EVOLUTION AND IMPLEMENTATION OF CDIO INITIATIVES AT ETSII-UPM

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ABSTRACT
The School of Industrial Engineering at Universidad Politécnica de Madrid (ETSII-UPM) has been promoting student-centred teaching-learning activities, according to the aims of the Bologna Declaration, well before the official establishment of the European Area of Higher Education. Such student-centred teaching-learning experiences led us to the conviction that project based learning is rewarding, both for students and academics, and should be additionally promoted in our new engineering programmes, adapted to the Grade-Master structure.

The level of commitment of our teachers with these activities is noteworthy, as the teaching innovation experiences carried out in the last ten years have led to the foundation of 17 Teaching Innovation Groups at ETSII-UPM, hence leading the ranking of teaching innovation among all UPM centres. Among interesting CDIO activities our students have taken part in especially complex projects, including the Formula Student, linked to the complete development of a competition car, and the Cybertech competition, aimed at the design, construction and operation of robots for different purposes. Additional project-based learning teamwork activities have been linked to toy design, to the development of medical devices, to the implementation of virtual laboratories, to the design of complete industrial installations and factories, among other activities detailed in present study.

The implementation of Bologna process will culminate at ETSII-UPM with the beginning of the Master's Degree in Industrial Engineering, in academic year 2014-15. The program has been successfully approved by the Spanish Agency for Accreditation (ANECA), with the inclusion of a set of subjects based upon the CDIO methodology denominated generally "INGENIA", linked to the Spanish "*ingeniar*" (to provide ingenious solutions), also related etymologically in Spanish with "*ingeniero*", engineer. INGENIA students will live through the complete development process of a complex product or system and there will be different kind of projects covering most of the engineering majors at ETSII-UPM.

KEYWORDS
CDIO as Context, Integrated Curriculum, Integrated Learning Experiences, Active Learning (Standards: 1, 3, 7, 8)

INTRODUCTION

Student motivation and active engagement to their own learning process is a key success factor in Higher Education, especially in Science and Engineering studies, as recognized and highlighted in several studies, reports and declarations, such as the Bologna Declaration and the subsequent related declarations from Prague, Berlin, Bergen, London, Leuven and Budapest-Vienna, aimed at the implementation of the European Higher Education Area (EHEA). Making students drivers of change is perhaps the most effective part of a global strategy, for the promotion of professional skills in Engineering Education.

Problem- or project-based learning (typically PBL) methodologies clearly tend to motivate students to participate and become involved in their own learning process and is an excellent way of analysing whether students have acquired the basic concepts taught in the theory classes and if they are capable of applying them in real situations. These PBL experiences have proven to be effective in primary, secondary and university education and in scientific-technological, bio-sanitary, humanistic and artistic contexts. In consequence, most technical universities, before awarding the engineering degree, almost always include the standard final degree project as part of the studies, which, basically, is a PBL learning experience.

In direct connection with the promotion of project-based learning methodologies worldwide, even though its holistic approach to engineering education development goes far beyond project-based learning, the CDIO^{TM} Initiative (www.cdio.org) is probably the most ambitious approach. The CDIO^{TM} Initiative is focused on the establishment of an innovative educational framework for producing the engineers of the future, by means of providing students with an education stressing engineering fundamentals by means of “Conceiving - Designing - Implementing – Operating” (CDIO) real-world systems, processes and products (Crawley, et al. 2007). Throughout the world, CDIO Initiative collaborators are adopting CDIO as the framework of their curricular planning and outcome-based assessment. CDIO also promotes collaboration and sharing of good practices among engineering educational institutions worldwide.

The main purposes of present study are: a) to provide a background of activities carried out in the last decades at the School of Industrial Engineering at Universidad Politécnica de Madrid (ETSII-UPM), linked to the CDIO approach; b) to detail current actuations at ETSII-UPM oriented to a more systematic integration of CDIO experiences within our program of Industrial Engineering, and, hopefully, c) to serve as introduction, support and discussion document for our forthcoming application for becoming members of the international CDIO Initiative.

HISTORICAL BACKGROUND AND CURRENT CHALLENGES

The ETSII-UPM (www.etsii.upm.es, see Figure 1) has been promoting student-centred teaching-learning activities, according to the aims of the Bologna Declaration, well before the official establishment of the European Area of Higher Education (Vera, et al. 2006). In the last years we would like to highlight the Innova.Edu projects, funded by our centre during the academic years 2004-2005 and 2005-2006, which helped to promote several project-based learning activities in different subjects and to set common practices among our teaching staff for activities in the field of “conceive, design, implement & operate”. Additional educational innovation projects, funded by our University since 2007, have helped us to establish supplementary best practices for promoting student motivation, to implement novel subjects linked to project-based learning, to enhance our faculty teaching skills, to improve our assessment and evaluation plans, among other innovations. Such improvements have led to the Accreditation of our Industrial Engineering program by ABET (www.abet.org) in 2010.

Figure 1. ETSII-UPM Campus, main hall and collaborative learning environments.

The level of commitment of our teachers with these educational innovation activities is noteworthy, as the teaching innovation experiences carried out in the last ten years have led to the foundation of 17 Teaching Innovation Groups at ETSII-UPM, hence leading the ranking of teaching innovation among all UPM centres. Among interesting CDIO activities our students have taken part in especially complex projects, including the Formula Student (since 2003), linked to the complete development of a competition car, and the Cybertech competition (since 2001), aimed at the design, construction and operation of robots for different purposes. Additional project-based learning teamwork activities have been linked to toy design and manufacture experiences, to the complete development of medical devices, to the implementation of virtual laboratories, to the design of complete industrial installations and factories, among other activities summarized in Table 1 and detailed in the references.

Table 1. Summary of some CDIO activities carried out at ETSII-UPM in the last decade.

CDIO Experience	Product / system developed	Related subject	Reference
Formula Student	Competition car	Development of a competition car I & II	Sánchez-Alejo, 2009, 2011
Cybertech	Robots for different purposes	Automation, Electronics	Hernando, 2011
Machine Design	Different kinds of innovative machines and products	Engineering Design	Munoz-Guijosa, 2011
Medical product development	Biomedical devices and systems	Bioengineering	Díaz Lantada, 2013a
Edimpo: CAD-CAE machine design	Two-stage gear box	Machine Design I & II	Díaz Lantada, 2013b
The enterprises' game	Manufacturing company	Mechanical Technology, Project Engineering	-
Wind-powered slot-car competition	Wind-powered turbine	Electrical Engineering	Veganzones, 2011
Toy design experience	Completely functional toys	Design & Manufacturing with Polymers	Díaz Lantada, 2007

Figure 2 includes some photographs of different products and systems implemented by our students in some of the aforementioned CDIO activities, including an autonomous robot for tracking a line (Cybertech competition, Hernando, et al. 2011), a competition car (Formula Student, Sánchez Alejo, et al. 2009), a wind-power assisted slot-car competition (International BEST competition, Veganzones, et al. 2011), a collaboratively designed flexible manufacture cell (Márquez, et al. 2011), and designs and rapid prototypes of different toys (crane and plane) (Díaz Lantada, et al. 2007).

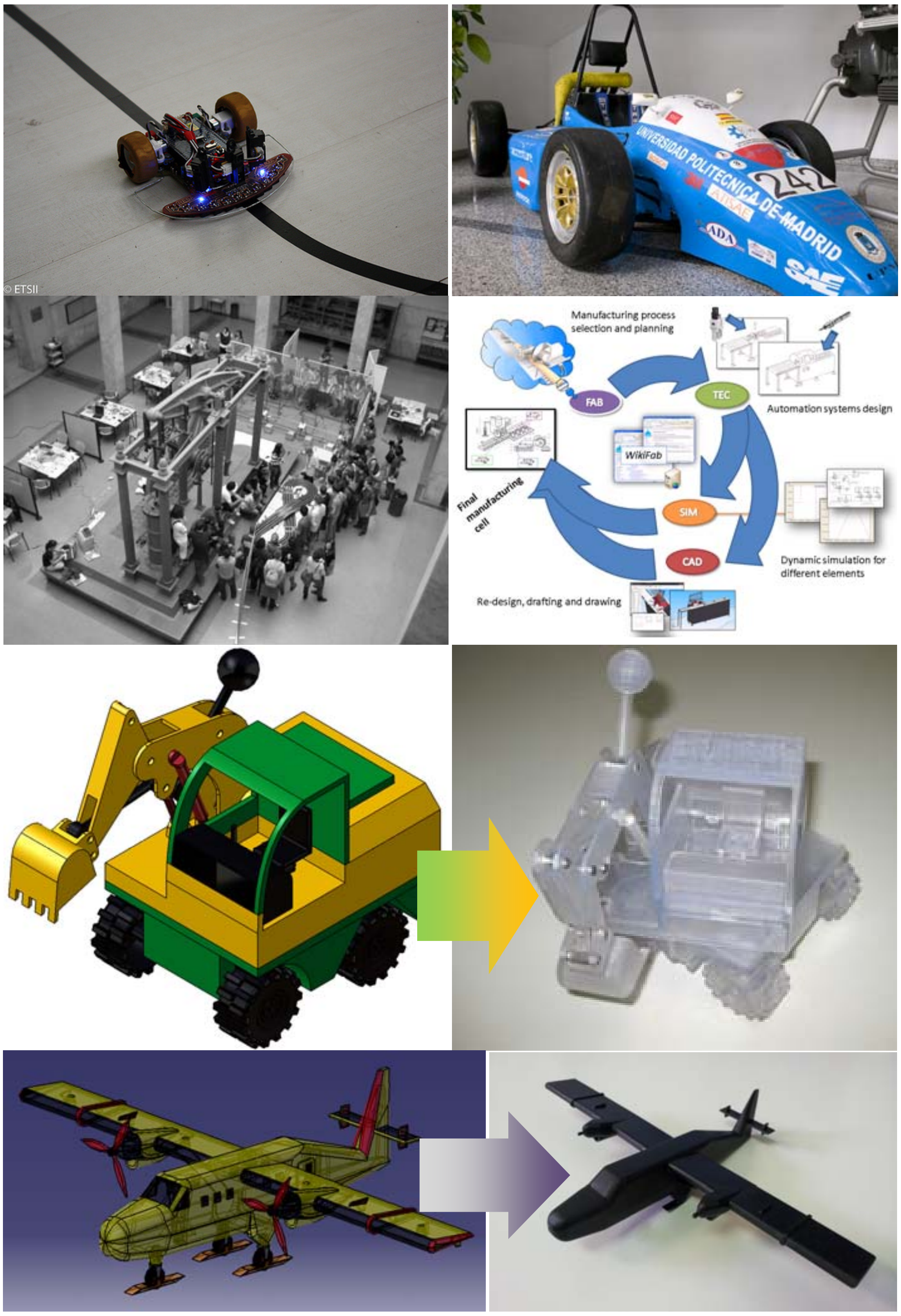

Figure 2. Example of different designs and implementations of products and systems in the context of CDIO-related initiatives carried out at ETSII-UPM in the last decade.

The different project-based learning carried out at ETSII-UPM in the last decade have been linked to at least 15 subjects and counted with a global participation of more than 200 students each year. Main areas of Engineering have been covered by such activities, including: Automation and Electronics, Mechanical Engineering, Manufacturing Engineering, Materials Science and Technology, Computer Science and Technology, Electrical Engineering, Energy and Industrial Management, and the experiences have been very positive, both for students and teachers. However, some of the already mentioned activities have been linked to single one-semester subjects, in which just the “conceive” and “design” stages have been tackled, due to schedule constraints.

It is interesting to highlight some exceptions, which have let students live through the whole “conceive-design-implement-operate” cycle, including the Formula Student project, the Cybertech competition and the toy-design experiences, in which the use of rapid prototyping technologies has been of great help for obtaining functional prototypes for trials in just one semester. Other remarkable student-centred activities, which have helped us to face students with real products, processes and systems, have been linked to the development of virtual prototypes, virtual laboratories and collaborative learning environments, also positive for the promotion of project-based learning activities (Romero, et al. 2007, Márquez, et al. 2011, García-Beltrán, et al. 2011, Ahnert, et al. 2011), in some cases resorting to play-based methodologies (Díaz Lantada, et al. 2007, Veganzones, et al. 2009, Pacios, et al. 2011) and to collaboration with external agents, such as enterprises, associations, customers… (Díaz Lantada, 2013c).

As can be appreciated, at ETSII-UPM, we are deeply concerned about students’ involvement in their own learning process and implicated in strategic actuations for the promotion of project-based learning activities, linked to real products and systems, as drivers of curricular planning, of continuously evolving teaching-learning methodologies and processes, and of an outcome-based assessment. We truly believe that **providing an integrated support framework for driving the aforementioned PBL actuations towards common actuation principles, based on the “conceive-design-implement-operate” guidelines, will be beneficial for students and teachers.** The implementation of the **“INGENIA” Initiative** is the key for achieving standardized and complete CDIO experiences and for providing the 100% of our students with the opportunity of living the whole development process of a product or system, as detailed further on.

“INGENIA”: INTEGRATED PROMOTION OF CDIO INITIATIVES

The implementation of Bologna process will culminate at ETSII-UPM with the beginning of the Master’s Degree in Industrial Engineering, in the next academic year 2014-15. The program has been successfully approved by the Spanish Agency for Accreditation (ANECA), with the inclusion of a set of subjects based upon the CDIO methodology denominated generally “INGENIA”, an acronym from the Spanish verb “*ingeniar*” (to provide ingenious solutions), also related etymologically in Spanish with the word “*ingeniero*”, engineer. INGENIA students will experience the complete development process of a complex product or system and there will be different kind of projects covering most of the engineering majors at ETSII-UPM. Students will choose among the different INGENIA, depending on their personal interests.

INGENIA subjects will be compulsory for all students enrolled in the first year of the Master’s Degree program at ETSII-UPM (a two-year program with 120 ECTS). The subjects (similar CDIO concept but different possibilities) are 12 ECTS equivalent, which correspond to a student workload between 300 to 360 hours, distributed along two semesters with the following structure: 120 hours of supervised work plus between 180 to 240 hours of personal student work, organised usually in teamworks. Professor supervised part of the subjects will be divided into 30 hours dedicated to adapt basic theoretical knowledge derived from other subjects to those directly related with the project, the second set of 60 hours will be devoted to practical work in the lab, with professor supervised sessions. Students also will receive two seminars of 15 hours each, one oriented to transversal outcomes, in particular, workshops on teamwork, communication skills and creativity techniques, and the other one about Social responsibility issues such as environmental impact, social, political, security, health, etc. The distribution of these lectures, practical sessions, seminars and workshops, will be shared among the 28 weeks on the two semesters of the first year, resulting in 4 hours per week of lectures or practical sessions in the regular schedule of students, the seminars and workshops will be programmed out from the regular schedule, but with full compatibility with the student schedule during both semesters.

Placing the INGENIA subjects in the first year of a 120 ECTS program is indeed interesting, as additional 12 ECTS will be devoted to the final degree thesis normally during the second year. Therefore, at least 20% of the whole Master's Degree is devoted to project-based learning aimed at the complete development of engineering products and systems. Program structure is detailed in Figure 3 and the integration of CDIO activities can be easily appreciated (INGENIA subjects in pale blue and Final Master's Thesis in pale green). In addition, the INGENIA subjects will help us to complement our competence-based strategy, by placing special emphasis on several professional skills difficult to obtain in more traditional teacher-centred activities, such as conventional master classes and expert talks.

Expected outcomes include the promotion of: students' ability to apply knowledge of mathematics, science and engineering, students' ability to design experiments and interpret data, students' ability to design engineering systems and components to meet desired goals, students' ability to communicate effectively and to work in multidisciplinary teams, or students' ability to use modern resources, in accordance with the ABET professional skills our program pursues (Shuman, et al. 2005). Table 2 includes the different CDIO topics proposed for the INGENIA subjects for the academic year 2014-2015, covering most Engineering disciplines.

Hours/week	THIRD SEMESTER	ECTS	Hours/week	FOURTH SEMESTER	ECTS
	Final Master's Thesis	6		Final Master's Thesis	6
6	Curricular configuration	9	6	Curricular configuration	9
2	3 specialization subjects (Automation & Electronical, Chemical, Electrical, Energetic, Materials, Mechanical, Construction, Org.)	3	2	3 specialization subjects (Automation & Electronical, Chemical, Electrical, Energetic, Materials, Mechanical, Construction, Org.)	3
2		3	2		3
2		3	2		3
2	1 subject on Industrial Installations	3	2	1 subject on Industrial Management	3
2	1 subject on Industrial Technologies	3	2	1 subject on Industrial Technologies	3

Hours/week	FIRST SEMESTER	ECTS	Hours/week	SECOND SEMESTER	ECTS
4	INGENIA (first part)	6	4	INGENIA (second part)	6
2	2 subjects on Industrial Management	3	2	2 subjects on Industrial Management	3
2		3	2		3
2	2 subjects on Industrial Installations	3	2	2 subjects on Industrial Installations	3
2		3	2		3
2	4 subjects on Industrial Technologies	3	2	4 subjects on Industrial Technologies	3
2		3	2		3
2		3	2		3
2		3	2		3

Figure 3. Program structure (Master's Degree in Industrial Engineering).
120 ECTS program with at least 20% devotion to project-based learning activities.

Table 2. CDIO topics proposed for the INGENIA subjects for the academic year 2014-2015, covering most Engineering disciplines.

Different topics for the INGENIA Subjects	Product / system developed & objective
Formula Student	Students will take part in the complete development project of a competition car, from the conceptual design stage, to the final trials and competition.
Engineering design: Machine development project	Students will live the whole process of creating an innovative machine, from the conceptual design stage, to the final trials with real prototypes, searching for design improvements.
Development of daylife products	Students will live the whole process of designing an innovative product, from the conceptual stage, to final trials with virtual and physical prototypes.
Smart systems engineering	Students will experience the process of designing a smart system, using state-of-the-art engineering resources and taking account of the whole life-cycle.
Structural optimization by integral approaches	Students will develop finite element models of different real structures for adequately studying their behavior and validate their models by means of real structural trials.
Thermal solar system design	Students will be able to project integral systems capable of generating a thermal good from solar radiation. Adequate calculations will lead to technical and economical viability.
Innovation for sustainability	Students will develop a technical and organizational model for granting access to basic needs in extreme poverty contexts.
Spin-off enterprise lab	Students will live the whole process of creating a technology-based enterprise, developing the whole business plan.
Computer-aided chemical engineering	Students will apply different computer-aided chemical engineering strategies, to predict and improve processes in real chemical plants.
Development and management of industrial construction projects	Students will experiment with information management and project planning resources applied to real industrial construction projects.
Development of an electricity supply network	Students will live the development project of an electricity supply network, from an initial renewable energy source to population.
Design in bioengineering	Students will experience the process of creating an innovative medical device, from the conceptual design stage, to the final trials with real prototypes.
Induforum: Development of job promotion fair	Students will live through the complete development process of our annual student employment fair (Induforum), from estrategical planning, to the one-week fair at ETSII-UPM.

It can be appreciated that some of the proposals for the INGENIA subjects evolve from previous experiences already detailed, but most of them are novel initiatives consequence of the progressive involvement of our teaching staff in student-based teaching-learning methodologies. The proposed topics from Table 2 cover all specializations of our Master's Degree in Industrial Engineering and we believe that all of them are interesting. As additional reflection, the proposed two-semester structure for the INGENIA subjects is very appropriate, as the "conceive" and "design" phases can be adequately carried out during the first semester and the "implement" and "operate" stages can be tackled in the second semester. A whole academic year is ideal for maturing the development process of complex products and systems and will help us to improve several prior experiences, limited to design and simulation activities, with the benefits from obtaining final prototypes and carrying out operational trials.

Regarding assessment, we will try to manage the typical problems that arise when assessing teamwork activities. First of all, the proposed projects will be complex enough to promote positive interdependence between members of the team, so that each of the members is needed for the overall success and that there is enough workload to let all students work hard and enjoy the experience. In addition, we will encourage individual assessment, complementing the teamwork activities with individual deliveries and during the public presentations of their final results. The evaluation of professional skills will count with the help of ad hoc designed rubrics, consequence of recent educational innovation projects.

DISCUSSION AND FUTURE PROPOSALS

We believe that the described INGENIA framework, for the systematic promotion of "conceive-design-implement-operate" teaching learning activities in our forthcoming Master's Degree in Industrial Engineering, is completely aligned with the CDIO framework. Having a look at the CDIO adoption process diagram (www.cdio.org), it is important to note that our engineering context and previous experiences are very adequate for implementing the CDIO framework. The curriculum is already developed and the outcomes are clear and validated by ABET, although we understand that CDIO holistic approach to curriculum development goes beyond that and must be further improved and assessed. The teaching-learning methods from our colleagues, the available facilities and the recently developed support resources for the evaluation of professional skills are in accordance with the overall strategy and have brought us to the point of launching the integrated initiative. In the following months, several collaborative sessions will allow us to provide a final adjustment to our faculty CDIO and teaching skills. Although we have focused her on flagship INGENIA project, we are conscious that our curriculum must be complemented with discipline-led activities and professional practices. In fact, 18 ECTS of the Master`s Degree in Industrial Engineering will be devoted to other actions also aligned with the CDIO approach, such as co-ops with industry and research labs, collaboration in social and educational projects or technical seminars and workshops, among others.

Finally, our attendance to the Barcelona 2014 10th International CDIO Conference will help us to formalize our candidature to become part of the international CDIO Initiative and provide us with the excellent opportunity of discussing present approach with experts of CDIO framework. Their comments and proposals for improvement will help us to adjust our views and strategy, so as to obtain optimal results. We understand that the CDIO framework is a continuous improvement process and we are already expectant to experiment its results.

CONCLUSIONS

Present study has provided a background of activities carried out in the last decades at the School of Industrial Engineering at Universidad Politécnica de Madrid (ETSII-UPM), linked to the CDIO approach, and detailed current efforts aimed at a more systematic integration and promotion of CDIO activities within our Industrial Engineering program. The detailed set of "INGENIA" subjects is the key element of our strategy towards such systematic integration and promotion of CDIO activities, as we have also discussed. INGENIA subjects will be compulsory for all students enrolled in the first year of the Master Program at ETSII-UPM and will be an ideal complement to (as well as preparation for) other more traditional project-based learning activities, such as the Master's Theses carried out by students at the end of the program. We truly hope that present summary may be useful as introduction, support and discussion document for our forthcoming application for becoming members of the international CDIO Initiative.

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