ASSESSING 6 YEARS OF CDIO IN A COMPUTER ENGINEERING PROGRAM

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ABSTRACT

The Informatics (Computer) Engineering Bologna 1st cycle at ISEP (LEI) has over 1100 students and has adopted CDIO guiding principles in the major curriculum revision of 2006/2007 (Bologna Process implementation in Portugal). The program uses a practical approach to learning and over 30% of the students have a job, most of them full-time. It is one of the top-rated programs in Portugal in its area (usually ranked 4th place in terms of admission grades) and it is currently applying for EUR-ACE certification. The Informatics Engineering Master (Bologna 2nd cycle) at ISEP was awarded the EUR-ACE certification in April 2012.
In the last 6 years, hundreds of students have been exposed to the CDIO practices and over eight hundred have graduated. Has CDIO adoption really been worth the effort?
The objective of this paper is to assess the results of these years in terms of learning process effectiveness and graduates' quality. School records of the students in these 6 years (over 80,000 course grades in 30 courses) and the feedback of internship supervisors from companies or R&D centers will be used.

KEYWORDS

Program assessment, CDIO, Continuous improvement

INTRODUCTION

ISEP is one of the five largest engineering schools in Portugal. Created in 1852, it currently has more than 6750 students, 420 teachers and 130 staff. It is located at Porto and in the 2011-2012 school year lectured 11 first cycle and 10 master (Bologna 2nd cycle) engineering programs. ISEP adopted the CDIO Initiative and joined the consortium in 2008.

Between 2003 and 2006, the Informatics Engineering Department worked on the reformulation of its programs using, as main frameworks, the Association for Computing Machinery (ACM) Computing Curricula [1] and the CDIO Initiative, as well as a 20 years experience in lecturing professionally oriented informatics courses and programs. For the group in charge of this reformulation, it was consensual that the new "Bologna study plan" should have a large percentage of project work. The Informatics Engineering first cycle (LEI) study plan was essentially inspired by the CDIO Generic Syllabus version 1.0 [2], but for the "Technical Knowledge and Reasoning" part the ACM Computing Curricula recommendations were used – an Overview Report and five Curriculum Reports on Computer Science, Computer Engineering, Information Systems, Information Technology and Software Engineering [3].
Figure 1 shows the LEI's current curriculum (updated in 2006), in which an ECTU is one unit of curricular credit (ECTS [4]). The first to fifth curricular semesters are based on 12+4 weeks of classes, in which the last 4 weeks are fully devoted to problem based group projects. The sixth semester has classes during 5 weeks and the rest is mainly for the Capstone Project.

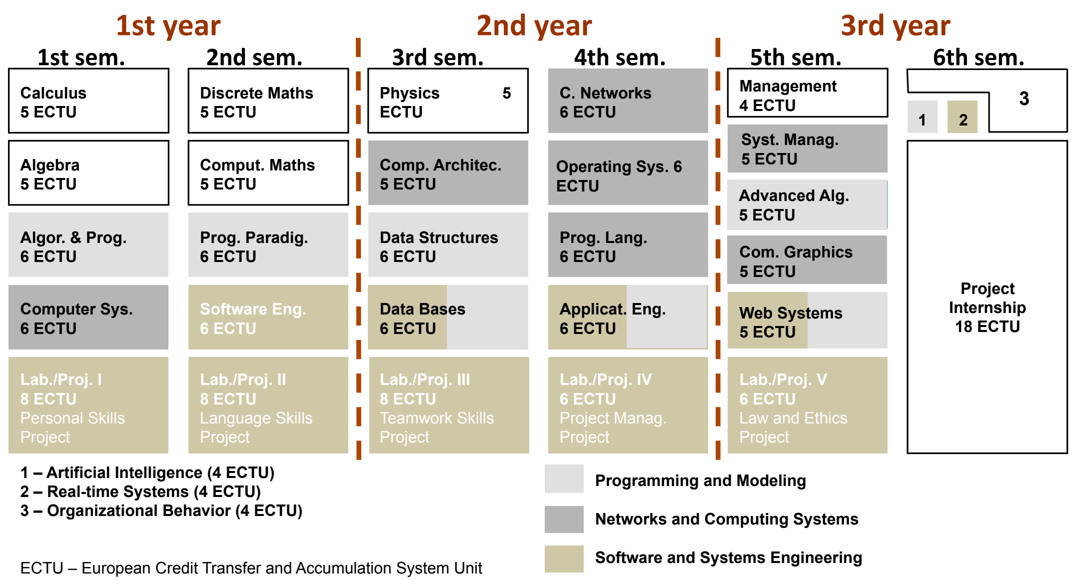

Figure 1. LEI curriculum since 2006-2007

CDIO main contributions (standards and good practices) to the curriculum in Figure 1 were:

- An improved hands-on approach to informatics engineering – Standard 1;
- Integration of personal, group, professional and other skills – Standard 3;
- A course to introduce informatics engineering ("Computing Principles") – Standard 4;
- Design-build-test courses ("Lab./Projects" and "Capstone Project") – Stds. 5 and 7;
- A process for the definition of global program outcomes – Standard 2;
- The balance between "science", "management" and "engineering" courses.

LEI is strictly organized in three simultaneous learning processes, without elective courses [7]. The processes were defined according to the key competence areas described in the LEI Syllabus and validated by the stakeholders:

- Software and system engineering (Figure 2)
- Programming and modeling
- Network and computer systems

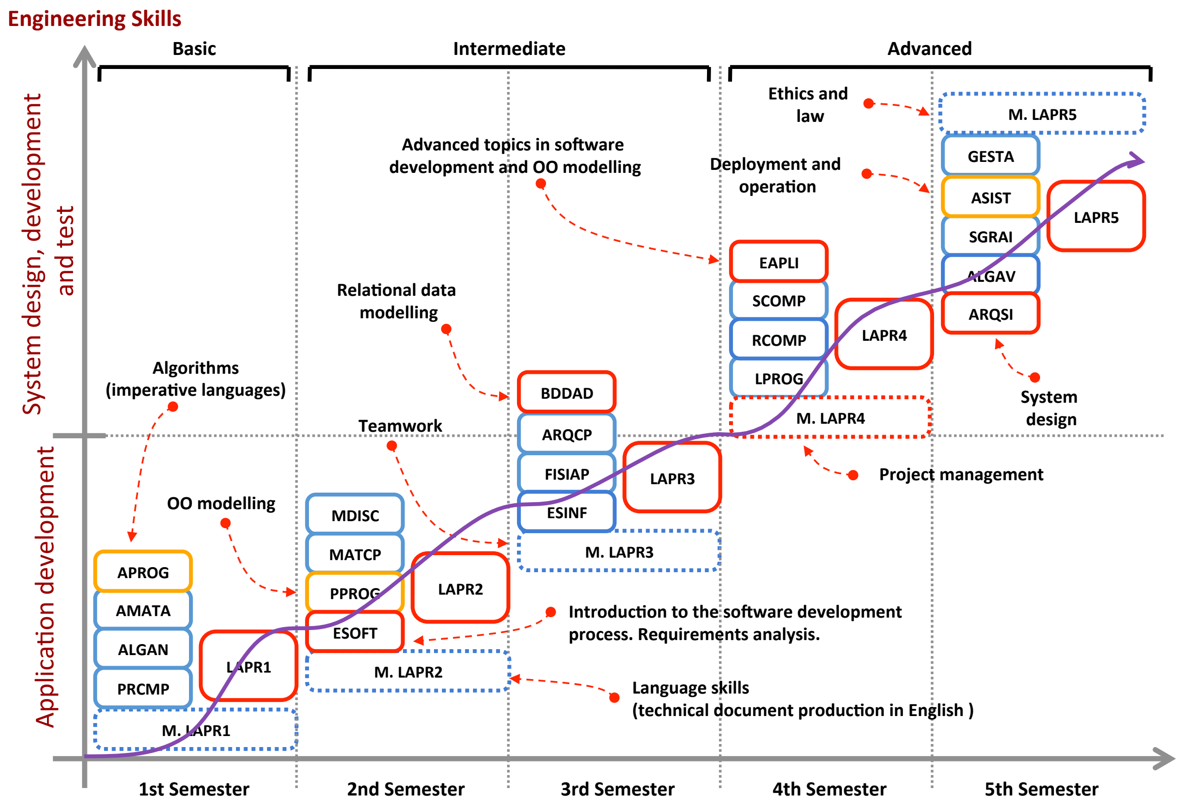

Figure 2. LEI software and system engineering learning process

Furthermore, each process has a set of core courses (in red in Figure 2) and accessory courses (in orange). The courses not directly related with the learning process are depicted in blue. The process in Figure 2 includes five Lab/Project courses (LAPR1 to 5), Software Engineering (ESOFT), Databases (BDDAD), Applications Engineering (EAPLI) and Systems Architecture (ARQSI). It also has three Accessory courses: Algorithms (APROG), Object Oriented Programming (PPROG) and Systems Administration (ASIST).

PROGRAM ASSESSMENT

The management of an engineering program with over one thousand students is a daunting task, requiring the use structured management approaches and objective performance data. The structure of the assessment framework used in LEI [5] is program independent and encompasses three levels:

- Program, focusing on “final product” quality, i.e. to assess employers’ satisfaction and the quality of graduates. The Syllabus is the main reference;
- Learning Process, focusing on individual learning process and students’ assessment (efficiency, etc.). The metrics are usually analyzed in the scope of a 4-years trend;
- Course, focusing on each course’s assessment, including its integration in a learning process. The results are usually analyzed in the scope of a 4-years trend.

Table 1 summarizes the key metrics of the framework used in LEI. Some of the metrics are externally imposed by accreditation entities (e.g. years to graduation), but the others were internally defined in the scope of CDIO standards and overall program efficiency requirements. For every of them the evolution over time is usually more important than the actual results, so a four year window has been used.

Table 1. LEI-ISEP Assessment Framework

	Program Assessment	**Learning Process Assessment**	**Course Assessment**
Objective	Graduate quality assessment and rating	Learning process and student assessment	Course assessment
Scope	Applies to all students graduating	Applies to: - Learning processes - Program's semesters - Students	Applies to all courses
Metrics	- Employers' satisfaction - Capstone project/internship grades - Graduates' quality rating distribution - Years to graduation - Program dropout rate	- Students success rate - Success patterns for processes	- Course grades - Success rate - Students' dropout
Application	School year	Semester and multiple years for processes	Semester

RESULTS

Based on the assessment framework, some results will be presented for each of the three assessment levels in Table 1, in order to illustrate CDIO's contribution for LEI's success.

Course Assessment

The most basic course assessment metric is the analysis of the success rate. Table 2 depicts a summary of five years of results of all courses. The percentage of students finishing the courses increases along the program, so that over 80% of the students are assessed in 3rd year courses. Students' efficiency (approved/evaluated) also improves along the program.

The evolution of these numbers in the last few years has been generally positive, though there were some minor fluctuations. The results of the former program, prior to the introduction of CDIO, were much worse, especially in the first two years of the program. In some cases they were half the current values. Students' motivation has increased noticeably, especially with the introduction of a project course at the end of each semester.

Approval rating in project courses is usually 10 points higher than in conventional courses, as depicted in Figure 3. The notable exception is LAPR2, which runs in the 2nd semester of the program and it is the first course in which the students are faced with an integrated and structured approach to software development.

The usual good results of project courses have been met with some skepticism (and resentment) from faculty, even after 6 years, especially because of team versus individual assessment. It is a difficult problem without a definite solution. Too much emphasis on individual assessment within the team affects teamwork, which is a key objective of these courses. On the other hand, faculty strongly objects the possibility of a student to pass without fully deserving it, just because he was in a good team.

Team monitoring procedures during the project have been changed in order to help the students to improve their teamwork practices and to better assess individual contributions, especially serious problems of misbehavior by team members. Starting this year, GIT version control system (http://git-scm.com/) is being used to better assess individual contributions in software projects. Using the commits' log it will be possible to better assess the team's development process and team members' individual contributions to the project.

Table 2. Summary of results per year (2007/2008 to 2011/2012)

		Enrolled in courses	Assessed/ Enrolled	Pass/ Enrolled	Pass/ Assessed
1st year	2007/2008	4263	63%	44%	69%
	2008/2009	4489	63%	46%	74%
	2009/2010	4285	67%	42%	63%
	2010/2011	4183	74%	55%	74%
	2011/2012	3640	72%	50%	69%
2nd year	2007/2008	2871	77%	59%	78%
	2008/2009	3221	76%	53%	70%
	2009/2010	3294	72%	47%	66%
	2010/2011	3312	74%	51%	68%
	2011/2012	3563	84%	62%	73%
3rd year	2007/2008	1727	85%	77%	91%
	2008/2009	2145	89%	77%	87%
	2009/2010	2464	85%	75%	89%
	2010/2011	2367	84%	69%	82%
	2011/2012	2270	84%	72%	85%

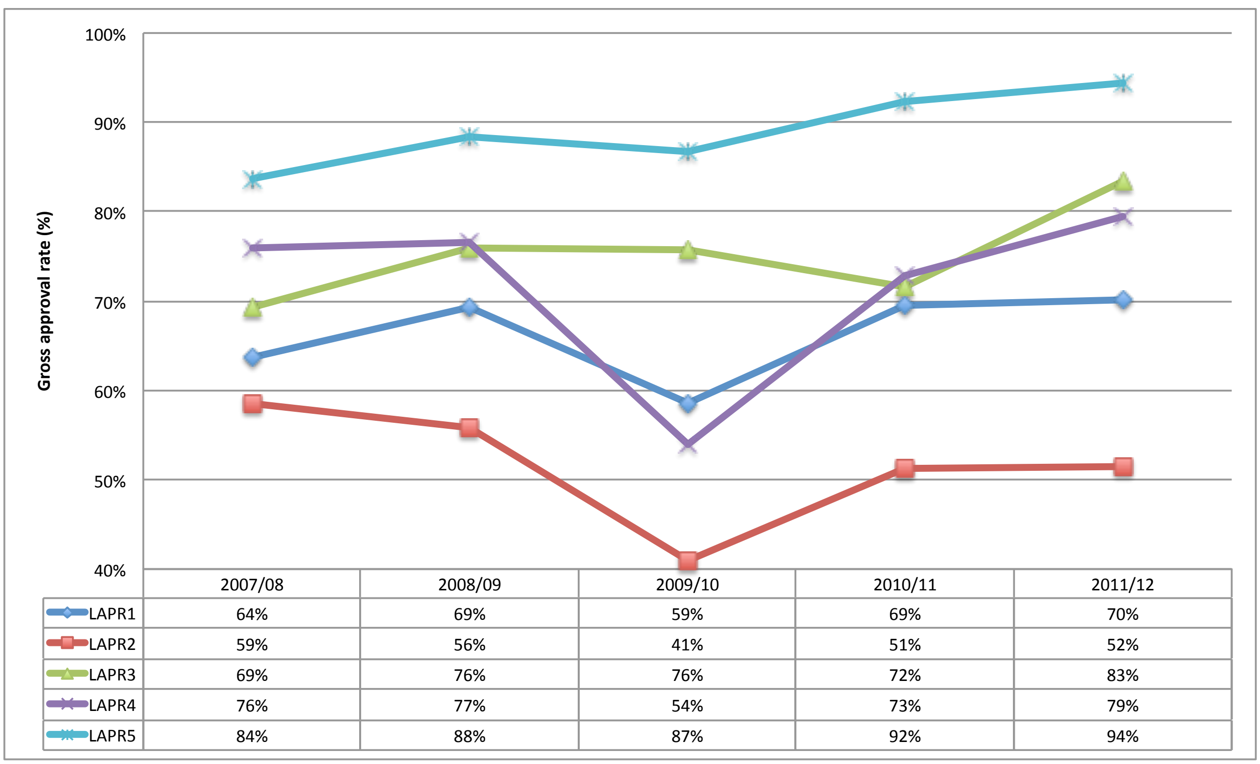

Figure 3. Gross approval rate (pass/enrolled) in project courses

Learning Process Assessment

CDIO standard 3 was used as the rational for the definition of learning processes, namely as sets of courses that provide sets of skills and competences related to known professional profiles. Theoretically the processes made sense, but it is important to assess if the students actually comply with them.

First, compliance was defined as enrolment and approval in the courses by the prescribed order and in the correct year over a 3-year timeframe. That is, compliance over longer periods (e.g. 4 or 5 years for working students) wasn't studied and was classified as noncompliance. The study of the students graduating in the last 3 years shows that over 80% of them fully comply with the processes, minus one course (7 in 8 or 8 in 9 courses per process). Over 1/3 fully comply with the processes.

Some patterns of the Software and System Engineering process (9 courses) are presented in Table 3. The numbers represent the year the student approved the course and the "0" (shadowed cell) represents a non-common course. The total number of students in this particular case was 315. It is possible to extract hundreds of different patterns for a sub process, but only the ones with most students are of interest. The patterns are also grouped in "families", i.e. they differ in one course and most of the students are the same. For example, the members of the 4th pattern in Table 3 belong also to other three patterns in the table. This means that there is one student that has just failed LAPR2, 11 that have just failed EAPLI and 14 that have just failed ESOFT. These 4 patterns represent 133 different students (42% of the population).

Table 3. Software and System Engineering process patterns (sample)

Num. Students	Size	LAPR1	ESOFT	LAPR2	BDDAD	LAPR3	EAPLI	LAPR4	ARQSI	LAPR5
121	8	1	0	1	2	2	2	2	3	3
118	8	1	1	1	2	2	0	2	3	3
108	8	1	1	0	2	2	2	2	3	3
107	9	1	1	1	2	2	2	2	3	3

On the other hand, the overall program compliance, using a tolerance of 4 courses, was below 40%. The full compliance was a meager 11%. Thus, one can conclude that these closely connected courses effectively correspond to sub processes and that they should be managed as a block. The definitive argument to validate the process approach would be an analysis of the correlation of the grades in the processes' courses. Unfortunately, actual grades fluctuate a lot between courses, depending on the subjects, the percentage of project assessment versus exam in the grade and the teaching staff teaching and motivating skills, i.e. teaching staff quality. One believes that comparing grades between courses and processes is not feasible.

One of the benefits of the adoption of the CDIO inspired learning process concept is the possibility to analyze students' behavior in the process' courses as a whole. Therefore, the identification of some "alarm patterns" in a process, e.g. a big percentage of students failing to acquire a specific set of competences, is much simpler as it is also easier to identify the underlying causes.

Program Assessment

Soft skills

The focus on soft skills is a distinctive aspect of CDIO, so seven soft skills modules/courses were introduced in LEI. The assessment of the graduates' soft skills competences takes place at the end of the capstone project/internship course, which is in the last semester of the program. The vast majority of students opt for an internship in a company or in an R&D unit, so internship supervisors are requested to provide qualitative feedback on the students' behavior (sections 2 to 4 of the Syllabus) [6]. The results of the last four years, presented in Figure 3, are very positive. Time and schedule management are the two areas with worse results, but this is also a cultural problem in Portugal. In order to mitigate these shortcomings, a soft skills module (16 hours) about personal time management was introduced in the first year

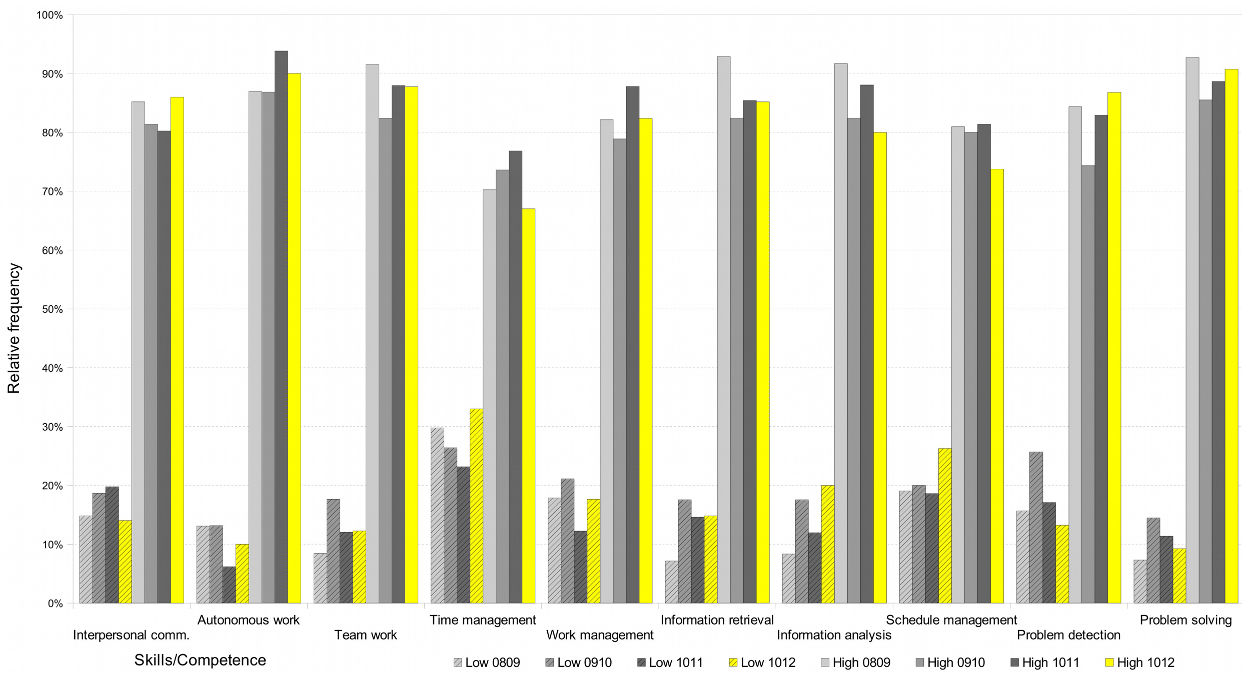

Figure 4. Student skills/competence evaluated from inquires to internship supervisors

Graduate grading

The cumulative grade point average used in Portugal is not at all useful to grade the quality of the graduates, thus a descriptor based grading system was proposed as more suited to CDIO compliant engineering programs [8]. It complements the current grade with a set of three descriptors that individually describe proficiency in program Knowledge, Skills and Competence, aiming to improve professional/social recognition of graduates and to facilitate the profiling of those graduates by employers.

The application of this tool to LEI is based on three distinct categories of curricular units, mapping one-to-one with Knowledge, Skills and Competence. The solution also addresses issues like "engineering is much more than knowing things", "engineering schools' diplomas essentially endorse knowledge", and "employers disregard global average indicators". It can be seen as a natural consequence of CDIO adoption, understandable by stakeholders and simple to operate. Applying the new descriptor based grading system to a significant sample of graduates (Figure 4) allowed the identification of a few dominant “graduate stereotypes”, each one with its own balance between Knowledge, Skills and Competence. Thus, the descriptor based grading is being marketed to employers as a recruiting aid tool, allowing them focus their recruiting efforts in the stereotypes that better meet their specific requirements.

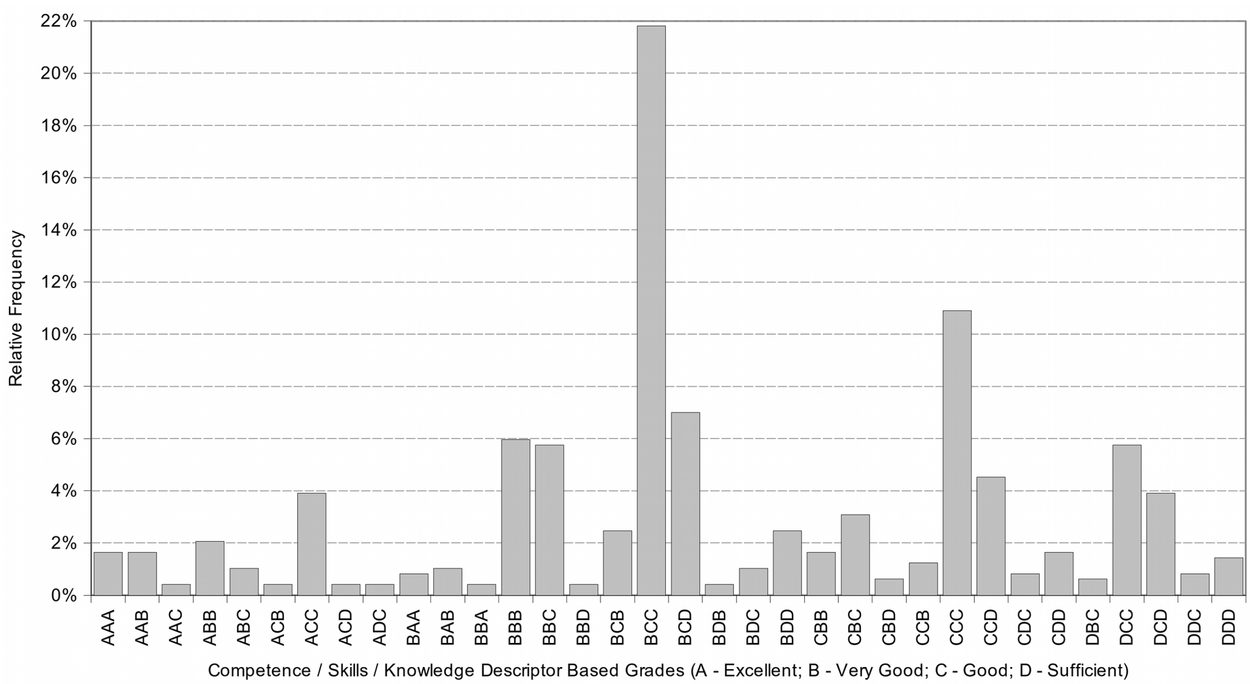

Figure 5. Descriptor based grading of LEI graduates (2008-2012)

Annual dropout

Dropout is a serious problem in higher education in Portugal, especially for freshmen. As can be seen in Table 3, freshmen dropout has decreased sharply in the last two years. Total dropout has also decreased, in spite of the severe economic crisis that has affected Portugal since 2008. Dropout in the second and third years is usually related to economic problems and in most of the cases is just a temporary suspension of enrollment.

Table 4. Student dropout

	2008/2009		2009/2010		2010/2011		2011/2012	
Year	**Enrolled**	**Dropout**	**Enrolled**	**Dropout**	**Enrolled**	**Dropout**	**Enrolled**	**Dropout**
1	437	87	420	91	426	57	363	39
2	381	29	385	31	350	32	408	34
3	319	14	368	26	403	27	427	30
Total	1137	130	1173	148	1179	116	1198	103

Dropout causes in the first year are usually related to students’ dissatisfaction with the program or problems in adapting to higher education. LEI has about 30% of full-time working students, mostly enrolled in night classes (18:30 to 23:30, Monday to Friday). Workload is particularly important for these students, as the CDIO inspired pedagogical approach, with a strong focus on practical work and teamwork. These students are advised to adopt the part-time registration scheme (50%), which has had a noticeable growth in recent years, but even so some end up quitting.

CONCLUSIONS

The introduction of CDIO best practices in LEI aimed at improving graduates' quality and learning process's efficiency. This was very important because the school had to increase the number of students in Computer Engineering in order to offset reduced demand in other programs (e.g. Chemical Engineering). The overall results were very positive, so that LEI is now publicly recognized as one of the 5 top rated Computer Engineering programs in Portugal and it was invited by the Engineers Accreditation Board (Ordem dos Engenheiros) to be the first Portuguese Bologna 1st cycle engineering program to apply for EUR-ACE accreditation.

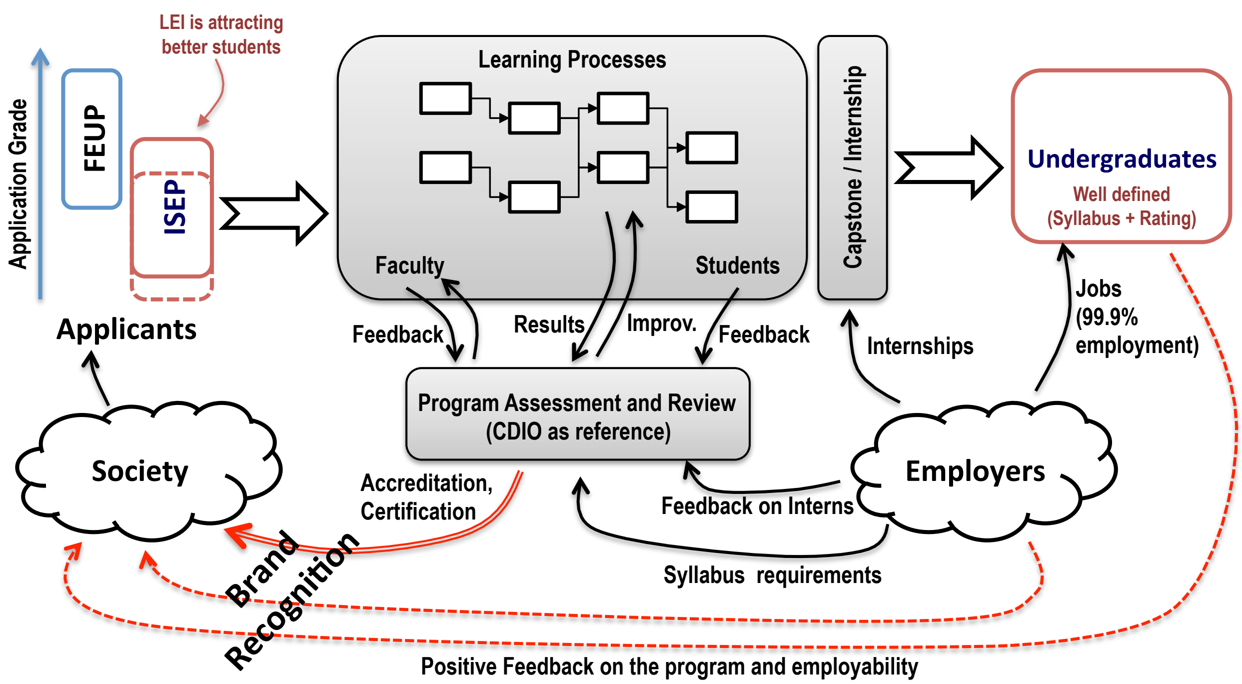

Figure 6. The virtuous cycle of using CDIO in LEI

Internally, CDIO best practices also resulted in a noticeable reduction in 1st year students' dropout and an overall increase on students' efficiency. Graduates' quality perception by employers has also improved, especially due to the introduction of soft skills modules and a strong focus on the software development process. Moreover, there has been a remarkable increase in capstone projects/internships' quality, which cannot be assessed by grades or any other single metric. Here one can identify a key limitation on the application of metrics to assess quality and efficiency in engineering education: the requirements evolve. This is especially true in new and fast paced areas like computing. In the last 10 years, computer engineering has evolved a lot, not only technically, but also in engineering practices like agile development, software patterns, unit testing, test driven development, etc. Courses and programs have to evolve fast to keep up with reality and CDIO's strong focus on engineering practice has been definitely a plus for LEI's students and graduates, which are now in very high demand by employers. This is a key success metric for a program and there is no better publicity than this.

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