ENGAGING INDUSTRY WITH ACADEMIC PROGRAMMES – A MASTER'S PROGRAMME IN EMBEDDED SYSTEMS

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ABSTRACT

The commitment of academia with the external environment, namely the industry, is in many countries, such as Portugal, practically inexistent. Within the Portuguese higher education dual system, polytechnic institutions still offer the best scenario in industry-academia relations, although resuming almost exclusively to the placement of students in an industrial environment. This scenario is still insufficient to accomplish the task of developing employable graduates with advanced technical skills and practical know-how.

The Engineering School of the Polytechnic Institute of Coimbra has recently proposed a new Master's Programme in Embedded Systems with the peculiarity of being build in a close partnership with four local companies, which includes programme definition, management, quality assurance, lecturing, financing, workspace preparation, and students support.

KEYWORDS

Master Programme, Academia-Industry Cooperation, Embedded Systems, Curriculum Development, CDIO

INTRODUCTION

Academia-Industry cooperation is regarded as fundamental to build a strong and competitive economy in developed countries. This cooperation is, in many cases, limited to internship programmes for last-year students or graduates; learning outcomes and syllabus contents are usually the exclusive responsibility of faculty members. In some cases, when asked to, industry experts may advice in short and vague terms to academia requests to programme definition or required student skills.

This is an often experience for programme definitions in Portugal, where the implementation of most engineering programmes lack the participation of industrial partners. A report from the Organisation for Economic Co-operation and Development (OECD) [1] regarding the tertiary education in Portugal referred the general disengagement of the academia with the community and business. The results from this report were acknowledged by all partners in Portuguese academic and industrial community, recognizing the importance of cooperation by all stakeholders for the quality of the programmes, namely in Business and Engineering areas.

Some Professors from the Engineering School of the Polytechnic Institute of Coimbra, Portugal (ISEC), with close contacts to local companies in joint R&D projects and/or consulting, became aware of the companies' difficulties in hiring qualified people. These difficulties became especially relevant in some critical areas, where skilled professionals are rare. One of these areas is the development and validation of embedded systems. The importance of this area is enhanced by the number and relevance of the projects they actually have funded by the European Framework Programmes or the European Space Agency. This lack of qualified personnel regards not only technical aspects but also soft skills. This situation triggered the idea of building a master programme able at producing skilled engineers in embedded systems.

This paper presents a recent proposal of a new Master's programme in Embedded Systems (MES). It is the result of a very close cooperation between ISEC, and four local companies, Critical Software [2], ISA [3], Active Space [4] and WIT Software [5], which are the most relevant companies of the region in this field. The core businesses of all of these companies are technological-based and represent an important portion of Portuguese high-valued exports.

A thorough work was made both by instructors from ISEC and experts from these companies resulting in a strong commitment to the elaboration of a programme in embedded systems, fulfilling not only the companies' declared needs, but also maintaining a generic nature allowing future partners. This programme has been accepted by the Portuguese Ministry, and will start next academic year 2010/2011.

This paper is organized as follows: it starts by introducing the rationale behind the creation of a new programme in embedded systems, and then describes the main approaches for attracting the industry into a commitment with such a programme. The programme structure and characteristics is then presented, followed by a description of how the programme relates to CDIO standards. The paper ends by pointing some future work.

ATTRACTING INDUSTRIAL PARTNERS

In order to have qualified professionals aimed at positively responding to demanding projects, the companies follow basically two complimentary approaches: they hire experienced workers, or they hire recently graduates or students and go through a process of internal training. The first approach is expensive, as skilled professionals are difficult to attract to Portugal, but provides results in a very short time. The second approach is not as expensive because it is easier to find recently graduated professionals, but has the drawback of being risky and has a long return of investment.

We have proposed to four of the most significant companies of Coimbra's region in the area of embedded systems, a third way of getting qualified professionals, with some important benefits for all the partners. Throughout a close cooperation between the school and the companies, we have built a specialized programme from the scratch, at Master's level, able to fulfil the companies' needs by providing the students with the requested skills. Since the companies actively participate in the programme definition, quality assurance, students tutoring, and placement of the students within the companies, they will have, by the end of the programme, qualified graduates able to immediately respond to most of their projects in this area.

We have also included some more short-term benefits for the companies, which include:

- the companies' workers may have training sessions by attending some specific modules of the programme;
- some projects of the companies may be executed by the students during project-based courses.

The benefits for the school and school's mission are manifold:

- the programme gets financial support from the companies;
- the school assures employability of the graduates that are supported by the companies, provided they meet the minimum defined goals;
- the programme will have some modules conducted by professionals, where expertise does not exist within the faculty members;
- the school positively contributes for the development of the region;
- the students benefit from the diverse client portfolio owned by the industrial partners, providing a large variety of projects with a spread spectrum of technical skills.

The main objective of this partnership is thus to have the companies totally engaged with the programme, controlling its quality, and thus being co-responsible for the qualification of their future employees.

Enhancing industrial partner participation by joining new partners will reduce project's exposure to fading companies' interests and student over-specific training.

BUILDING THE MASTER'S PROGRAMME IN EMBEDDED SYSTEMS

The Master's Programme in Embedded Systems has thus been planned with the following main goal:

- To educate students with specialized knowledge in the design, build, evaluation and operation of embedded system, and with the necessary skills to perform an effective work in an industrial environment.

Defining the Context

Having in mind the goals of the programme, several decisions have been made defining a context for this programme:

- this programme mixes knowledge from Electrical and Computer Engineering. Students that enrol to this programme will mainly originate from Bachelors from these areas. There should be homogenization courses so that the fundamental knowledge of both engineering areas is assured by all the students;
- there should be one design-implement course to provide the necessary skills of design-implement experiences, in working groups, relating fundamental subjects in the associated engineering knowledge areas;
- there should be one design-implement course, where students must apply their skills in real-world projects provided by the industrial partners;
- there should be a learning workspace that may mimic an industrial environment, where students may follow the classes and work on their projects;
- the courses shall be organized in modules, such that each module may be conducted by a specialized instructor, which may originate from the academia or the industry. Each of these modules has 8 class-hours, which are scheduled for single-days;
- the modular organization of the courses shall also allow external students to attend single modules; the external students may be workers from partner companies or any other interested people;

- the partner companies shall be part of a consulting group and shall be co-responsible for the programme coordination and quality assurance;
- each student shall be tutored by one company during his entire academic path;
- the students shall spend 3/8th of the programme working on an industrial placement (this fulfils a Portuguese legislation demand).

The Master in Embedded Systems has thus been designed as a two-year programme, awarding 120 European Credits (defined through the European Credit Transfer and Accumulation System – ECTS [6]), which corresponds to a total student workload of 3120 hours (from which 1170 hours are spent in an industrial placement).

The structure of this programme is presented in Figure 1.

Year 1		Year 2	
Semester 1		**Semester 3**	
Fundam. Course 1 (5 EC)	Applied Lab 1 (15 EC)	Special. Course 1 (5 EC)	Industrial Placement (45 EC)
Fundam. Course 2 (5 EC)		Special. Course 2 (5 EC)	
Elective Course 1 (5 EC)		Elective Course 3 (5 EC)	
Semester 2		**Semester 4**	
Fundam. Course 3 (5 EC)	Applied Lab 2 (15 EC)		
Fundam. Course 4 (5 EC)			
Elective Course 2 (5 EC)			

Figure 1 – Organization of the Master's Programme in Embedded Systems

(EC – European Credits; 1 semester = 30 EC)

The first two semesters are organized around two courses based on conceive-implement strategy, named Applied Lab 1 and Applied Lab 2. In these courses students, working in groups, have to design and implement one or more project/product, based on specifications from academia and from industrial partners. A strong instructor commitment from both faculty and industrial partners should be put in place so that soft skills are taken into account. During these courses, as well as during Industrial Placement, the students will be able to practice group work, communication skills, etc.

The project or product to be designed and implemented in each semester should be closely related to the topics of the two Fundamental Courses of the same semester, aiming at applying and consolidating their topics and skills. In these two semesters the students also attend two Elective Courses, aimed at homogenizing their skills, due to their different backgrounds (mainly from the Electrical Engineering or Computer Engineering Bachelors).

In the third semester, two Specialized Courses provide topics closely related to the industrial partners' working areas, where the students shall perform their industrial placements. Another elective course allows the students to complement their education in areas where they lack of necessary knowledge or skills.

Defining Specific Learning Outcomes

In the early stages of the curriculum development, we have enquired the industrial partners about the skills they classify with the most importance for the students to acquire throughout this programme. While we asked for the identification of both engineering knowledge and personal skills and attitudes, the industrial partners only demonstrated to have strong opinions about the desired engineering skills and knowledge, but lacked the same clarity as to the personal skills and attitudes.

We have thus built a table identifying the most desired engineering skills by the industrial partners (Table 1), which was used to designing the curriculum.

Table 1 - Learning Outcomes obtained from partner's evaluation process

Learning Outcomes		**Importance**
On completion of the programme, students shall be able to:		*0-null; 1- relevant; 2-fundamental*
1	Program systems at different levels, from object-oriented to assembly.	2.0
2	Analyse, design, program and evaluate real-time applications with timing and spatial constraints, using software engineering best practices.	1.8
3	Model, design, program, synthesize, simulate, assemble, test, and debug systems with programmable logic devices.	1.4
4	Know, evaluate, and adapt at functional and structural level operating system kernels, including real-time kernels.	1.4
5	Use techniques for the implementation, development, verification and validation of embedded systems, according to standards.	1.4
6	Know, evaluate and apply different types of sensors and actuators used in embedded systems.	1.2
7	Design, produce, assemble, test and debug digital circuit boards.	1.0
8	Know and evaluate architectural details of modern microprocessors and associated units, such as buses, memories, mass storage devices, and input/output devices.	1.0
9	Know, evaluate and apply different communication medias and standards, wired or wireless, internal or external to embedded systems.	1.0
10	Analyse, design, program and evaluate applications for mobile devices (PDA and cell phones).	1.0
11	Analyse, design, simulate and test digital control systems.	1.0
12	Understand the behaviour of digital and analogue electronic systems under faults, and apply test and verification techniques.	0.8
13	Use basic concepts of industrial vision.	0.8

Designing the Curriculum

The context and the learning outcomes were the basis for designing the curriculum of the Master's Programme in Embedded Systems.

Each Course, or Curricular Unit, either Fundamental, Elective or Specialized, was designed as having 5 EC, divided into Modules of 1 or 2 EC. Each module of 1 EC corresponds to 10 lecturing hours plus 16 hours of self-study or work assignments, totalling 130 hours of student workload for each Course. All these courses are scheduled to the first half of the corresponding semesters, reserving the second half of the first two semesters to the Applied Lab courses. The

Industrial Placement starts at the second half of the third semester until the end of the programme.

Table 2 presents the curriculum of the MES, with the corresponding Course Types, Student Workloads and weights in terms of European Credits.

Table 2 – MES curriculum

Sem.	Course	Type	Student Workload	European Credits
1st	Real-Time Systems	Fundamental	130	5
	Electronic Systems Design	Fundamental	130	5
	Computing Architectures and Platforms	Elective	130	5
	Instrumentation and Electronics	Elective	130	5
	Applied Lab I	Lab	390	15
2nd	Embedded Systems Programming	Fundamental	130	5
	Digital Circuit Design	Fundamental	130	5
	Software Development Fundamentals	Elective	130	5
	Applied Control Systems	Elective	130	5
	Applied Lab II	Lab	390	15
3rd	Communication Systems and Smart Buildings	Specialized	130	5
	Advanced Programming	Specialized	130	5
	Systems Dependability	Specialized	130	5
	Communication Systems and Wireless Networks	Specialized	130	5
	Elective	Elective	130	5
3rd/4th	Industrial Placement	Placement	1170	45

The Bologna Process [7] within the European Higher Education Area defines generic learning outcomes for students to be awarded with Bachelor's, Master's or Doctorate's degrees. These are based on the 'Dublin' Descriptors, which indicate shared expectations about student's achievements and abilities at the end of each of the cycles of the Bologna Process.

Qualifications that signify completion of the second cycle (Master's) are awarded to students who [8]:

a) have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with Bachelor's level, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context;
b) can apply their knowledge and understanding, and problem solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study;
c) have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgements;
d) can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously;
e) have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous.

The MES curriculum was thus designed with mutually supporting disciplines for integrating all the skills defined by both the 'Dublin' Descriptors and the specific learning outcomes identified by the industrial partners. This demonstration is resumed in Table 3.

Table 3 – MES integrated curriculum demonstration

Matrix demonstrating the acquisition of generic and specific competences.	**Year 1**	Real-Time Systems	Electronic Systems Design	Instrumentation and Electronics	Computing Architectures and Platforms	Applied Lab I	Embedded Systems Programming	Digital Circuit Design	Software Development Fundamentals	Applied Control Systems	Applied Lab II	**Year 2**	Communication Systems and Smart Buildings	Advanced Programming	Systems Dependability	Communication Systems and Wireless Networks	Industrial Placement
Generic Competences (Dublin Descriptors)																	
a) demonstrate knowledge and understanding		3	3	3	3	3	3	3	3	3	3		3	3	3	3	3
b) apply knowledge and understanding		3	3	3	3	3	3	3	3	3	3		3	3	3	3	3
c) integrate knowledge, handle complexity, formulate judgements		3	2	2	2	3	3	3	1	2	3		2	2	3	2	3
d) communicate conclusions, knowledge and rationale		1	1	1	1	3	1	1	2	2	3		1	2	1	1	3
e) continue to study in self-directed or autonomous way		1	1	1	1	3	1	1	1	1	3		1	1	1	1	3
Specific Competences (Identified by Industrial Partners)																	
1. System programming		3	2		2	A	3	2	3	3	A		3	3		3	A
2. Real-time applications		3				A	2		2		A			2	2		A
3. Programmable logic devices.					2	A	2	3			A						A
4. Operating system kernels.		3			2	A	3	1			A						A
5. Embedded systems standards.			1	1		A		2			A				3		A
6. Sensors and actuators.			3	3		A					A		2			2	A
7. Digital circuit boards.			3	2		A					A		2			2	A
8. Microprocessors architecture.			1		3	A		2			A						A
9. Communication medias and standards.			2			A					A		3			3	A
10. Applications for mobile devices.						A					A			2			A
11. Digital control systems.						A				3	A				2		A
12. Faults, test and verification techniques.			2			A		2			A				3		A
13. Industrial vision.						A				2	A						A

1 – Introduced in the Course, but is not part of the students' assessment.
2 – Addressed in the Course, and may be part of students' assessment.
3 – Covered by the Course, included in course learning outcomes, and is part of the students' assessment.
A – May be covered by the Course, depending on the projects.

DOCUMENTING CDIO STANDARDS

The Master Programme in Embedded Systems was designed from scratch having in mind the CDIO principles for teaching engineering. The programme structure is thought to favour long project implementation periods allowing students to go through all the conceive-design-implement-operate steps. Also team work is favoured by the Applied Lab and Industrial Placement structure. The teams should include instructors, industrial partner's advisers as well as first and second year students. Students should develop technical, personal and interpersonal skills to implement a system or product taking into account client characteristics but also system's implementations and operational environmental consequences.

During first year Applied Lab, assignments and projects will have several components to conceive-implement embedded systems. Students should be able describe and present their projects. The second year Industrial Placement will allow students to operate complex systems as they will be themselves *embedded* in an industrial environment that will require their work. To achieve this goal industrial partners assumed the compromise to provide students with projects for both first year Applied Lab and second year Industrial Placement.

A strong engagement with industrial partners is the main aspect of this programme; industrial partners are part of the coordinating board of the programme. From the industrial partners stand point, evaluating the programme results is of major importance; a set of evaluating tools must therefore be developed.

So far both instructors and industrial partners have developed a curriculum based on a set of skills identified through the responses to a questionnaire. This small syllabus is clearly insufficient to promote an effective evaluation of the programme. Evaluating the graduate's achievements, the instructor's capabilities and also the industrial partner's commitment requires a more detailed list of topics that can be valued and ultimately transformed in a full evaluation process. A detailed syllabus is therefore required and must be implemented.

The required syllabus has a few particularities that directly relate to this programme. The MES is a Master's level programme that recruits students from Bachelor's level programmes, which were developed in a most traditional way. We cannot therefore control some basic knowledge of underlying sciences and core engineering fundamentals.

The design-implement activities will take place in a specially equipped workplace. An Embedded Systems Laboratory is currently being equipped in accordance with the courses needs, providing a physical workspace specially designed for this programme.

The change process necessary to enhance faculty skills and teaching competences is still in its very early stages.

Some of the key success factors identified by the CDIO standards, such as the faculty recognition and incentives, a culture of faculty learning, student expectations and academic requirements are not yet in place. Within the group of instructors of this master's programme there is however a clear recognition that a different programme culture is being built and about half of the instructors have a close link to the industrial partners.

Table 4 summarises CDIO adoption status by the MES programme.

Table 4 – CDIO Standard adoption status

Standard	Adoption Status
1. The Context	Inherent to programme structure. All students will be able to Conceive, Design, implement and Operate a set of embedded systems.
2. Learning Outcomes	Development of technical learning outcome syllabus well advanced. Personal and interpersonal skills currently under discussion.
3. Integrated Curriculum	Programme structure inherently requires mutually supporting disciplinary courses. All structures are put together in the Applied Lab and Industrial Placement courses.
4. Introduction to Engineering	The MES is second cycle programme. All basic engineering practices are assumed as acquired. Nevertheless, the Applied Lab I course reinforces these practices.
5. Design-Implement Experiences	First year Applied Lab courses will provide basic level design experiences and Industrial Placement will provide system operation experience.
6. Engineering Workspaces	A dedicated workplace is being implemented. This facility will provide a place for hands-on learning of product, process, and system building.
7. Integrated Learning Experiences	The programme structure favours the acquisition of disciplinary knowledge as well as personal and interpersonal skills. Detailed syllabus should provide a work plan for each student.
8. Active Learning	Programme structure and Applied Lab provide a basis for active learning experiences. However, these are not yet defined or planned.
9. Enhancement of Faculty Skills Competence	Several instructors have close links to the industrial partners. More actions are being planned.
10. Enhancement of Faculty Teaching Competence	In the early stages of implementation.
11. Learning Assessment	Assessment methods matched with learning outcomes are being defined.
12. Programme Evaluation	An evaluation process is in the early stages of development.

CONCLUSIONS AND FUTURE STEPS

This Master in Embedded Systems is a unique programme in the Portuguese context, aiming at a close relation between Academia and the Industry regarding the education of their future employees. The first step has been successfully achieved, by having the programme formalized and accepted by the Portuguese Ministry. The start of the programme is targeted for academic year 2010/2011.

The next steps regard the elaboration of the programme regulations, detailed learning outcomes and contents of the subjects, staff preparation, fund raising, setup of a laboratory, and students' recruitment. Along with these initiatives, the course is also engaged in a process of joining the CDIO initiative.

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