CDIO AND THE EUROPEAN PROJECT SEMESTER: A MATCH FOR CAPSTONE PROJECTS?

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ABSTRACT

The CDIO Initiative is an open innovative educational framework for engineering graduation degrees set in the context of Conceiving – Designing – Implementing – Operating real-world systems and products, which is embraced by a network of worldwide universities, the CDIO collaborators. A CDIO compliant engineering degree programme typically includes a capstone module on the final semester. Its purpose is to expose students to problems of a greater dimension and complexity than those faced throughout the degree programme as well as to put them in contact with the so-called real world, in opposition to the academic world. However, even in the CDIO context, there are barriers that separate engineering capstone students from the real world context of an engineering professional: *(i)* limited interaction with experts from diverse scientific areas; *(ii)* reduced cultural and scientific diversity within the teams; and *(iii)* lack of a project supportive framework to foster the complementary technical and non-technical skills required in an engineering professional. To address these shortcomings, we propose the adoption of the European Project Semester (EPS) framework, a one semester student centred international capstone programme offered by a group of European engineering schools (the EPS Providers) as part of their student exchange programme portfolio. The EPS package is organised around a central module – the EPS project – and a set of complementary supportive modules. Project proposals refer to open multidisciplinary real world problems and supervision becomes coaching. The students are organised in teams, grouping individuals from diverse academic backgrounds and nationalities, and each team is fully responsible for conducting its project. EPS complies with the CDIO directives on Design-Implement experiences and provides an integrated framework for undertaking capstone projects, which is focussed on multicultural and multidisciplinary teamwork, problem-solving, communication, creativity, leadership, entrepreneurship, ethical reasoning and global contextual analysis. As a result, we recommend the adoption of the EPS within CDIO capstone modules for the benefit of engineering students.

KEYWORDS

Engineering education, project-based learning, student-centred learning, multicultural teamwork, multidisciplinary teamwork, CDIO Standards 1, 7, 8, 9, 11.

INTRODUCTION

Communication, creativity, leadership, entrepreneurial thinking, ethical reasoning and global contextual analysis are the missing basics for 21st century engineering education

(Committee on the Engineer of 2020, 2005). To address this challenge different frameworks, such as the CDIO Initiative and the EPS, have been proposed. This paper analyses how EPS can, together with CDIO, contribute to this goal.

The CDIO approach was developed in the nineties at Massachusetts Institute of Technology (MIT), with the cooperation of scientists, representatives of industry and students. The CDIO Initiative (the international organisation) was founded in 2000 by MIT, Chalmers University of Technology, KTH Royal Institute of Technology and Linkoping University and, to date, more than 100 universities are participating (Crawley *et al.*, 2014).

The EPS is a one semester student-centred capstone programme designed by Arvid Andersen (Andersen, 2001). The programme aims to foster the development of scientific, technical and soft skills in engineering students through multicultural teamwork and open, multidisciplinary problem-solving (Andersen, 2004). EPS commenced in 1995 in Denmark and is currently offered by a group of 16 European engineering schools, the EPS Providers[1].

This paper addresses the improvement of engineering education quality in general and, in particular, the outcomes of capstone engineering modules. The features of CDIO capstone modules and of the EPS programme are presented, identifying existing weaknesses and strengths. The main contribution of this work lies in the identification of the frailties in existing engineering capstone project/internship modules and on the recommendation to overcome them by adopting the EPS framework, whenever the legal and cultural context allows it.

In terms of the paper structure, Section 1 provides the introduction, Section 2 addresses problem and project-based learning, Section 3 presents the CDIO and EPS innovative engineering education frameworks, Section 4 describes the case of EPS@ISEP, Section 5 discusses the synergies between CDIO and EPS and Section 6 draws the conclusions.

PROBLEM AND PROJECT BASED LEARNING

In essence, engineering is the art of creating solutions for real world problems supported by scientific, experimental and technological backgrounds. In the context of engineering education, creativity can be seen as offering students opportunities to shape new knowledge, whereas learning can be seen as a knowledge creation process with collaborative efforts. To foster creative engineers, engineering schools have been exploring problem- and project-based learning approaches (Zhou, 2012). These learning approaches include cognitive, collaborative and content dimensions.

According to Edström and Kolmos (2014), problem orientation indicates that learning starts by analysing and defining problems, be they open and ill defined, or well defined. The choice of problems depends on the learning objectives. While to learn new methodologies open problems are preferable, to master specific methods narrower problems are more suitable. Problems are the starting point of any learning process; they are placed in a context and based on the learner's experience. If the course is also project-based, the task involves more complex and situated problem analysis and problem-solving strategies. The main issue of conflict between problem-based learning and project-based learning is the open or closed nature of the initial problem or project. Problem-based learning supporters say project-based learning is task based, with a strong task predefinition done beforehand by the tutor(s)/supervisor(s) of the project. Project-based learning supporters say the autonomy of

[1] http://www.europeanprojectsemester.eu

the students must be preserved, *i.e.*, a project workflow encompasses the initial solution specification and many problem solving events.

Problem-based learning has long been used for professional training in medicine and other health-related professions. This approach is centred on the knowledge construction around open-ended situations and problems (Savin-Baden, 2004). This learning methodology gives the student the ability to learn, in isolation and in teams, but is centred on the solution. This is perfect for the medical profession where doing the diagnostic (finding the solution) is the important task to be done. More recently, it has been proposed as a solution to the improvement of engineering education, having been implemented in some engineering programmes. The strategy for teaching design has been practiced in engineering programmes for many years and has many similarities with the problem-based learning strategy (Mills and Treagust, 2003).

However, the issue with the engineers is that, besides finding the right solution, they must also build it. So, while medical schools have replaced lecture based education with problem-based learning, many engineering schools replaced lecture-based education with project-based learning, where the solution building phase is central and has been perceived as the most critical phase in engineering. In project-based learning, students learn things while finding and solving problems (Lunev *et al.,* 2013). Project-driven approach originated in the eighties in Germany, being based on constructivist learning theory. This method is student centred, and is now a widespread teaching method in disciplines where students must learn to apply knowledge, not just acquire it (Brodeur *et al.*, 2002). In the whole process, teachers play the roles of organizer, mentor, helper and facilitator. Project driven model of teaching can stimulate students' interest and desire for knowledge and develop abilities of independent learning, analysis and problem solving. During the teaching students can learn by "doing" and focus on solving practical problems (Lingling *et al.*, 2012). A key feature of project-based learning is to motivate and empower students with the feeling that they have the capability to solve problems and, thus, promoting project accomplishment. Furthermore, project-based learning allows some form of customization to suit students with varying capabilities, allowing proficient students to work on more complex projects (Pee and Leong, 2005). According to Brennan *et al.* (2013), project-based learning increases the self-efficacy levels of students in engineering-relevant attributes, with the largest increases in the attributes most closely aligned with the intended learning outcomes.

ENGINEERING EDUCATION FRAMEWORKS

Several engineering education frameworks have been proposed to prepare engineering students to face the globalisation, lifelong learning, scientific and technological challenges. This section analyses and compares CDIO engineering programme framework and EPS engineering capstone project/internship framework.

Conceive-Design-Implement-Operate

The CDIO Initiative focuses on the how to educate students to become effective modern engineers, *i.e.*, able to participate and, eventually, lead the conception, design, implementation and operation of systems, products, processes and projects. For a real impact on engineering students training, theory must be complemented with practice, ensuring efficient and deep learning, and with the development of personal and interpersonal skills, fostering self-confidence and encouraging leadership (Crawley *et al.*, 2014). According to Lunev *et al.* (2013) and Takemata (2013), project activities within CDIO include problem clarification, idea generation, selection and substantiation and prototype development, evaluation and refinement.

The Initiative is an open-architecture endeavour designed to be adaptable and adoptable by any undergraduate engineering programme (Berggren *et al.* 2003) and, as such, provides guidelines to implement a CDIO-compliant engineering degree programme. A key aspect of these directives is their alignment, at a high level, with national accreditation and evaluation standards, stimulating the adoption of the framework by any engineering programme[2].

European Project Semester

The EPS is an international teamwork semester programme designed to train engineering and business students to work in international teams (Andersen, 2012). EPS adopts a problem- and project-based learning approach to challenge students with various educational backgrounds, and from different European and US study programmes, to join their competences in a multidisciplinary project based on real life problems in close collaboration with industrial partners and research institutes for a period of one semester (Segalàs *et al.*, 2011; Rohaert *et al.*, 2012). This approach stimulates students to contribute with and apply their specific knowledge and develop transversal skills, namely social and communicative skills, during the different stages of the process of team collaboration (Malheiro *et al.*, 2014). According to Abata *et al.* (2013), the educational process in the EPS programme is best described as experiential learning, *i.e.*, students acquire information through the study of a subject as opposed to textbook exposure. The dimensions of experiential learning are analysis, initiative, and immersion, matching the EPS atmosphere.

The EPS programme is a 30 European Credit Transfer Units (ECTU) package structured as follows: 20 ECTU assigned for the project module and 10 ECTU for complementary modules. These are focussed on the development of soft skills considered essential for 21st Century Engineers (Jollands *et al.*, 2012), such as communication or teambuilding, project-related activities such as project management and transversal topics such as sustainability (Mills & Treagust, 2003; Rydhagen *et al.*, 2011; Nicolaou *et al.*, 2012) and ethics and deontology (Chang & Wang, 2011). By default, EPS, as an engineering capstone programme framework, is intended for the final year of the engineering programme. The EPS providers have discussed, agreed upon and posted on the EPS Providers site[1] the European Project Semester framework. These are the so-called "10 Golden Rules of EPS" that an EPS provider must comply with: (*i*) English is the working language of EPS; (*ii*) EPS is multinational with a group size of minimum three and maximum six students, being four or five the ideal number; a minimum of three nationalities must be represented in each EPS group; (*iii*) ideally, but not necessarily, an EPS project is multidisciplinary; (*iv*) an EPS semester is a 30 ECTU package, the duration of which is not less than 15 weeks; (*v*) an EPS project has a minimum of 20 ECTU and the complementary subjects account for a minimum of 5 ECTU and a maximum of 10 ECTU; (*vi*) the main focus on EPS is on teamwork; (*vii*) the subjects included in the EPS must be project supportive; English and a basic crash course in the local language must be offered; (*viii*) the subjects must include Teambuilding in the very beginning and Project Management in the beginning of an EPS semester; (*ix*) project supervision/coaching must focus on the process as well as the product; and (*x*) EPS must have continuous assessment including an Interim Report and a Final Report.

[2] http://www.cdio.org/framework-benefits/cdio-syllabus

The EPS providers offer EPS programmes not only compliant with this generic framework, but also with diverse flavours. There are programmes focused on engineering (the majority of providers), business (Lodz Technical University), product design (University of Antwerp and Technical University of Catalonia at Vilanova i la Geltrú) or media (St. Pöelten University of Applied Sciences) and with different operational approaches. There are programmes offered to 3rd year students (all providers), to 3rd and 4th year students (Polytechnic Institute of Porto) and 3rd, 4th and 5th year students (Polytechnic University of Valencia).

EPS@ISEP

The EPS@ISEP programme – the EPS programme provided by the School of Engineering – Instituto Superior the Engenharia do Porto (ISEP) – of the Polytechnic Institute of Porto – welcomes engineering, business and product design students and includes six modules: Project (20 ECTU), Project Management and Team Work (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU) and Ethics and Deontology (2 ECTU). These 2 ECTU modules are project supportive seminars oriented towards the specificities of each team project. For example, communication, which includes scientific-technical English, contributes to the development of the project deliverables; project management focuses on task identification, human resource allocation, task planning and scheduling, resource management, plan enforcing and eventual rescheduling; sustainability addresses the ecological footprint; ethics and deontology analyses the ethical and deontological concerns; and marketing tackles the market analysis, segmentation and positioning of the prototype (Malheiro *et al*. 2013). Figure 1 presents the EPS@ISEP schedule and illustrates the concretization of golden rules *viii* and *x*.

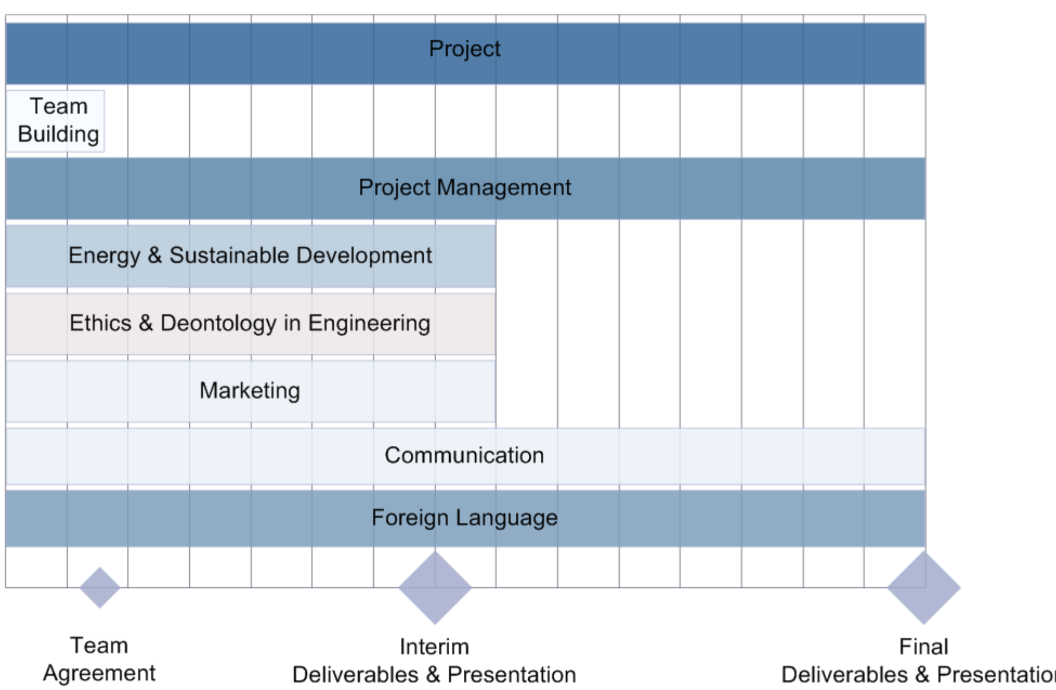

Figure 1. EPS@ISEP schedule

In order to accomplish rule *ii* at ISEP, a Belbin questionnaire is used to determine the individual worker profiles allowing the design of teams with complementary elements from as many diverse scientific backgrounds and as multinational as possible. Once the teams are defined, one of the first tasks the members are faced with, during team building activities (rule *viii*), is to define their own set of conflict resolution rules – Team Work Agreement – using the mechanism proposed by Hansen (2010). The resulting document is signed by all team members and archived in the team folder.

According to Rossiter (2013), assessment drives learning and hence a good assessment design is the key to effective student development. EPS@ISEP uses the assessment scheme proposed by Hansen (2010). Assessment occurs twice during the semester and contemplates self and peer (S&P) and supervisor assessment (SA). The S&P assessment takes into account the quality and quantity of the technical contribution, openness to others ideas, teamwork performance, leadership, attitude and initiative shown (Ashworth, 2011). The SA assessment reflects both team performance as well as the individual performance of each student. The interim assessment is intended to give individuals and teams feedback about their performance so far from the point of view of their peers and of the supervisors. The supervisors use the assessment to monitor team working and to give constructive feedback and advice where needed (Ashworth, 2011).

EPS@ISEP adopts a unique supervision model where a panel of multidisciplinary experts acts as a consulting committee. As far as communication is concerned, the panel is aware that it is interacting with students from diverse scientific and cultural backgrounds. Furthermore, in the weekly supervision meeting only the topics previously specified by the team in the wiki agenda are discussed. Another very important aspect of the coaching methodology is the prompt feedback given to the students. Students meet with supervisors once a week to discuss the topics the team has previously posted in the wiki agenda.

The teams have to produce several deliverables, including the project wiki, report, video, paper, manual and brochure. The report structure (provided beforehand) includes as mandatory sections the introduction, state of the art, project development, marketing, sustainability, ethical concerns and conclusions. The marketing, ethical and deontological concerns as well as eco-efficiency and sustainability measures chapters are produced and refined within the corresponding complementary modules. The structure and presentation of the deliverables are addressed in the communication seminar. The wiki is a key tool to the EPS process since it acts both as the collaborative work platform for team members and supervisors as well as the project show case.

Before the beginning of the semester, a set of project proposals regarding real world problems are collected. The origin of proposals varies and includes industry, services, R&D institutions or the school itself. The proposals tend to be multidisciplinary problems, *i.e.*, require the integration of multiple technical and scientific competences. A proposal defines the problem/challenge to tackle, the minimal set of requirements, mostly mandatory directives and standards, and the maximum budget. Figure 2 illustrates a list of project requirements regarding a swimming robot project from the spring of 2014, as posted in the team's wiki. This type of proposal directs the team towards the conception and design stages and, then, towards the implementation and operation stages of the capstone project/internship. Depending on the complexity of the projects, the average cost of an EPS@ISEP project in terms of materials is approximately 350 €.

Project Summary

Design, develop and implement of a biologically inspired swimming robot.

The project requirements are:

1. Reuse existing components or use low cost hardware solutions
2. Use of open source and freeware software
3. Power autonomy of 12 h
4. Comply with the following EU Directives:
   I. Machine Directive (2006/42/CE 2006-05-17);
   II. Electrical Safety: Low Level Voltage Directive (2006/95/CE 2006-12-12);
   III. Restriction of Hazardous Substances (ROHS) in Electrical and Electronic Equipment Directive (2002/95/EC 2003-01-27);
5. Mandatory adoption and use of the International System of Units (The NIST International Guide for the use of the International System of Units)
6. Use open source technologies.

Figure 2. Swimming robot proposal[3]

Figure 3 displays the outcome of these two milestones for the swimming robot proposal.

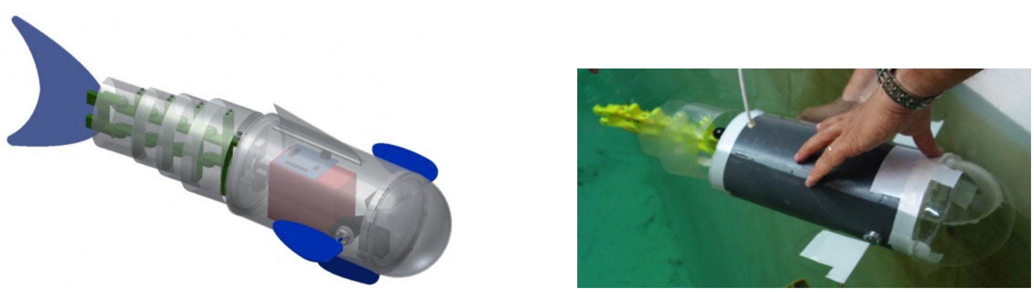

Figure 3. Swimming robot design (left) and prototype (right)

EPS@ISEP has been running in the spring semester since 2011. In this period 90 students have participated (60 have successfully accomplish the programme and 30 are currently enrolled) from fourteen different nationalities and 22 scientific backgrounds. The scheduled classroom activities involve thirteen teachers from seven ISEP departments and account for a total of 472 h/semester. The projects are financed by sponsors, clients or via the fees of international (non-EU) students. Dislocated EU students are supported by EU Erasmus+ mobility grants, typically covering one round trip and the accommodation costs.

[3] http://www.eps2014-wiki1.dee.isep.ipp.pt/doku.php

DISCUSSION

The CDIO Initiative, at the engineering curriculum level, and the EPS, at capstone module level, aim to prepare engineers for the 21st century challenges. We claim that the EPS capstone framework can help CDIO to achieve this goal more effectively at the capstone project/internship level. Figure 4 illustrates the matching between the EPS and the CDIO frameworks at the engineering capstone project/internship level. The Conceive and Design (CD) phases of the CDIO correspond to the first stage of EPS, ending in the interim assessment, and the Implement and Operate (IO) phases to the second stage of EPS, culminating in the final assessment.

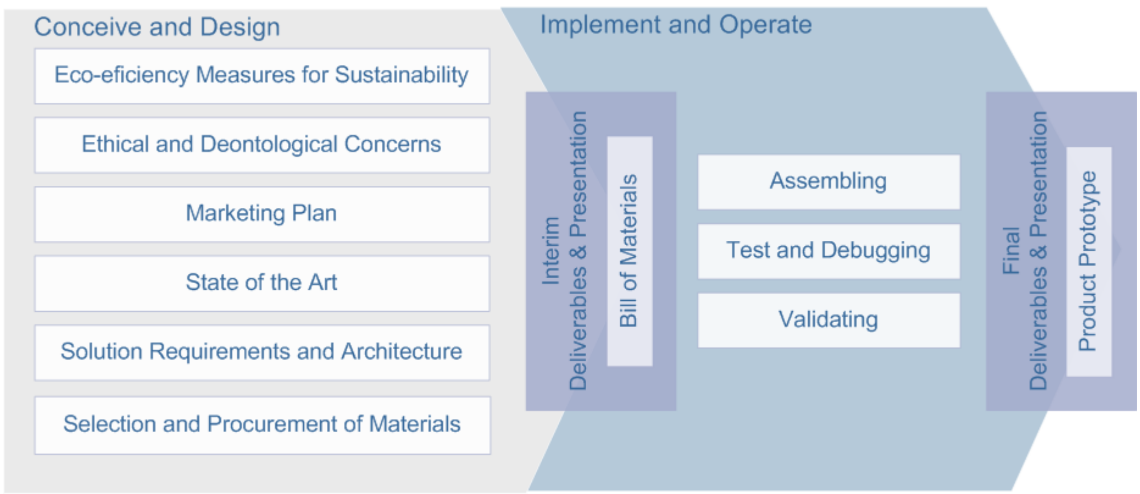

Figure 4. EPS and CDIO

Besides the traditional State of the Art survey and the identification of the Solution Requirements and Architecture, the CD stages of EPS include studies on Sustainability and Eco-efficiency and Ethical and Deontological Concerns, the Selection and Procurement of Materials and the definition of the product Marketing Plan. These tasks are essential in the creation of an engineering product and are driven not only by financial considerations, but also by ethical and ecological considerations.

The transition between the CD phases and the Implementation and (latter) Operation phases is marked by the interim assessment milestone, where the deliverables of the first two phases (interim presentation and report) are assessed. The interim report must describe the different studies performed as well as the bill of materials and the list of functional tests of the product prototype. This serves not only to give feedback to the students about their work, but also to comply with the schedule and enforce a balanced time distribution between the two project milestones.

The EPS IO phases correspond to the product prototype Assembly, Test and Debugging as well as Validation (in accordance with the previously defined functional tests). The process ends with the final assessment milestone. The teams must hand-in all deliverables, present and discuss, both as a team and individually, the results. The assessment considers the engineering process (the evolution between milestones and the product prototype) as well as the relevant complementary skills, including team work. In the EPS process, the required development of complementary skills is supported by the project supportive modules.

The diversity of project themes requires a multidisciplinary, dynamic and motivated team of supervisors. EPS coaching may need a period of adaptation since the students define the agenda of the weekly meetings and the teachers ensue, *i.e.*, the role of teachers changes from leader to consultant. This approach, as well as the referred EPS teaching cooperation, fits into the CDIO Standard 9 - Enhancement of Faculty Competence.

The EPS gives the students the practice of being integrated in a multicultural and multidisciplinary team, *i.e.*, with people of diverse engineering fields and nationalities. This exposure to the multicultural perspective develops cross cultural communication skills essential to the global market. Furthermore, it involves students in all the phases of the engineering process, ranging from the initial open problem statement to the final product prototype. The teams are free to find their own solution to the problem, taking into consideration not only technological and financial constraints, but also the sustainability, ethical, deontological and marketing perspectives. This autonomy gives students a necessary practice of "independence" (and comprehension of the engineering process) required for future entrepreneurship.

CONCLUSION

The EPS and CDIO share concerns and goals regarding the improvement of the engineering programmes. The main advantage of the EPS programme is that it attains the desired educational objectives of implementing problem- and project-based learning, fostering student autonomy and creativity from students engaged in a multicultural and diverse dialog, while simultaneously respecting the physical constraints that limit higher education institutions, and minimizing the changes and disruptions to the rest of the engineering curriculum.

While the CDIO initiative addresses the implementation of solid and sound changes at the engineering curriculum programme level, requiring deep commitment of all involved in the educational process, EPS is focussed at the engineering capstone project/internship level and can act both as a test bed of the best engineering education practices and, particularly, as a complement to CDIO. The focus at the capstone project level allows the intervention at a critical phase of an engineering programme with minimum changes at the curriculum level, since EPS and CDIO share the same fundamental engineering education principles: students must learn to solve real world problems (conceive, design, implement and operate), develop personal and interpersonal skills and work in teams. EPS goes a step further by considering that students must be exposed to cultural, scientific and technological diversity during their learning period.

EPS can act as a test-bed for project-based learning in institutions outside the CDIO initiative[4], giving the teachers a chance to practice and test CDIO-like approaches in education, and motivating them for deeper changes in the overall curriculum and educational methodologies. It is obvious that changing only one semester (the final one) is much easier than changing all the semesters of the curriculum. For CDIO compliant engineering programmes, EPS can give students a better preparation for a professional life. More creativity is assured by the diversified engineering branch and cultural backgrounds of the group's students (impossible in a traditional engineering degree) and their freedom in the guidance of their chosen project. The contact with the initial specification, procurement and marketing phases, besides placing the students in contact with engineering tasks usually

[4] Institutions wishing to implement the EPS framework should contact the network of EPS providers.

absent from project-based learning, contributes to a greater familiarity with typical entrepreneurship related tasks. As a result, we recommend the adoption of the EPS framework within CDIO capstone modules for the benefit of students.

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