MASS CUSTOMIZATION IN ENGINEERING PROGRAMS: A FRAMEWORK FOR PROGRAM MANAGEMENT

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ABSTRACT

The management of an engineering program with over one thousand students is a daunting task, which requires the use structured management approaches and objective performance data. In this paper it is presented the rational for the adoption of a process approach for large engineering programs management. As a case study, the assessment framework used at an ACM and CDIO based Informatics Engineering program in Portugal is presented.

KEYWORDS

Program Assessment, Process Management, Assessment Framework, CDIO

INTRODUCTION

Instituto Superior de Engenharia do Porto (ISEP, School of Engineering - Polytechnic of Porto) is the largest polytechnic engineering school in Portugal with more than 6000 students, over 400 teachers and almost 200 staff. It is located at Porto and in 2009/10 lectures 10 first cycle and 10 second cycle Bologna programs. In 2010/11 it is expected that 2 new Bologna cycles will start lecturing, totalling 22 engineering programs.

Licenciatura Engenharia Informática (LEI-ISEP) is an Informatics Engineering 1st cycle program (3 years – 180 credits) created in 1985, but extensively improved in 2006/07 with the adoption of Bologna declaration in Portugal. The new structure is based on ACM Computing Curricula (2005), namely a combination of the Computer Science and the Information Technology curricula, and structured along the CDIO principles.

The program is structured in 6 semesters:

- Semesters 1 to 5 have 12 weeks of ordinary classes (4 or 5 courses per semester) followed by a 4 week long design-build course.
- The last semester has some modular 3 week courses, but it is mainly devoted to an internship or a capstone project.

It is important to detail the major student fluxes in LEI-ISEP, depicted in Figure 1, as they are directly related to the diversity of LEI-ISEP's ecosystem. Starting with influxes, LEI-ISEP accepts about 300 new students every year from 3 admittance mechanisms, 292 in the 2009/10 school year, to be exact:

- Standard university admittance, 175 vacancies for daytime classes and 20 for nighttime classes. Most are 18 years old students who have just finished secondary education. Applications are managed on a national base and there are usually 4 to 5 applications for each vacancy in LEI-ISEP, which places it in the top tier of informatics engineering programs in Portugal.
- Special admittance mechanism for working students older than 23 (9 vacancies) and for students previously enrolled in other university programs, both in Portugal and abroad (67 vacancies). Many of these students had an unsuccessful previous experience in a higher education program and seek a new start in LEI-ISEP. Others seek to move to LEI-ISEP because it's a program highly regarded by the market, with full employment in less than 6 months.
- About 21 re-enrolments of LEI-ISEP students who had suspended their studies and want to retake them.

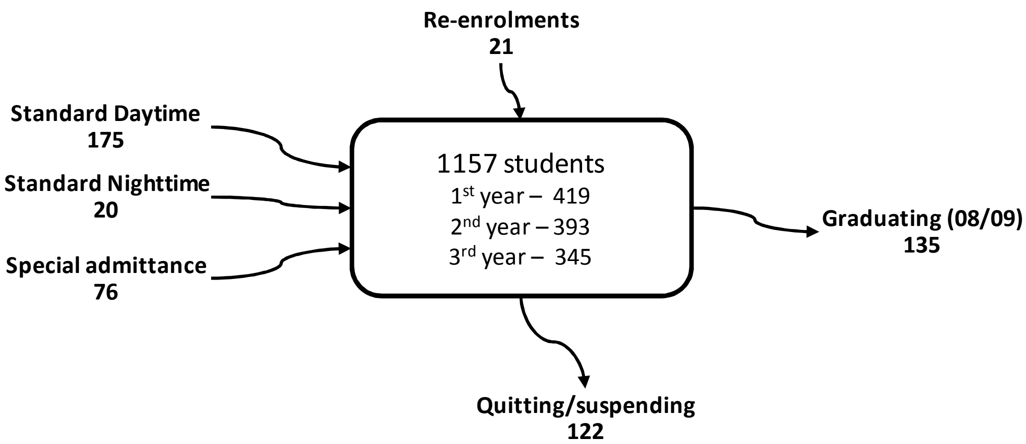

Figure 1 – Student fluxes in the school year 2009/10

Regarding the outflows; an average 135 to 140 students usually have graduated per year in the last three years, while around 120 have suspended their enrolment or quitted LEI-ISEP altogether. Around 20 to 30 students usually retake their studies every year, so one can probably state that LEI-ISEP's dropout is about 90 to 100 students per year. Dropout is related to several factors, but is especially acute for working students that come to realise the challenge of having a full-time job and studying. Nevertheless, some of these students retake their studies later on, when their professional activity allows them to. The other main cause of dropout is the failure of young students to adapt to the higher education environment. Some enrol several times in LEI-ISEP's first year only approving in at most a couple of courses and then they quit.

In all, in the 2009/10 school year, there were 1157 students enrolled in LEI-ISEP, 419 in the 1st year, 393 in the 2nd and 345 in the 3rd. The numbers provided in Figure 1 are not enough to understand LEI-ISEP, as the student population is far from being homogeneous. For example, most students attend daytime classes, but there are 348 students enrolled in nighttime classes (18:00 to 23:30), usually because they have full-time jobs. Also, most students are enrolled as ordinary students (5 or 6 courses per semester), but there are 230 students enrolled as partial students, which have half the number of courses per semester of an ordinary student (maximum of 3 courses), thus taking at least 6 years to graduate. Most of these students attend nighttime classes.

Such a heterogeneous environment is the direct result of the massification of higher education and is not by any means exclusive of LEI-ISEP. Governments are a driving force in this process, using higher education as a fast paced social engineering tool, especially in southern Europe countries, which trail northern Europe countries in most education indicators. Globalization further accelerates this trend, as countries regard education as way to improve the competitiveness of the existing workforce, whose jobs are endangered by foreign completion competing on price. LEI-ISEP has a key role in this process, as roughly 1/3 of the students have a full time job.

In spite of the democratization of higher education systems, government and accreditation bodies still use "universal" performance indicators like "dropout ratio" and "number of years to graduate" in program assessment. Believing that these broad and simplistic indicators are of little use and may even lead to erroneous conclusions, the authors propose the use of a framework for program management and assessment.

PROCESS APPROACH TO PROGRAM MANAGEMENT

CDIO Standard 3 — Integrated Curriculum
A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.

As is implied in CDIO standard 3, a program must have a learning process. When characterized by its flow structure, a process can be broadly classified either as a job shop or a flow shop. A job shop process uses general purpose resources and is highly flexible: there is no restriction on the definition of new workflows. A flow shop process uses specialized resources and predefined workflows. Consequently, a flow shop is less flexible than a job shop.

The job shop process is the most appropriate in the production of products in small batches or when the number of operations in the process is small or variable. The flow shop is most appropriate in the production of products in large batches, so that it is feasible to develop a specialized efficient production system/process for that type of product.

Using the process analogy, one can say that a master studies program or a PhD program are both examples of small batch processes with mostly independent/unrelated courses, which can be easily implemented and managed in a job shop approach. The curricula are structured in semesters and years, each having a predefined small set of mandatory courses, being the offer of many optional courses a further evidence of the use of this approach. In these programs, the student is almost free to choose the courses he wants to attend and when to attend them, though some courses may have some pre-requisites. This diversity makes program management a very complex and difficult task, but the small number of students usually allows for the individual management of each student's customized process. This scenario fits the "artistic process" concept presented by Hall [1]. Incidentally, courses with a small number of students usually have good results and when problems do arise, the close relation between program's manager and the students allows for feedback to be provided on time to act.

Undergraduate engineering studies programs in Southern Europe usually have a large number of students (over 500 students are quite common; there are four programs with over 750 students at ISEP) and a large set of courses in 6 semesters (25 to 30 courses are typical), many of them chained or interrelated. The number of optional courses is usually limited. But, as we have seen before, there is a lot of diversity in the student population, which hinders the use of a "one fits all" approach to the process' management. On the other hand, to manage such a process using a job shop or artistic process approaches is not feasible. Furthermore, the special characteristics of the higher education environment make it difficult to use some common quality control tools:

- It's almost impossible to objectively monitor teaching quality and it is quite difficult to assess course quality. Students' results (approvals, marks, etc.) are not a reliable quality indicator, as it can be directly controlled by teachers. Student feedback by the way of anonymous quality questionnaires can also be a very useful tool. Unfortunately, students are often very suspicious about electronic questionnaires, which leads to the use of paper ones. In a large program this may be a logistics nightmare (e.g. over 9000 enrolments in courses in LEI-ISEP per year), there are often very low response rates and the sample may be biased towards the students more likely to attend classes.
- The CDIO Syllabus is a good candidate for a program's quality benchmark, but it is a final one. Most syllabus skills are acquired in not one but in multiple courses along the process, which makes it difficult to define intermediate quality standards for students' skills. The definition of a Syllabus per year/semester could help somehow; but it would be always difficult to assess (supplementary multidisciplinary tests/evaluations for the students?).
- Higher education is mostly public financed in Southern Europe, thus chronically underfunded.

Therefore, there is the need for a program management approach that defines standard processes, in order to support a large number of courses and students, but also allows for controlled variations in output, in order to support the specificities of several subgroups in the student population. One such approach is mass customization [2], a flow shop approach used for long in manufacturing and service industries to provide customized products from standard processes.

Learning process

The concept of a learning process is presented in figure 2. A process can be defined as an ordered set of interrelated courses which will provide the student with a set of well defined skills. The process final outcomes are a subset of the program's Syllabus.

The course is the basic entity in the process and it may belong to several processes. A course has a set of outcomes which are used for student assessment. Some of the course's outcomes are directly related to the process or processes it belongs. Nevertheless, one must stress that learning is a complex process where is not possible to decouple the effect of each course on the student. In fact, it's quite the opposite: a program should be designed in order to provide the student an integrated learning experience in which the final result should be more than the sum of the parts. The experimental learning model [3], which is the foundation of CDIO, is an example of this: the concrete experiences in design-implement experiences deeply affects the way the student learns in the following courses.

A key motive for the use of learning processes is quality control. Juran defined quality as "fitness for use" [4] and this allows us to define an effective quality assessment mechanism to be used during the learning process: the skills of the students at the beginning of a course should meet the course's minimum requirements. If this doesn't happen for a sizable number of the students, then there is definitely a quality problem upstream. It may not be immediately traced to the previous course in the process, learning processes are much more complex than an assembly line, but it provides the program manager the information and the opportunity to act in order to solve the problem. Also, one can argue the initial assessments tend to be more impartial than the course's final assessment. The course teacher will naturally adapt the final course's assessment to fit the students' overall skills and to overcome eventual problems that arose during the course.

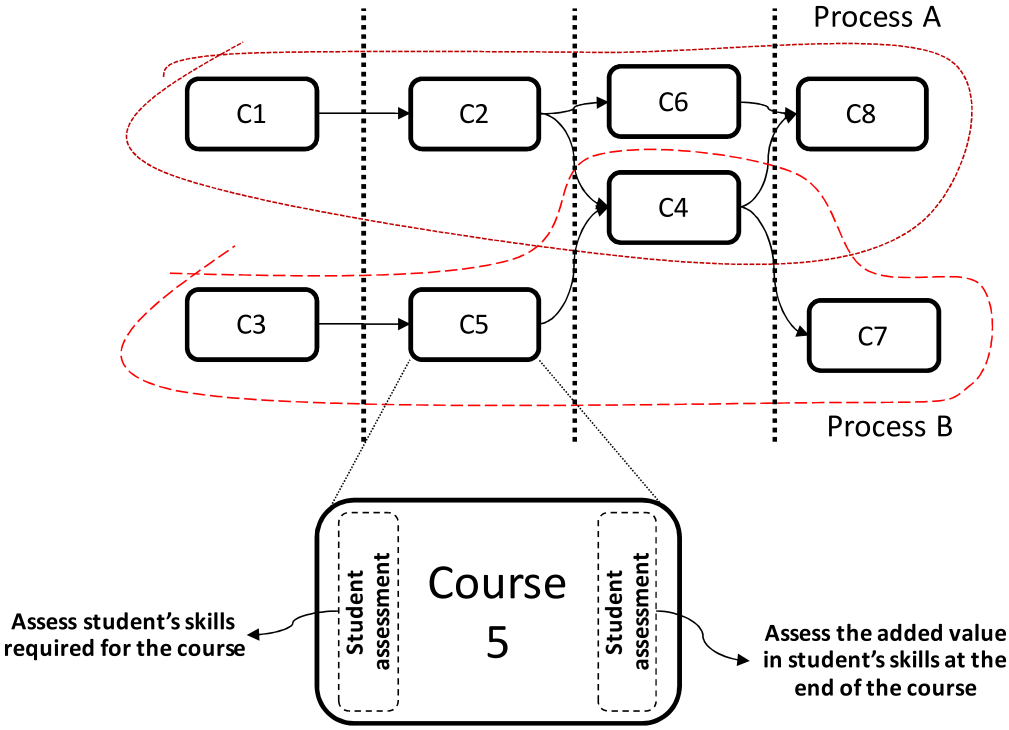

Figure 2 – Learning processes

In this approach, the program's main "processes" (sets of related courses) must be identified, so that these courses can then be managed in an integrated fashion: each course is client of the preceding one and a server to the next. The fitness for use of the student in one of the process's course (fulfilling the courses pre-requisites in terms of real student's skills) is directly related to the process's quality up to that point.

AN ASSESSMENT FRAMEWORK FOR PROGRAM MANAGEMENT

The adoption of CDIO provided the foundation for the creation of a structured management approach for the effective management of LEI-ISEP, as depicted in Figure 3. This iterative approach has the following phases:

1. Using the program's Syllabus as a reference, the curriculum should be redesigned as a set of learning processes, each of them with clearly defined learning outcomes. Some courses may belong to more than one process.
2. Student segmentation is the key for the definition of successful management approach. An iterative approach to segmentation should be followed, supported by students' academic results, as evidence often trumps preconceptions.
3. Construction of assessment frameworks for the program ("final product inspection"), for the learning processes and semesters and for individual courses. The Syllabus provides the core objectives/skills to be measured at the end of the program, being the capstone project or an internship the first place where this can actually be measured. Intermediate objectives are harder to measure directly.
4. Continuous improvement based on facts. Results and evidence should drive change, both in the program and in the assessment framework.

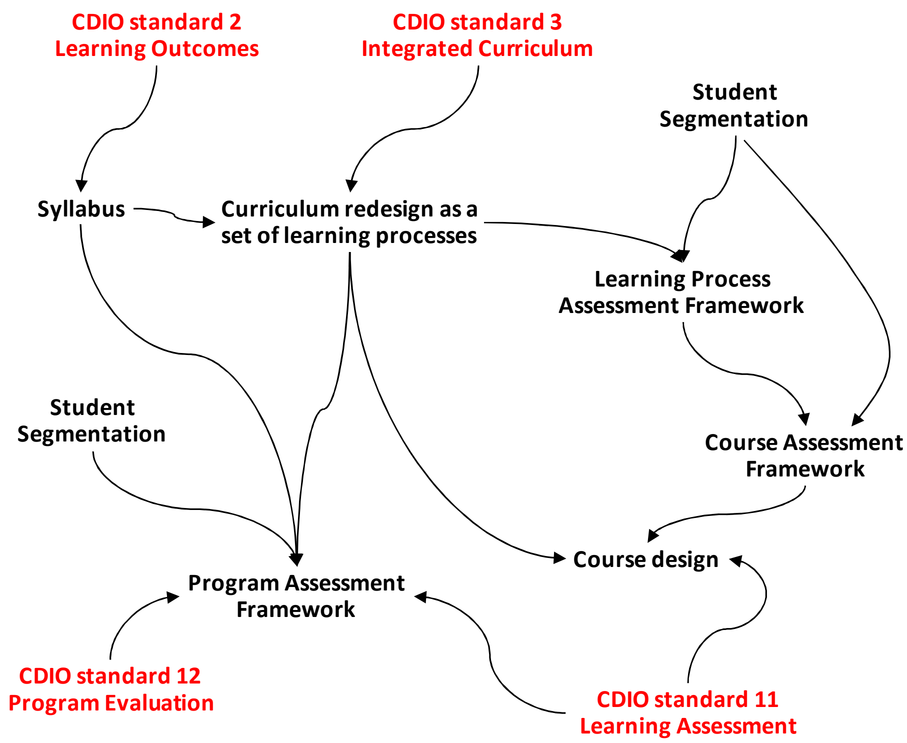

Figure 3 - Creation of an assessment framework for LEI-ISEP

Curriculum redesign as a set of learning processes

The identification of learning processes is clearly program dependent. Three learning processes were identified in LEI-ISEP, as depicted in figure 4:

- Networks and Computing Systems
- Programming and Modelling
- Software and System Engineering

Some courses belong to more than a process and there are eight courses that aren't included in any process. One is the capstone project/internship; the others are math, physics and management courses. Though some of the math courses are clearly interrelated, they are support courses and there is no point in defining a process for them.

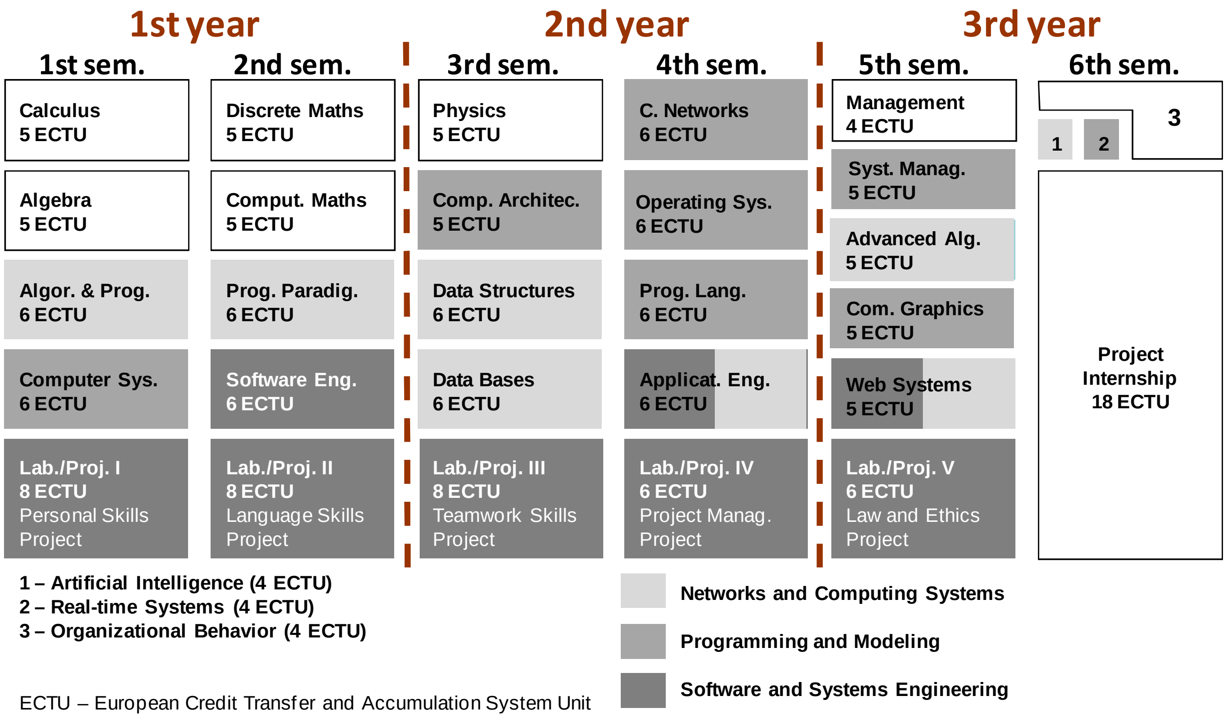

Figure 4 – The three learning processes in LEI-ISEP

The first learning process to be defined was the Software and System Engineering process, which by itself lead to a novel approach to software/system development process learning and practicing [5]. This process was chosen because in CDIO the development process is a key skill the engineer should master and was identified as one weakness of LEI-ISEP.

The learning process, depicted in figure 5, uses an iterative approach, in which the student continuously refines his skills over several courses, developing increasingly complex projects. The process' core courses are: Lab./Proj. I (LAPR1); Software Engineering (ESOFT), Lab./Proj. II (LAPR2); Lab./Proj. III (LAPR3); Applications Engineering (EAPLI); Lab./Proj. IV (LAPR4); Web Systems (ARQSI); Lab./Proj. V (LAPR5). These courses define the learning process' critical path, while other courses provide the skills (programming, modelling, etc.) needed for the students to develop software/systems and thus practice the software/system development process.

As the learning process covers five semesters, three proficiency levels were defined: basic; intermediate and advanced. A detailed description of artefacts and disciplines was provided for each level, as well as the contributions of each course in the critical path. Three themes (Application Development, System Development and Project Management) were also defined in order for faculty and students to better understand each phase of the learning process.

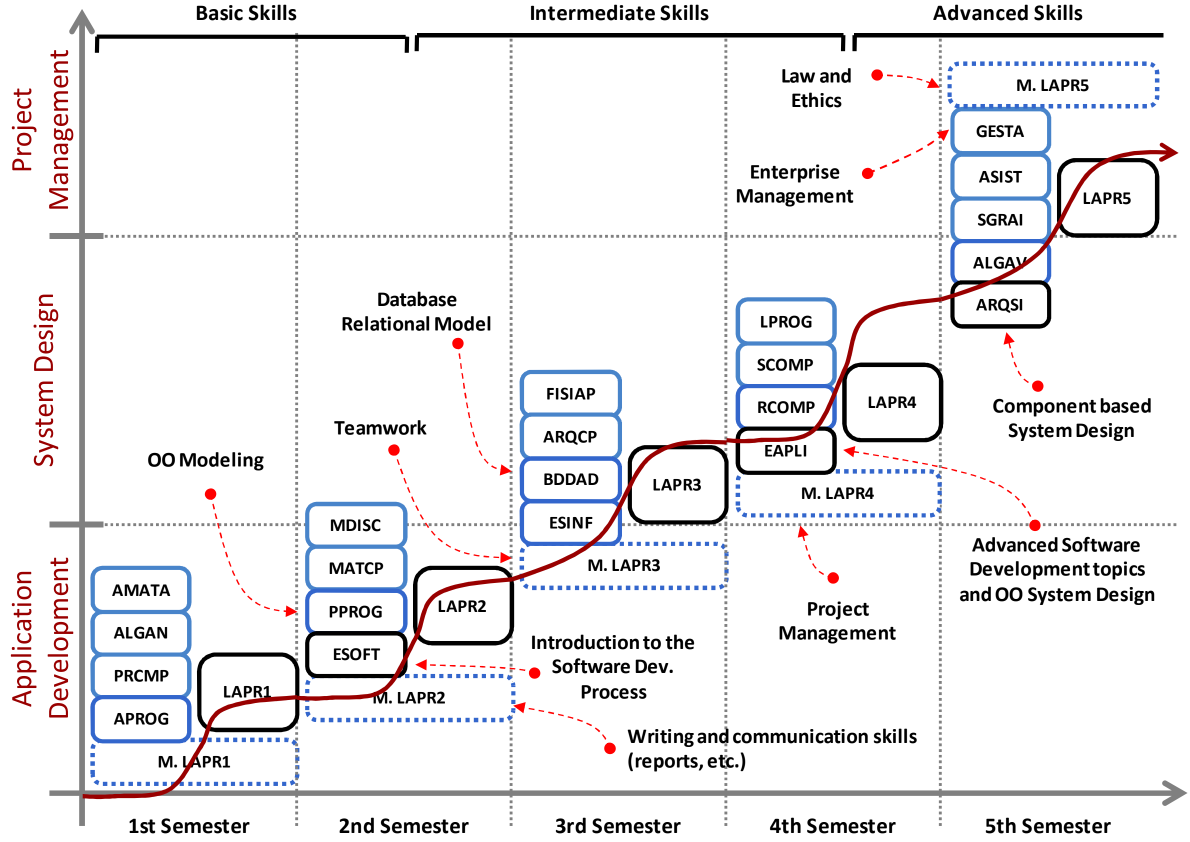

Figure 5 – The Software and System Engineering learning process

Student Segmentation

Student segmentation is also program dependent. Two main inputs were used to define student segments: program inputs presented in figure 1 and the analysis of students' results. It was possible to identify several criteria:

- Daytime/nighttime classes;
- Type of Math course in secondary school (type A and B);
- Students' admittance (standard, M23, re-enrolments, others);
- Working/full-time/partial students;
- Student's academic record (re-enrolments in course, etc.).

With these criteria it's possible to define many more segments, though some of them don't make any sense. For example: the combination daytime+partial+non-working students has no statistical relevance.

Assessment Framework

The structure of the proposed assessment framework is program independent and encompasses three levels:

- Program, focusing on final product inspection;
- Learning Process, focusing on individual learning process assessment and the identification of problems during the process;
- Course, focusing on course assessment, including its integration in a learning process.

Table 1 summarises the framework used a LEI-ISEP. Some of the metrics are externally imposed by accreditation entities (e.g. years to graduate), but the others were internally defined in the scope of CDIO standards and overall program efficiency requirements.

Table 1
LEI-ISEP Assessment Framework

	Program Assessment	**Learning Process Assessment**	**Course Assessment**
Objective	Final product inspection	Learning process assessment	Course assessment, including its integration in a learning process
Scope	Applies to all students graduating	Applies to: - Learning processes - Program's semesters	Applies to all courses
Segmentation	Students school record: - Graduation in 3 years - Graduation in 4 or more years Student's admittance Daytime/Nighttime courses Full-time/partial	Semester (1 to 6) Learning Process - Programming and modeling - Software engineering - Networks and Computing Systems Student's admittance Daytime/Nighttime courses Full-time/partial Student's curriculum	Student's admittance: - Ordinary Math A type - Ordinary Math B type - M23 - Others Daytime/Nighttime courses Student's curriculum: - Regular course - Re-enrolment - Course in advance
Metrics	Core skills of the student defined in the syllabus Years to graduate Dropout rate	Success rate of each student, both absolute and relative (successes/enrolments)	Course grades and students' attendance records to classes
Description	- Assessment on capstone project or internship (results, report, presentation and individual discussion). - Employer feedback on capstone project or internship - Employer feedback on ex-student after 3 years - School records (dropout and years to graduate)	Students' grades are grouped by student and segment	Students' grades are grouped by course and segment

Continuous Improvement

The purpose of using an assessment framework is to improve both program's efficiency and effectiveness. This approach has been implemented and refined in LEI-ISEP for the last 3 years, in the scope of the deployment of CDIO. It's very difficult to define the correct assessment framework on the first try. Several iterations are usually required and there is always room for improvement, especially on metrics and student segmentation. As an example, in figure 6 is presented a graph with students' efficiency in the 2008/09 school year. The results of all first students and the 2008/09 freshmen are presented and it is possible to understand that the later group's results (3rd line from top) are much better than the ones which include students repeating the first year. This type of analysis lead to a reorganization of first year's classes, creating three segments with specific pedagogic approaches: freshman; repeating students and nighttime students. This segmentation resulted in a better usage of resources and in a further improvement of freshmen students' efficiency in the first semester of 2009/10.

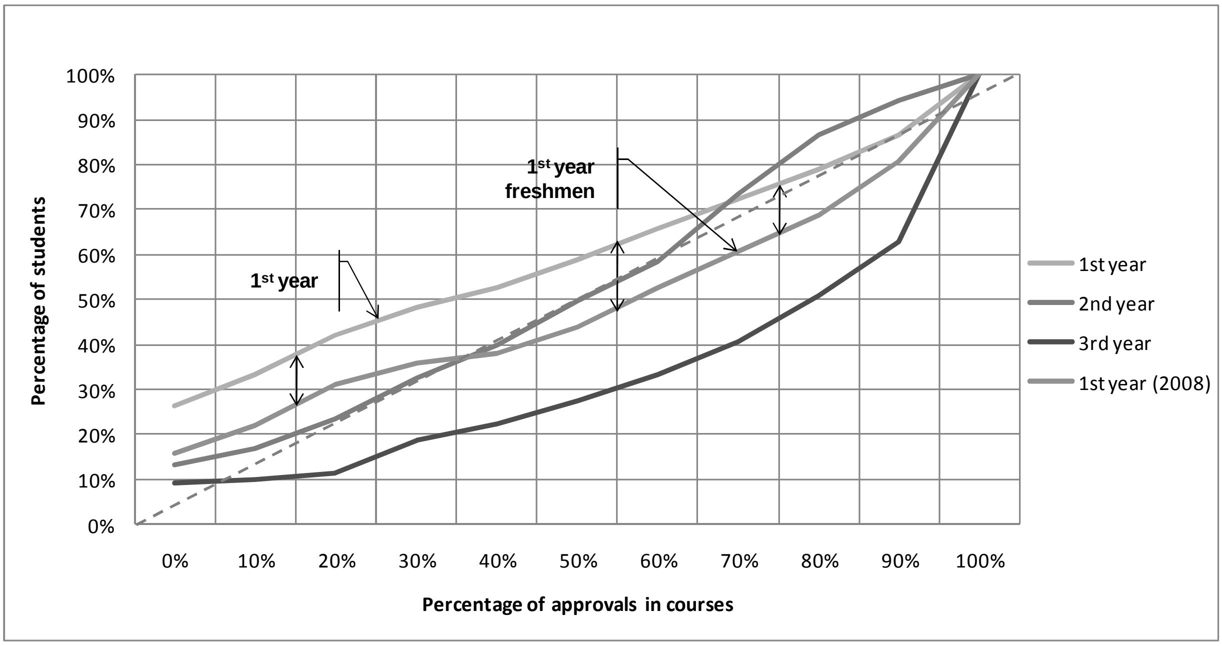

Figure 6 – Student efficiency in LEI-ISEP in 2008/09

Regarding actual improvements on the program and the learning processes, they were aplenty. The sole definition of learning processes resulted in an extensive reengineering of many courses. Many of these changes wouldn't have happened otherwise due to inertia. But the existence of a process makes the need for change obvious and teachers have eagerly cooperated. The first process to be defined was the Software and System Engineering process and the other two processes followed, though work on one of them is still going on. The effort of defining and implementing the learning processes shouldn't be underestimated. Faculty has to be involved, but a strict timeline should be imposed on the working groups. Teachers will try to maintain the status quo in their courses, often providing valid scientific and pedagogic arguments, but the whole learning process is more important than any particular subject.

It's too early to claim solid improvements in the product, i.e. student quality. Even so, it is possible to say that employers are satisfied with students' skills [6], in spite of the turbulence imposed by a quick implementation of the Bologna process in Portugal. We believe the use of the assessment framework helped LEI-ISEP in handling the change process in a controlled way.

CONCLUSION

The management of undergraduate engineering programs with a large number of students is quite challenging, due to the sheer number of students and their diversity. In this paper it was presented the rational for the adoption of a structured process based approach for large engineering programs management. As a case study, the assessment framework used in a CDIO based informatics engineering program (LEI-ISEP) in the last three years was presented. The authors believe that the use of such a tool fosters program continuous improvement and is a useful tool for program accreditation and/or certification.

REFERENCES

[1] Joseph M. Hall, M. Eric Johnson, When should a process be art, not science?, Harvard Business Review, March 2009, pp 58

[2] B. Joseph Pine II, Bart Victor, Andrew C. Boynton, Making mass customization work, Harvard Business Review, September-October 1993, pp 108

[3] Crawley E., Malmqvist J., Östlund S. And Brodeur D., Rethinking Engineering Education: the CDIO Approach, Springer, 2007, pp144.

[4] J. M. Juran, How to think about quality, Juran's Quality Handbook, 5th Edition, J. M. Juran e A. Blanton Godfrey (Edit.), McGraw-Hill, New York, 1999, pp. 2.1 – 2.18

[5] Angelo Martins, Alberto Sampaio, Antonio Costa, Software Development Process at LEI-ISEP, 5th International CDIO Conference, Reframing Engineering Education: Impact and Future Direction, June 7-10, 2009, Singapore Polytechnic, Singapore.

[6] Antonio Costa, Angelo Martins, Three years of CDIO/ACM based Informatics Engineering undergraduate program at ISEP, to be presented at 6th International CDIO Conference 2010, June 2010, Montreal.

Biographical Information

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