA course were scheduled. Two faculty members worked closely with the students with the specific objective of integrating all the sustainability aspects into their project.

Key guidelines for dealing with this holistic integration were developed, establishing four phases to carry out the works: identification and selection of the relevant issues, deep analysis of specific social and environmental impacts, the practical integration into the product and a final reflection. As it was explained in detail by Miñano et al. (2016), this method is inspired in several methodologies like Life Cycle Assessment (Curran, 1996) and Social Life Cycle Analysis (Benoît & Mazijn, 2009), Value Sensitive Design (Cummings, 2006), ethical assessment of technology (Wright, 2011) and ISO standards 14000 and 26000.

As a deliverable, the teams must prepare a document which structure is provided beforehand, synthesizing their analysis, reflections and actions on the final product. The report is evaluated by the instructors and it represents 12,5% of the final score of the INGENIA course.

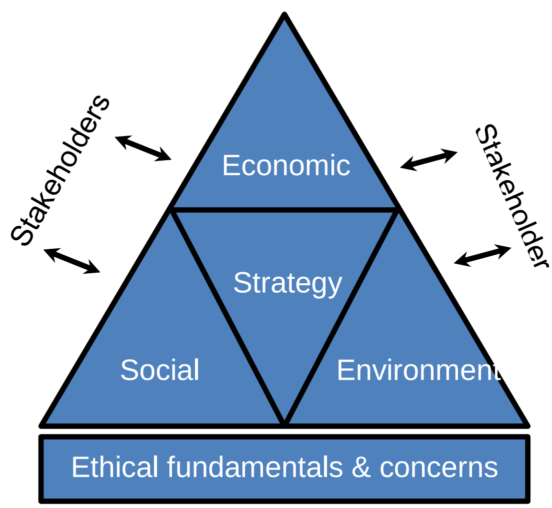

Figure 1. Framework for integrating sustainability and ethics in the INGENIA subjects.

RESULTS

The experience developed during these courses has been analysed from two perspectives: a) the progress of the students in relation to their sustainability competences, and b) the teaching-learning process itself. To study the progress in the acquisition of sustainability competences, two questionnaires were designed: the first one about knowledge on professional responsibility and impacts of engineering, and the second one about self-perception of skills for the integration of sustainability in projects. Both individual questionnaires were completed by the students at the beginning and end of the 2014-15 and 2015-16 courses.

To assess the teaching-learning process, the meetings held between the teachers of the module and the students' questionnaires about the final evaluation of the courses 2014-15, 2015-16 and 2016-17 were considered.

Questionnaire on knowledge on professional responsibility and impacts of engineering

In this questionnaire, the students had to answer open questions about aspects of professional ethics:

P1 Indicate the values and/or ethical principles that you consider fundamental in relation to professional practice in the field of engineering (4 maximum).

P2 Do you know any deontological code related to engineering? If yes, indicate which one.

And on knowledge about relevant impacts of engineering in a global context (3 maximum):

P3. Negative environmental impacts

P4 Positive environmental impacts

P5 Negative social impacts

P6 Positive social impacts.

Paired samples were considered (n = 65 in the 2014-15 academic year and n = 141 in the 2015-16 academic year) with a pre and post-test.

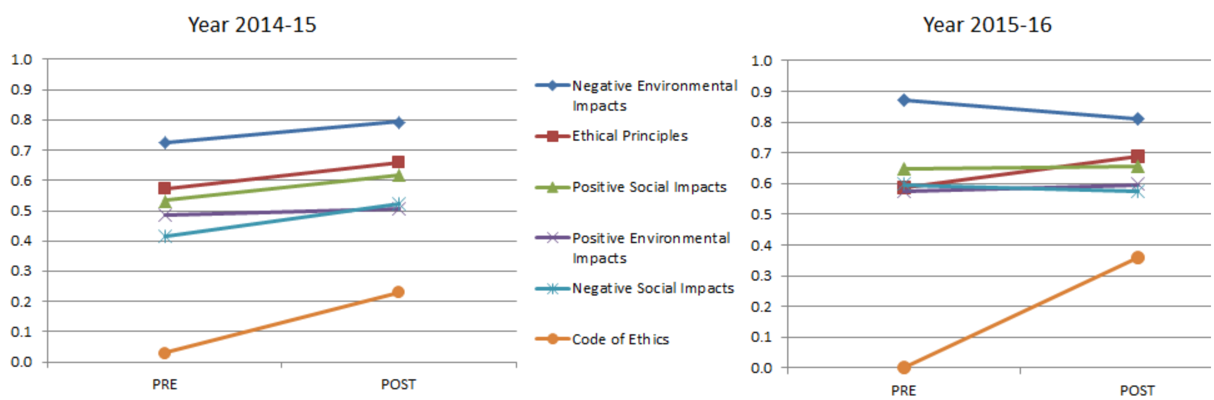

Figure 2. Comparison (pre-post) of the number of valid answers about knowledge of professional responsibility and impacts of engineering (average adjusted to 1).

In the 2014-15 academic year, quite satisfactory results were obtained, with significant improvements in almost all the items. In the 2015-16 course the initial results were much better than in the previous academic year, and the final results are also better than in the 2014-15. However, only significant improvements were observed related to the ethical aspects (P1 and P2), showing worse results in negative impacts items (P3 and P5).

Questionnaire on self-perception of skills for the integration of sustainability in projects

In the second questionnaire, we ask the students to rate on a 0-5 scale their abilities to identify impacts (environmental, and social), perform an analysis and assess them (environmental, and social), and to introduce changes in projects that optimize those impacts (minimize negative impacts, and promote positive impacts), following CDIO steps. Paired samples were also considered (n = 59 in the 2014-15 academic year and n = 143 in the 2015-16 academic year)-.

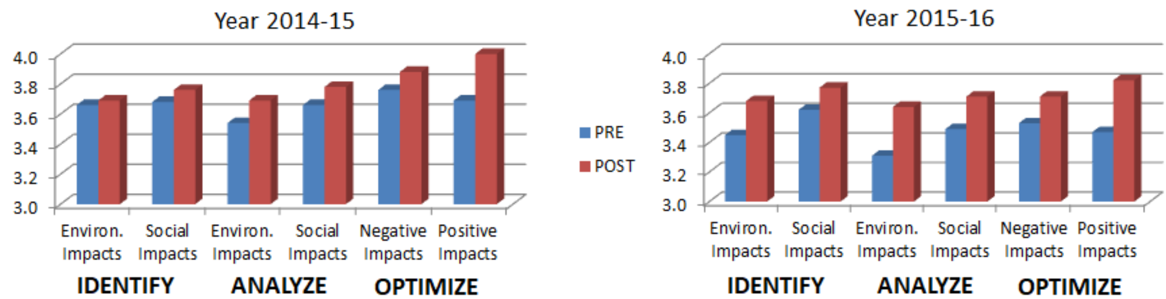

Figure 3. Students' self-perception about their capacities for integrating sustainability criteria in engineering projects (average over a 0-5 rank).

In general, the students have a very positive perception of their abilities. The median in almost all variables is 4, which indicates that more than 50% of students have a good perception of their abilities in these aspects, and the first quartile is 3 in all questions (more than 75% is rated with a score greater than or equal to 3).

All the aspects improve after having studied the INGENIA/CDIO subjects, being all of them statistically significant (95%) in the course 15-16 (the size of the sample was greater). The most relevant improvement is in "the ability to enhance positive impacts". The other aspect that improves much is the "analysis of environmental impacts", in which they perceived themselves less conscious. This makes the differences between items decrease with respect to those observed at the beginning of the course, which is a positive data on the influence of the work developed in the sustainability module.

Questionnaire on teaching-learning process

In order to obtain information on the assessment of the students about the teaching-learning process, quantitative data (numerical assessment from 1 to 5 on different aspects) and qualitative data (open questions on the most positive, the most negative and proposals for improvement) were collected.

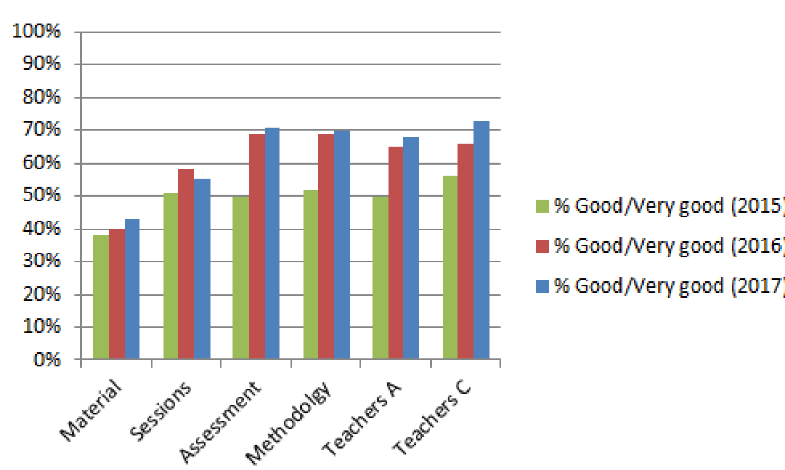

Figure 4. Students' assessment of the teaching process of the sustainability module (C) Evolution along three years.

The quantitative results show that the aspects most valued by the students were the support of the teaching staff, both module C (sustainability) and module A (technical), and the global teaching-assessment methodology. In the last course, more than two thirds of the students rated the performance in these aspects as "good" or "very good". It is also observed that the results have been improving with the courses, especially in these areas (in the first course evaluated, the percentage of students who valued it positively was around 50%).

Regarding the aspects that the students consider to be more positive, the knowledge on skills and attitudes learned have been the most mentioned in all the courses. In the first year, more references to more practical learning appeared, especially in the environmental dimension ("learning the Life-cycle Assessment methodology"), and in the subsequent courses more frequent comments on the identification and analysis of impacts appear, and their application in specific cases.

On the other hand, there are two aspects that, according to the students' opinion, should be improved. The first issue is related to the back-up documents provided for their individual homework (more than half of the students consider it to be fair or poor), while the second refers to the scheduling and development of some lectures. Nevertheless, it is relevant that in almost all aspects a positive evolution can be observed throughout the three courses.

DISCUSSION AND CONCLUSIONS

As a result of this work of analysis and reflection on the experience of these three years, some conclusions have been synthesized. In the first place, the general perception of the teaching staff is that the experience has reached a good level of maturity, so that, maintaining the proposed conceptual model and the basic methodological structure, we should continue working by adapting it to the specific circumstances of each of the different INGENIA/CDIO subjects.

Secondly, the institution has become aware that the experience takes place in a complex and diverse context. This is mainly due to the high academic requirement of the master's degree in which the INGENIA subjects are framed, different profiles and motivations of the students, time restrictions, great diversity of subjects and orientation of the INGENIA subjects, teacher rotation and the diversity of profiles in the teaching staff, among other causes.

Thirdly, this has led us to readjust the teaching objectives, synthesizing the essentials, in order to adapt them to the reality of the academic context in which we work. The fundamental objective will be to convey the importance of considering the aspects of sustainability into the development of a project and all its possible implications, assuming its complexity and diversity of dimensions. As a secondary objective, it would be necessary to acquire specific skills and/or techniques, assuming that the scope of the sustainability module in the INGENIA subjects is not enough to cover all the technical aspects of its different dimensions with all rigor.

In this sense, our conceptual model has proved to be useful because of the global vision it provides, and to make present important aspects of professional practice that are not usually addressed in academic training. The consideration of stakeholders is something that the students are not used to, and it is new to them. The ethical aspects have been one of the areas in which a significant improvement has been identified, as well as in the self-perception that they have of promoting positive impacts, related to a strategic vision oriented to the creation of shared value.

Moreover, this global vision and a greater awareness among students of the importance of sustainability as part of an engineering project, are among the results that they consider to be the most positive of the work developed in the module. Another aspect that has stood out in the evaluations is the usefulness of the acquired learning concepts, being these very diverse, from concrete techniques of environmental analysis (life-cycle assessment), to abilities to identify possible impacts or groups of interest.

Finally, the most important challenge we are currently facing is to achieve a better adaptation to circumstances of each INGENIA/CDIO subject, so that sustainability is not perceived as something separate or without connection to the project to be developed. With this objective in mind, it has been decided to improve the coordination among the professors of al the modules -not only the sustainability one, in order to plan the specific sessions at the most appropriate times and select the contents and tasks that better facilitates the integration of sustainability criteria to add value to the project.

We consider that the experience developed during the last three years has been very fruitful, consolidating the inclusion of sustainability as something of vital importance in the development of technological projects under CDIO standards, and creating a methodological framework on which to continue advancing and improving the training of future engineering professionals.

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