A KNOWLEDGE/SKILLS/COMPETENCE DESCRIPTOR BASED GRADUATE GRADING SYSTEM FOR CDIO PROGRAMS

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ABSTRACT

This paper discusses the problem of graduate grading and proposes a descriptor based grading system more suited to CDIO compliant engineering programs. It compliments the cumulative grade point average (used in Portugal) by 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 proposed solution for the Informatics Engineering bachelor program 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 grade 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 allowed the identification of a few dominant "graduate stereotypes", each one with its own balance between Knowledge, Skills and Competence. In the near future we envisage this grading system will help to improve graduate profiling and hiring by employers…

KEYWORDS

CDIO, Informatics, Grades, Grading systems.

INTRODUCTION

The Informatics Engineering 1st Cycle Program of ISEP (Porto School of Engineering) was reformed in 2006 to comply with European Bologna directives. At the same time it incorporated many recommendations and good practices from CDIO [1] like design-build-projects on all curricular semesters, deep learning replacing surface learning, reinforcement of capability/competency oriented curricular activities, and stimulating course and faculty collaboration, just to mention a few. Since 2006-07 three full academic years have passed (2007-08, 2008-09 and 2009-10) and a lot of quantitative program data has been collected [2], suggesting a rigorous evaluation and assessment of the CDIO inspired improvements in the Informatics Engineering Program (LEI). After September 2010 the authors decided to perform systematic data analyses so that CDIO impacts could be studied and conclusions gathered. From the authors' personal experience as program directors and capstone project managers, it was clear that LEI performance improved since 2006-07 and that graduates have better social and professional recognition. It was even noted that more and more graduates were achieving excellent capstone performances, despite many of them having low/median academic grades in most of the “conventional” courses. This “phenomenon” was also an important objective to study and understand.

In this paper we describe how access grades, “conventional” program course grades and “CDIO inspired” program course grades relate between themselves, using a sample of 100 LEI students enrolled in 2006-07/2007-08 and graduated in 2008-09/2009-10. From this analysis we identify the weaknesses of using “Cumulative Grade Point Average” (CGPA) [3] techniques as a means to describe the “quality” of graduates, and propose a new descriptor based grading system for individually characterizing graduate proficiency in program Knowledge, Skills and Competence. This alternative graduate grading system, which takes into account the evaluations of capstone project supervisors and external stakeholders, aims to improve the professional/social recognition of graduates and to facilitate the profiling of those graduates by employers.

CONTEXT

In Portugal access to public Higher Education Institutions (HEI) like universities and polytechnics is managed by a national ranking system, in which each candidate student applies up to six programs and has an “Access Grade”, in the 0-200 range, defined by a weighted average of secondary school course grades and final exams encompassing subjects like “Portuguese”, “Mathematics”, “Physics”, etc. As each HEI previously defines the maximum number of new students (*numerus clausus*) for its programs, the sorting and assignment of students to programs is globally performed by a computational system and results are published on a public web site. Since 2006 LEI is having more than three times candidates than placed students, of which more than 60% enrol the program as first option. In spite of those good placement results, LEI is competing for students with the Faculty of Engineering (FEUP) of the best ranked Portuguese university (Porto University). In Portugal the best universities tend to attract the candidates with highest access grades, and that also happens for Informatics Engineering in the metropolitan area of Porto. Figure 1 shows the relationship between access grades and enrolment options for LEI placed students and Figure 2 for the Informatics Engineering Master Program of FEUP (MIEIC-FEUP).

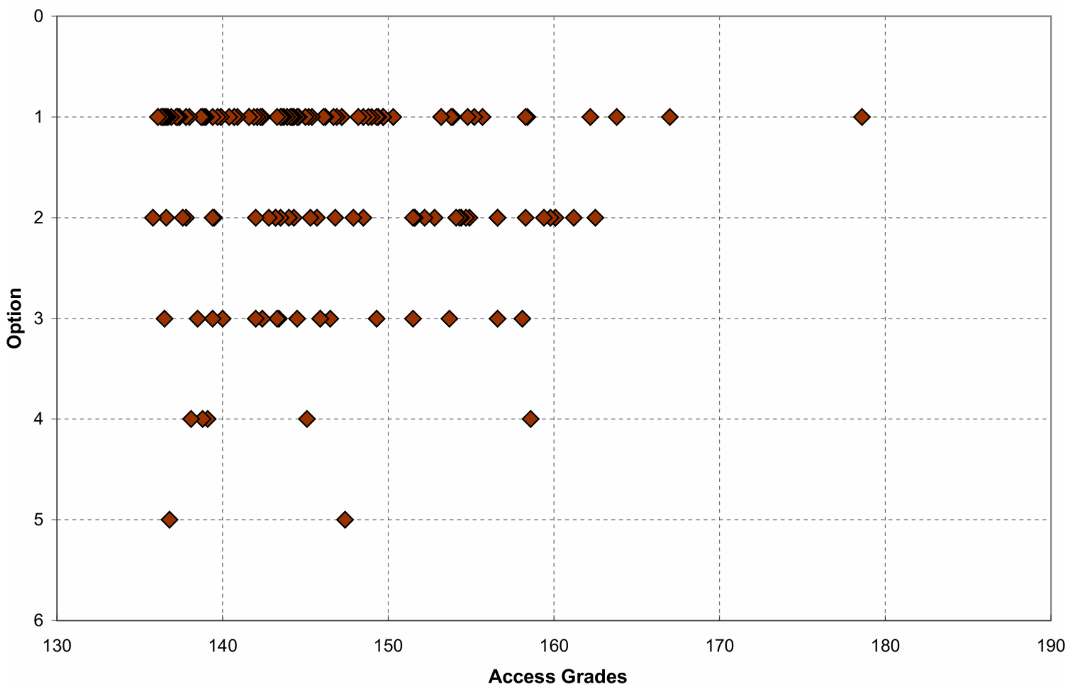

Figure 1. Access Grades x Enrolment Options for LEI Placed Students in 2010-11 (580 Candidates)

In Figure 1 it is clear that most of access grades for LEI placed students are greater than 135 and smaller than 160, with most of placed students enrolling as first or second option.

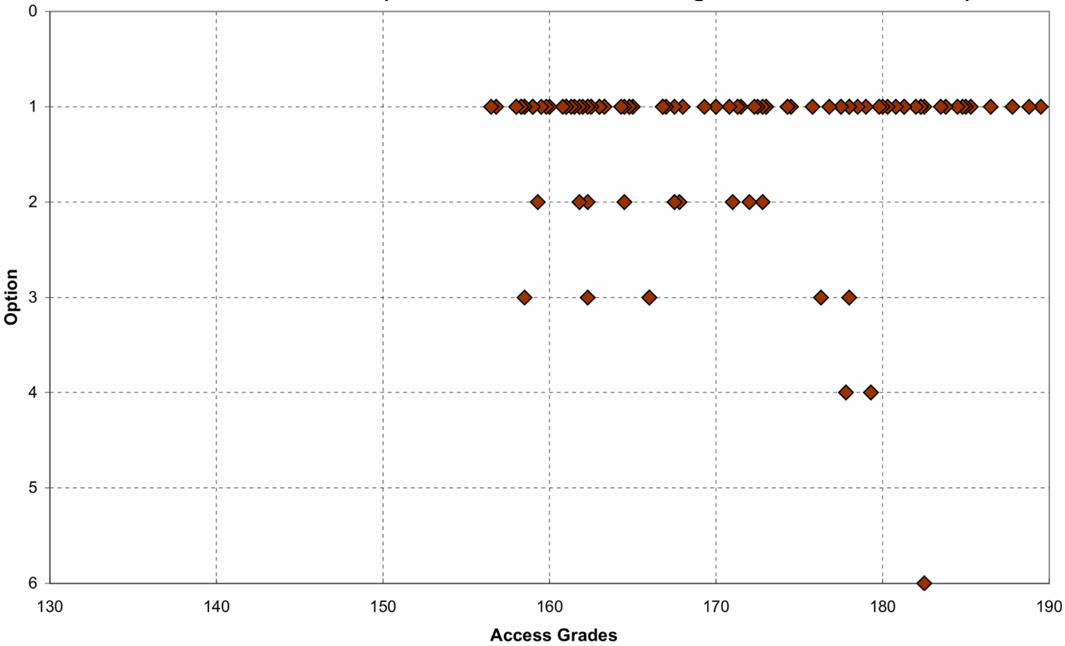

Figure 2. Access Grades x Enrolment Options for MIEIC-FEUP Placed Students in 2010-11 (600 Candidates)

In Figure 2 it is noticeable that most of access grades for MIEIC-FEUP placed students are greater than 160, revealing an obvious stratification between student placement in LEI and MIEIC-FEUP. This stratified student placement means that LEI gets students with lower access grades, less scientifically prepared, but not necessarily having lower potential for becoming competent informatics engineers. This challenging context was already known before 2006 and was a strong motivation to adopt CDIO in the reform and operation of the new LEI [2].

Some of the most important LEI performance indicators are related with the Capstone Projects. Since 2002 most of the Capstone Projects have taken place as internships in external organizations, with very positive feedback from internship supervisors. Table 1 shows the evolution of Capstone Projects proposals and internships per academic year since 2005-06.

Table 1
Evolution of Capstone Projects proposals and internships per academic year

Capstone Project	2005-06	2006-07*	2007-08	2008-09	2009-10	2010-11
Proposals	200	200	200	230	250	300
Internships	70	60	120	140	150	170

* 2006-07 was the transition year to the Bologna reformed LEI

Table 1 shows that labour market response to the new LEI has been positive and keeps improving. In terms of internship results, Figure 3 shows the relative frequency of Capstone Project grades (0 to 20 range). It should be noted that since 2007-08 evaluation of Capstone Projects is performed by a jury which always includes the LEI Program Director and the Capstone course manager, as well as the tutoring teacher and the internship supervisor, in order to guarantee grading comparability in the evaluation process.

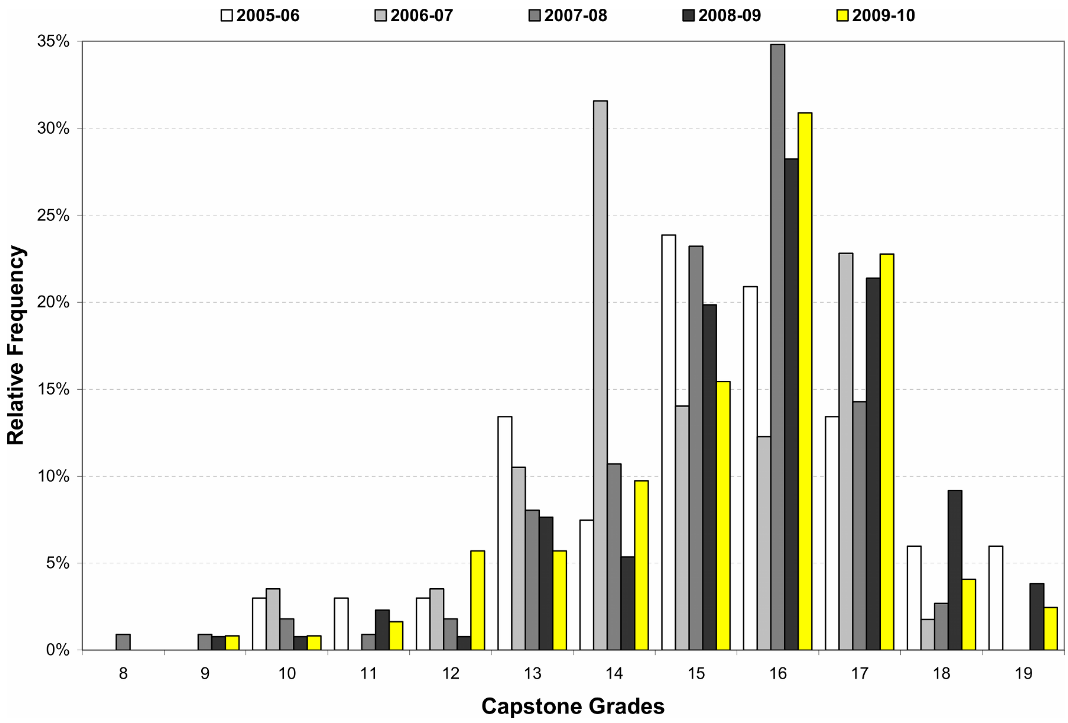

Figure 3. Relative Frequency of LEI Capstone Grades
for Academic Years 2005-06 to 2009-10

In Figure 3 we notice that, excluding 2006-07 (the transition year), grade distribution shows a clear and coherent pattern along the academic years. Figure 4 depicts how the internship supervisors evaluate a set of Capstone student skills and competence along several academic years. This evaluation is supported by a written rubric questionnaire that internship supervisors fill during Capstone/internship presentation.

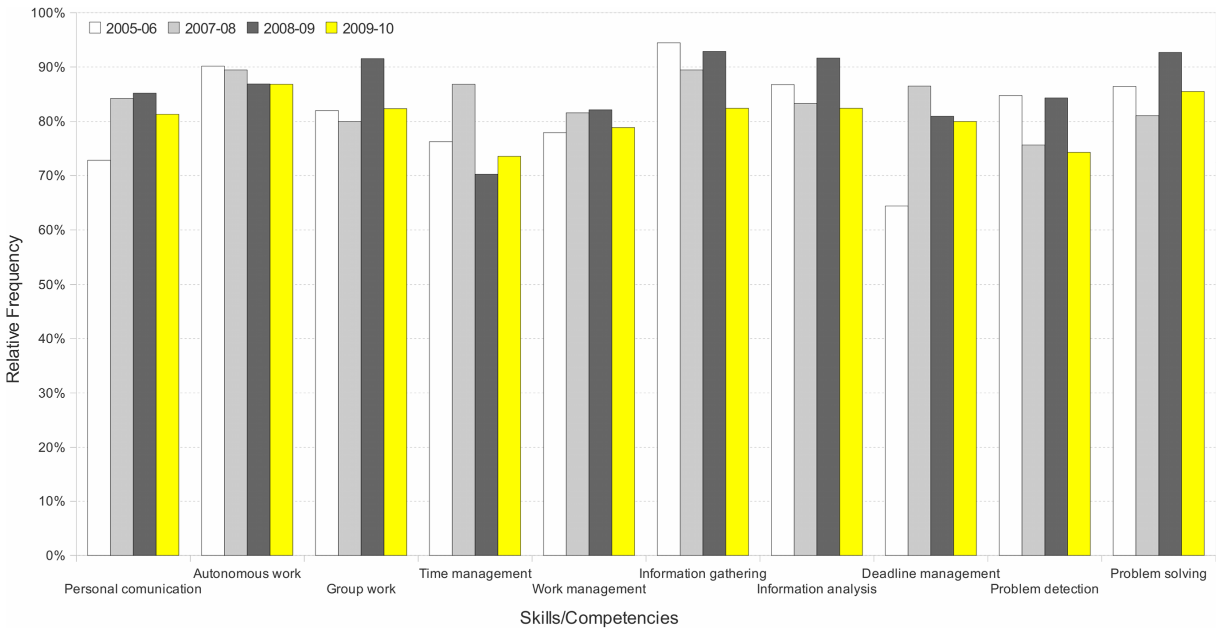

Figure 4. Student Skills/Competence evaluated from inquiries to Internship Supervisors

We observe in Figure 4 that skills and competence variation along the years is less than 20%, except for “Deadline management”, which improved in the new LEI Program. It is also important to say that employability after Capstone Project completion is almost 100%, which is mostly due to students becoming professionally integrated in the internship organization.

In late 2010, three full academic years of LEI past the 2006-07 Bologna transition, it was decided to gather information about students when entering the program and after concluding it. We already knew long ago that the “LEI Grade”, computed as a normalized sum of the ECTS weighted course grades, had low correlation with the Capstone Project grade (typically less than 0.3). Every year many students with low LEI grades managed to achieve very good Capstone Project grades, and most of the times it was quite surprising and thrilling to see how an “average student” transformed into a “very good professional”. Because we had access to placement access grades, LEI course grades and the program grade, a study was developed aiming to shed light on how that data might help understand the student transformation “phenomena”.

Figure 5 depicts the relationships between Access Grades (used for program placement), Math Grades (required final exam for informatics engineering) and LEI Capstone Project Grades (circle diameter proportional to grade).

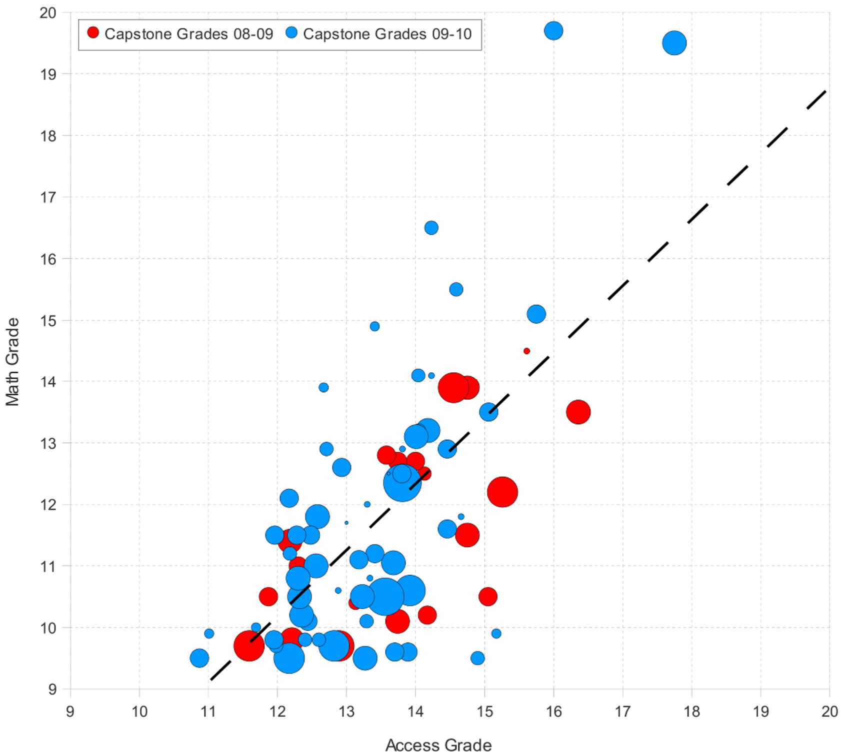

Figure 5. Access Grades versus Math Grades versus LEI Capstone Grades (sample of 100 students enrolled in 2006-08 and finishing in 2008-10)

It is clearly observed in Figure 5 that many students achieved very high Capstone Grades in spite of having low Access and Math Grades at the end of secondary school. There is also a good correlation between Access Grades and Math Grades, as it was expected (the dashed trend line).

Figure 6 relates the Access Grades (for placement), the LEI Program Grade and the LEI Capstone Project Grades (circle diameter proportional to grade). In Figure 6, Capstone Grades have almost no correlation (0.002) with Access Grades, and they have a low correlation (0.49) with LEI Program Grades. Without surprise, the dashed trend line approximates the relationship between Access Grades and LEI Program Grades (correlation 0.46).

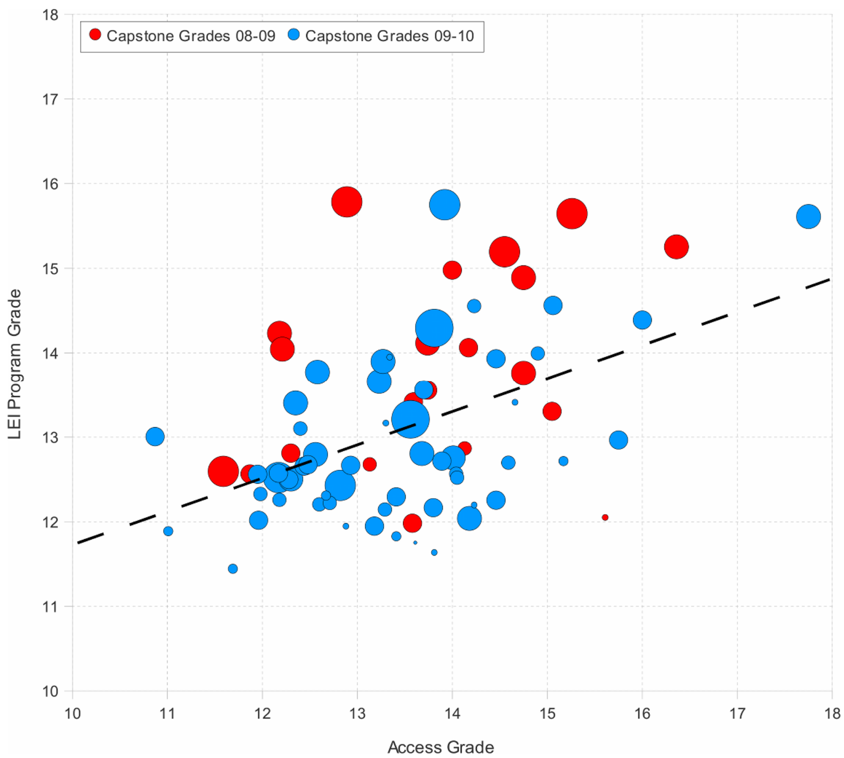

Figure 6. Access Grades versus LEI Program Grades versus Capstone Grades
(sample of 100 students enrolled in 2006-08 and finishing in 2008-10)

In synthesis, we have good reasons to believe that the LEI Program, in terms of process and product, has been improving since 2006, with many different evidences contributing and supporting this opinion. At the same time, we believe the use of a Cumulative Grade Point Average approach [3] to characterize the LEI product (program graduates) is not suitable to describe the "quality" of those graduates. Because a Cumulative Grade Point Average grade is just a number resulting from the amalgamation of lots of other numbers, it is not able to efficiently describe any kind of proficiency whatsoever. As such, a better alternative has to be found so that external stakeholders, especially employers, can easily differentiate the graduates and quickly identify the ones most suited to some specific type of work.

A CDIO INSPIRED GRADING SYSTEM FOR THE LEI PROGRAM

Aiming to better describe student's knowledge, skills and competences using the Syllabus as a reference, in the search for an alternative to the current LEI cumulative grade point average system two main alternatives were identified:

- Learning process based, i.e. describing the student's proficiency in each of the program's learning processes;
- Category based, i.e. describing the student's proficiency in each of the Syllabus' areas/categories.

Curriculum as a Set of Learning Processes

"*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 implied in CDIO Standard 3, a program must have one or more learning processes (ordered sets of interrelated courses), which provide the student with a set of well-defined skills. The process final outcomes are a subset of the program Syllabus.

Typically the course is the basic entity in the process and a course may belong to several processes. A course has a set of outcomes, which are used for student assessment, and some of those 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 effects of each course on the student. In fact, it is quite the opposite: a program should be designed in order to provide the student with an integrated learning experience in which the final result should be more than the sum of the parts. The experiential learning model [4], which is the foundation of CDIO, is an example of this: the concrete experiences in design-implement experiences deeply affect the way students learn in the following courses.

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 a client of the preceding one and a server to the next. The "fitness for use" [5] of the student in one of the process course, fulfilling the courses pre-requisites in terms of real student skills, is directly related to the process quality up to that point. The identification of learning processes is clearly program dependent. Three learning processes were identified in LEI, as depicted in Figure 7:

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

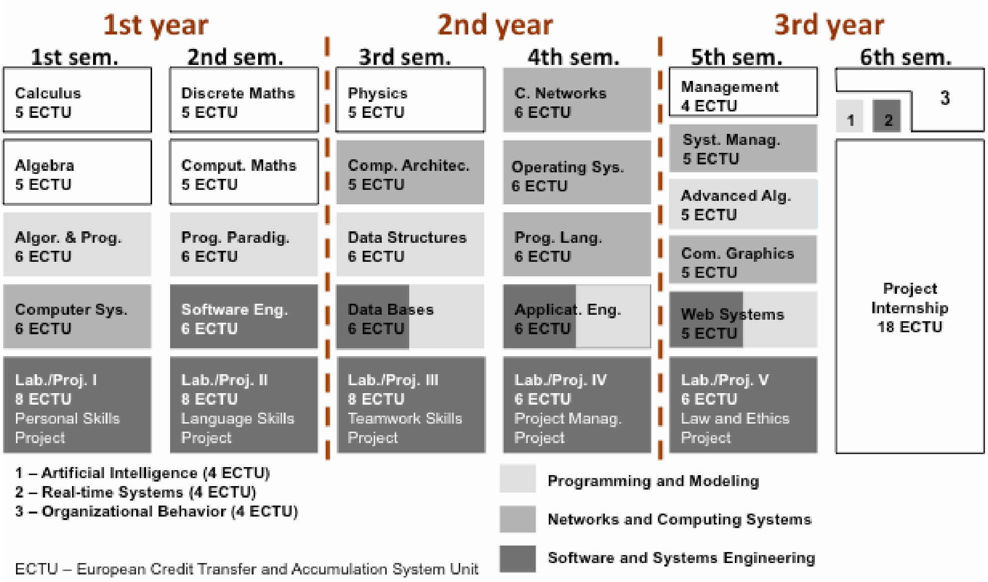

Figure 7. The three LEI learning processes

As shown in Figure 7, some courses belong to more than a process and there are eight courses that are not included in any process. One is the Capstone Project/Internship; the others are the 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.

To grade the graduate's proficiency in each of the three learning processes one could compute the average grade of each process courses and present them in a qualitative scale. But the real question is: does this provide a reasonable estimate of the graduate's knowledge and skills? We do not think so. A process is an important abstraction for quality control within the program [6], but the product's "final quality" is more complex than the proficiency in the several processes' courses. Another issue is that the Capstone Project is not included in any process and employers often regard it as a very relevant benchmarking tool, even more important than the program's cumulative grade point average.

Curriculum Mapping to a Set of CDIO Inspired Categories of Outcomes

The LEI curriculum has three types of courses:

- Standard, i.e. 12 to 16 weeks course with lectures and lab classes. The assessment usually includes some practical work and a final exam. Subjects range from Math and Physics to Management and Informatics related subjects.
- Lab/Project, i.e. 4 weeks intensive design-build team experience at the end of the semester. Each course also includes a 16 to 20 hours soft-skills module, as shown in Figure 7.
- Capstone Project, i.e. 20 to 30 weeks Project with internship in some organization or a R&D unit.

There is an "official" mapping between these courses' outcomes and the LEI Syllabus, thus one could select the four Syllabus categories as the base for a grading system. Unfortunately, although the mapping is quite good in category 1 (Technical Knowledge and Reasoning), it is far from perfect in categories 2 and 3 (Personal, Interpersonal and Professional Skills and Attributes). Nevertheless, there is a quite good match between the Lab/Project courses plus Capstone Project and category 4 (Engineering Skills, Attributes and Competence).

Fortunately, the European Qualifications Framework (EQF) offers a way to overcome this mapping problem by using three categories of learning outcomes [7]:

- "Knowledge", meaning the outcome of the assimilation of information through learning, where knowledge is the body of facts, principles, theories and practices that is related to a field of work or study. In the context of EQF, knowledge is described as theoretical and/or factual.
- "Skills", meaning the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of EQF, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments).
- "Competence", meaning the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of EQF, competence is described in terms of responsibility and autonomy.

Mapping the LEI Curriculum and the three EQF categories of learning outcomes at level 6 (corresponding to the 1st cycle Bologna qualification) was not a simple task, considering what is required at level 6:

- "Knowledge" – *Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles*.
- "Skills" – *Advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialised field of work or study*.
- "Competences" – *Manage complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts. Take responsibility for managing professional development of individuals and groups*.

Also, there is little to gain from designing a complex mapping between the courses and the three categories. The more straightforward the mapping is, the better it will be understood by employers and graduates. Therefore, we propose the following mapping:

- **Knowledge**: the standard courses, as they are most related to scientific, technical and factual knowledge.
- **Skills**: the Lab/Project courses, as they were designed to provide the students with real engineering skills which they were not able to fully develop in standard courses. Also the personal skills modules and the Organizational Behaviour course fit quite well in this category.
- **Competence**: the Capstone Project, being the course where students are most challenged in terms of realistic professional activity. The Lab/Project courses could also contribute to this category but, as explained before, employers already use the Capstone Project grade as benchmark, so it is reasonable to keep it in a separate category.

Descriptor Based Grading System for LEI Graduates and Employers

Having established the methodology for mapping LEI courses' results and the three EQF based categories, it was decided that a descriptor based solution was the most adequate way to transmit the relevant information in a simple and effective way. As such, an "A-D" qualitative scale was chosen, where A is "Excellent", B is "Very Good", C is "Good" and D is "Sufficient".

The method for determining the qualitative grades for each category is briefly explained:

1. For each of the three categories, a cumulative grade point average is computed using the corresponding courses' grades and the ECTS curricular weights, producing a numerical value in the 10-20 range.
2. Because readability and comparability is very important for employers, it was decided not to use annual percentage quotas to convert from the 10-20 range to the A-D scale (e.g., the 10% best values in each category get an A). Therefore, we had to define numerical thresholds to convert the numbers to the A-D scale.
3. To compute those thresholds (which are very program specific) we resorted to the sample of 100 graduates used to produce Figure 5 and Figure 6. One of our goals was to keep the number of A's no bigger than 10%, so choosing an appropriate A threshold in each of three categories was critical. After having defined the A thresholds, the B/C/D thresholds were easier to determine. Finally, by a detailed analysis of the 10-20 categorical results we were able to define the remaining thresholds and then proceed to the qualitative mapping phase, whose global results are shown in Table 2.

Table 2
Grade/Category distribution results for the 2008-09 and 2009-10 LEI Graduates

Grade	Competence	Skills	Knowledge
A – Excellent	11%	11%	5%
B – Very Good	54%	25%	25%
C – Good	25%	59%	54%
D – Sufficient	10%	5%	16%

4. For each graduate in the sample its corresponding qualitative proficiency level in the Knowledge, Skills and Competence categories was determined and a global list produced for further analysis and review.
5. After some threshold tuning the final grading list was produced, from which Figure 8 was derived.

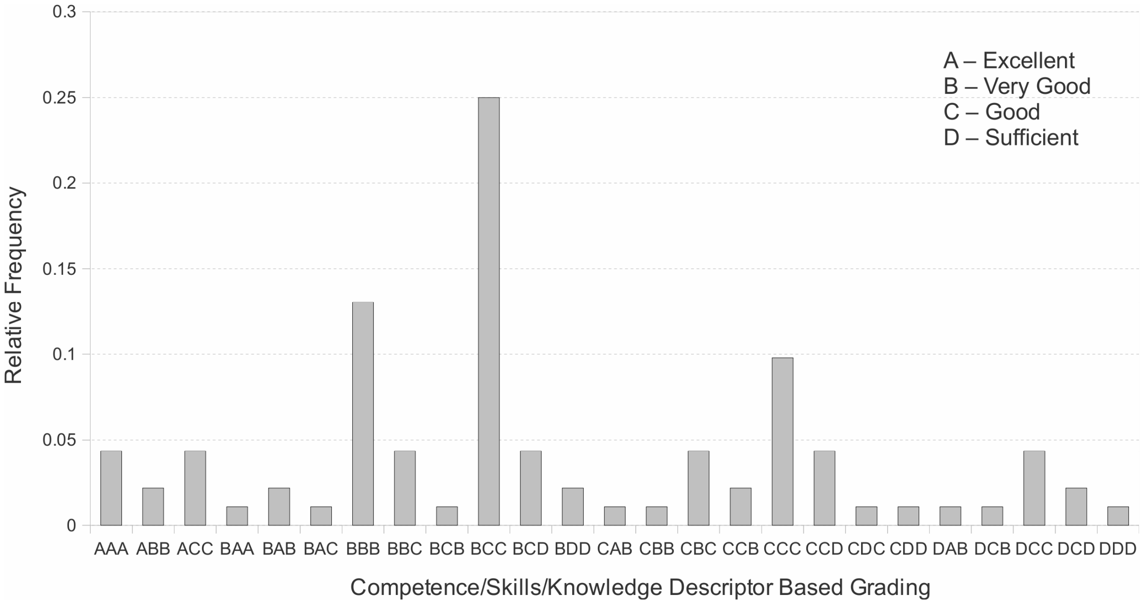

Figure 8. Descriptor based grading for 2008-09 and 2009-10 LEI Graduates

Analysing Figure 8, in which each three letter group represents (from left to right) the grading in Competence/Skills/Knowledge, we find 25 of the 64 possible grading combinations with the following grading peaks (stereotypes):

- BCC: very good in Competence, good in Skills, good in Knowledge;
- BBB: very good in Competence, very good in Skills, very good in Knowledge;
- CCC: good in Competence, good in Skills, good in Knowledge.

It is also worth mentioning that 11% of LEI graduates have “excellent competence”, but on the counterpart 16% only have “sufficient knowledge”.

CONCLUSIONS

This paper is a first attempt to grade not only knowledge and expertise acquired and practiced during engineering education, but also personal, vocational and societal aspects mainly related to skills and competence. The proposed descriptor based grading system aims to address and answer important issues known for many years (at least in Portugal):

- The “knowledge” oriented cumulative grading point average method, typically used to rank engineering graduates, is too much simplistic and even misleading, because it ignores that engineering is much more than “knowing things”;
- An engineering graduate has many non-knowledge related facets and some of them are very important for employers and other societal agents, but information about those facets is not officially available or endorsed by HEIs;
- Most employers disregard the “program grade” as an indicator of engineering quality, because it amalgamates things which are not comparable, and look for extra information about the graduates by email, phone, etc;
- The Capstone Project is prone to environmental factors that can affect the course grade. As such, it is not suitable to qualitatively describe all aspects of engineering proficiency.

The proposed descriptor based grading system may be seen as a natural consequence of CDIO adoption and its extensive use at the LEI Program in ISEP, but it needs to be verified and validated by external stakeholders and employers, looking for potential improvements. If this descriptor based grading approach is found useful, we foresee that the grading classification may be included in the Diploma Supplement [8].

Despite its flexibility, the proposed grading system must be used with care, especially by employers. If an employer knows what it is looking for, a system like the proposed one may be very useful. Let us consider three examples of employer needs in terms of Figure 8:

- Graduate with a "scientific emphasis": look for profiles like **A or **B (e.g. DAB).
- Graduate with a "customer contact emphasis": look for profiles like *A* or *B* (e.g. CAB).
- Graduate with a "development emphasis": look for profiles like A** or B** (e.g. ACC).

The proposed grading system has been able to identify a few relevant "graduate stereotypes" (Figure 8) which seem to be in good accordance with the personal experience of ISEP and LEI managers. Having such a small set of significant graduate stereotypes, if confirmed by external stakeholders and organizational leaders, may be used to fine tune the LEI Program and increase its "productivity".

Finally, although it is possible to develop a more complex and granular system, we think that too much complexity and information may lead to a less useful grading system, in which high level trends and "phenomena" may be difficult to identify…

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