Embedded Programming Bootcamp for Career Change

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***Abstract*— It is necessary to foster collaborations between academy and industrial partners, so that the set of skills and competences gained by the students are aligned with the needs of industry. Also, some areas are traditionally of scarce availability in the workforce market. One such area is embedded systems programming, due to the multidisciplinary nature of the required skills.**

To meet these challenges, a team of Electrical and Computer Science professors from ISEC collaborated with representants of industry to design and offer an intensive course (daylong classes during 6 months) with a narrow focus on embedded systems programming. Paid internships in several industrial partners are available to all students that successfully complete the course. The second edition of the course has recently concluded, with employers reporting students have met or exceeded expectations.

I. INTRODUCTION

According to the World Economic Forum [1], Developers are among the 8 most employed professions in 2020. Among programmers, it is possible to identify a particular group that is dedicated to developing integrated software (embedded software) in most modern electronic devices. These devices include home appliances, medical devices, automobiles, networking devices, industrial controllers, as well as the myriad of devices of the Internet of Things. Within the Information and Communications Technologies (ICT) area, the embedded/electronic systems' sector is the fastest growing worldwide - in fact, nowadays over 98% of existing microprocessors are embedded in the systems they control [2]. The fast growth of this sector is creating an exciting atmosphere, pushing companies to respond to an ever growing demand, and therefore forcing them to hire more employees.

On the other side, all the changes in the world economy, reflected in the recent economic crisis, created a large number of new unemployed people, with experience and excellent working skills in sectors with descending demand. These individuals, either unemployed or dissatisfied with their current situation, may be converted to help address the needs of companies operating in the TICE sectors.

Some instructors of ISEC (the Engineering Institute of the Polytechnic of Coimbra) with close contacts to local companies in joint R&D projects and/or consulting, became aware of the huge difficulties that these companies have in hiring qualified people. These difficulties became especially relevant for some critical areas, where skilled professionals are rare. One of these areas is the development of embedded systems. The relevance of embedded systems is enhanced by the number and importance of these companies projects funded by the European Framework Programmes or European Space Agency. This lack of qualification relates not only to technical aspects but also on soft skills. The "Apostar em TI" programme was then created by ISEC and the training department of Critical Software (an international information systems and software company, headquartered in Coimbra) to solve the problems of both the companies and the people looking to opportunities in the embedded systems programming area.

The "Apostar em TI" is aimed at individuals who have at least been enrolled in an undergraduate programme, have full availability, and are highly motivated to reconvert their careers and their lives, learning how to program for embedded systems.

The approach followed is based on intensive, highly practical academic part at ISEC, addressing Programming and Embedded Systems, followed by a paid internship in one of the partner companies. Until this day, 13 companies have joined the programme, guaranteeing an internship to all the students that successfully finished the 20-week training. The scientific and pedagogical coordination of the training is the responsibility of ISEC.

The "Apostar em TI" applicants are subject to a demanding recruitment and selection process by both ISEC and Critical Software HR department. During this process, those who have good logical thinking skills, good mathematical bases and high motivation to complete the program are selected.

In short, the "Apostar em TI" programme main goals are:

- to promote the professional requalification of people with strong ability for the areas of STEM (Science, Technology, Engineering, and Mathematics) and highly motivated to redefine their career path;
- to respond to the needs of companies in the ICT areas, in particular in embedded system programming;
- train professionals that will be capable of:
  - working autonomously or as a team, in a committed, proactive and professional way;
  - creating effective problem solving strategies using C and C ++ programming languages;
  - understanding the basic architecture of microprocessors as well as the logic circuits and interfaces associated with embedded systems;
  - understanding the operation of real-time systems.

The first edition of this programme is completed, and the second edition has completed the academic part. The results so far are very positive and very promising for future editions.

II. Program description

This program is developed in two phases:

1) Academic Phase to be held at ISEC's premises:
   - duration of 20 weeks, between February and July lecture of 200 hours of theoretical-practical classes by ISEC teachers 300 hour tutorial training by teachers and monitors
   - execution of a 3 weeks final project
   - presentation of workshops from partner companies and other guests
2) Professional Internship Phase, to be held in one partner company:
   - duration of 9 months, between September and June
   - paid professional internship
   - supervision by ISEC teachers

The pedagogical approach is essentially based on practical training, with exposition based on examples and case studies and on daily practical work. During the academic phase, students have a weekly average of 12 hours of classes and 15 hours of tutorial support. The minimum workload expected from students is of 36 hours per week, summing a total of 720 hours of effort, corresponding to 28 ECTS credits.

This is not a degree conferring course. However, trainees who successfully complete the academic phase will be awarded a diploma by ISEC.

The evaluation of the trainees is essentially continuous, based on the quality of the work developed and presented. Each assignment has a set of deliverables that are immediately evaluated, promoting continuous improvement. A dedicated classroom is devoted to this programme, so that the students may remain for as long as necessary to carry out their work. This creates an important collaborative as well as competitive working environment. All necessary devices, instruments and bibliography are provided by ISEC, however, each student should have their own laptop. The Embedded Systems early training is based on 8051 boards and STM32 for the advanced part of the course. A number of external peripherals such as Inertial Measurement Units and Led Arrays have been used to interface both processors.

Two areas of expertise are addressed: Programming (fundamentally C language, with some notions of Software Life Cycle and C++) and Embedded Systems (Digital Systems, Computer Architecture and Organisation, Interfaces and Communication, Real-Time Systems). Tables I and II detail the programme contents. The complementary internship training guarantees that students achieve a full integration with the programming activities required by the partner companies.

The final part of the programme consists on the development of an embedded system project, by teams of two students. Each project is based on two STM32F769-Discovery boards, communicating between them by serial port or radio frequency. In all projects a graphic interface for the LCD is developed, as well as access to a set of peripherals with I2C and / or SPI interfaces. All projects write their results and information collected to an SD card. Some examples of the proposed projects are as follows:

- Project 1 - Mars landing rover
  In this project two STM32F769-Discovery boards were used to develop a computer game that simulates the Mars Landing Rover spacecraft. The game implements the physical movement system simulation of the bodies subjected to a certain gravitational force. In this context one of the boards simulates the game and receives data from a joystick, the other board executes the graphic game mode. Each board has a radio frequency module and the sending card also has a joystick with a digital or analogue interface.
- Project 2 - Space Invaders

C Programming	C++ Programming	Software Development
• C programs generic structure • Expressions, Operators and Variables • Binary selection and operators • Cycles and functions • Strings and vectors • Memory arrays • Pointers • Data structures • Dynamic memory and memory management • Lists • Binary and text files	• Data abstraction • Classes and objects • Encapsulation • Operators • Composio e agregao • Dynamic memory objects • Heritage • Polymorphism	• Version management Git • Unity tests

TABLE I
PROGRAMMING COMPONENT OF THE "APOSTAR EM TI".

Digital Electronics	Computer Architecture	Interfaces and Communications
• Binary, hexadecimal and decimal numbering • Logic gates • Logic operators and Boolean algebra • Introduction to Flip-Flops and logic circuits • Basic notion of electricity • Ohms' Law, voltage and current	• embedded Systems characteristics • Introduction to microprocessors • Software/hardware interaction • RISC processors notions • Memory hierarchy • Memory organisation • Interrupt vs pooling	• Synchronous and asynchronous communications • SPI and I2C Interfaces • RS232 communications • Data acquisition, sensors and actuators • controllers • Analogue data acquisition • On/Off and inertial sensors

TABLE II
EMBEDDED SYSTEMS COMPONENT OF THE "APOSTAR EM TI".

In this project two STM32F769-Discovery boards are used to implement Atari's famous game "Space Invaders. The game was implemented in 1 vs 1 where each player uses an STM board for its interface. The game is played on both boards simultaneously and game state communications are implemented with serial port. On both boards it is necessary to program a graphical interface on an LCD as well as to obtain data from an analogue or SPI joystick.

- Project 3 - "Health Kiosk"
  Objective of this project is to develop a system that is able to measure the weight and height of an individual, as well as their heart rate using a photoplethysmograph. The system collects data from a MAX30100 (I2C) sensor that enables you to obtain, after processing, the heart rate. The system further implements control of a differential amplifier (XR10910) with an I2C interface to obtain data from a bridge-mounted load cell array.
- Project 4 - "Arkanoid Game"
  In this project two STM32F769-Discovery boards are used to implement the famous Arkanoid game. In this implementation game control is performed on one of the STM boards while being shown on the LCD of the other board. Player position data is obtained from an inertial unit of measurement (MPU9250) which allows the tilt of the control board to be obtained. The command data is sent by radio frequency using an nRF24L01.

III. Candidate profile and selection

For the purpose of course marketing and candidate selection, we resorted to the help of a company specialising in Human Resources management, with an history of close collaboration with some of our industrial partners. This experience was leveraged for the benefit of the our candidate selection process.

Due to the nature of the course, the candidates are not required to be knowledgeable in the relevant topics. We aim to select candidates that are highly motivated, have a clear understanding of the course objectives and goals, demonstrate logical reasoning capabilities, have good interpersonal and social skills and can commit full time to the course. Previous frequency of college-level education is required, although candidates are not required to have completed a course.

After an initial period of publicity and marketing, candidate applications were received and the candidate selection process ensued, following these steps:

1) *CV Screening:* An initial CV screening eliminates candidates that do not meet the course requirements.
2) *Telephonic Interview:* A brief phone call interveiew allows clarification of candidate profile and motivation, allowing further pruning of the candidate pool.
3) *Testing and Interview:* Selected candidates are invited for a session of psycho-technical tests, team exercises, and face-to-face interview with a HR (Human Resources) specialist and a professor associated with the course. In these tests and interviews, candidate capabilities, motivation and expectations are assessed. Candidates may also understand what is expected of them, in case they are selected.

After the first two selection steps (CV screening and telephonic interview) the pool of eligible candidates was down to 48 and 54 in the 1^{st} and 2^{nd} edition, respectively . The best candidates among these are selected to form a single class of 20 up to 24 students. Figures 1 and 2 illustrate the profile of the candidates actually selected for the 1^{st} and 2^{nd} Editions of the course. Age of students ranges from 22 up to 42 years old. The student background is clearly very diverse. It can be observed that most students do not have a prior background in topics related to embedded systems programming, nor, in fact, any engineering background at all.

IV. Program results

At this point the first edition of the programme is complete, and the second edition completed the academic phase. This allows us two extract useful information about the lesson management and student performance, and obtain some insights for future editions.

The lessons and scheduling of the subjects of the course were carefully thought and planned, with the close participation of the partner companies. We decided to always have two subjects being taught at the same time, meaning lessons related with Programming and with Embedded Systems were interleaved during the week. This was aimed at preventing excessive impermeability across topics. Interleaving two topics would allow students to better relate them and think how one could be used with the other.

In each day only one topic was addressed. There were some slight differences in the day organisation across the two editions. In the first edition, each day was organised into three parts: during the morning the lesson was basically theoretical. In the afternoon, the first two hours (it could vary from one day to the other) was devoted to exercises for practice. Then follow a set of exercises that the students had to submit for grading. This worked reasonably well. However, there was one undesired side-effect: students started to try to solve the exercises for grading before time, losing the invaluable exercises for practice. To mitigate this, the course faculty organised the exercises into a progressive larger one, so that students would not be able to complete the last part (for grading) without going through the first part (for practice) first.

Learning from the first edition experience, and to avoid over-stressing the students with and impending and daily evaluation, in the second edition we organised each day in the following manner: the morning was theoretical, as in the 1^{st} edition. During the afternoon, there were exercises for practice and students were required to submit. The submission was not for grading; instead it was a device to keep students from relaxing, and also for the monitors to examine the code and give feedback to students. To maintain students in focus and force them to keep the necessary rhythm, we needed some sort of grading to replace the daily exercises

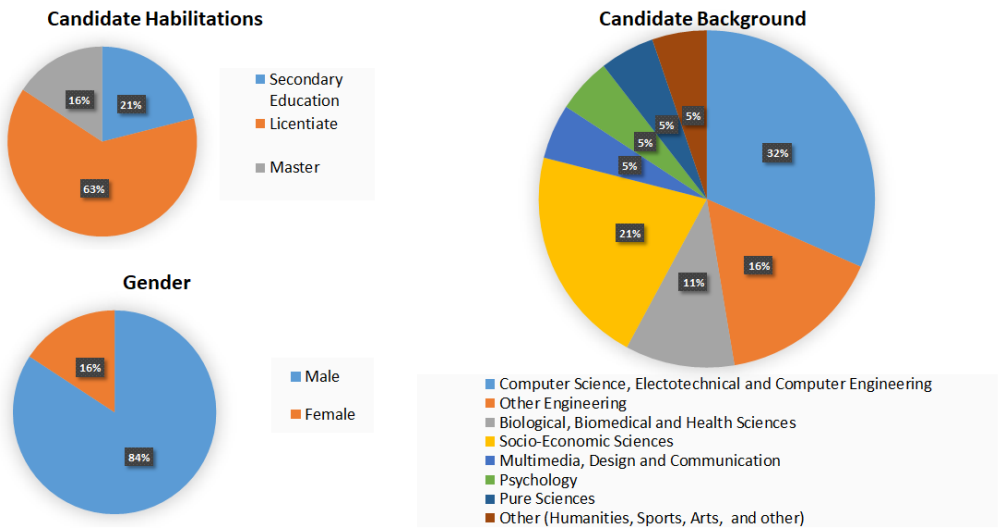

Fig. 1. Selected candidates - 1st Edition

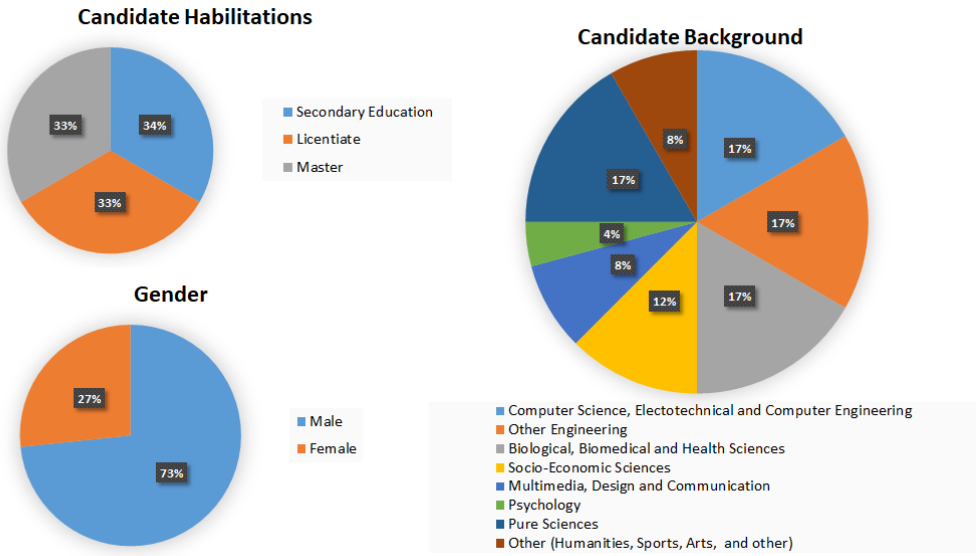

Fig. 2. Selected candidates - 2nd Edition

from the 1st edition. We introduced small/medium projects (called mini-projects) that were announced tendentiously at the end of the week and to submit either at the end of the day (after classroom time), or in a later day, depending on the size and complexity of the projects.

Grading was therefore based on three elements: daily exercises (1st edition) or mini-projects (2nd edition), periodical projects, and one large final project at the end. The daily exercises/mini-projects and periodical projects were mainly specific to one subject and the final project mixed all the subjects. The daily exercises/mini-projects were for individual solving. The periodical projects were for groups of two, as well as the final projects. Group constitution was mainly voluntary, except is some cases were the faculty noticed that some specific pairing would not work and in some cases we decided who would work with who. Generally, we would force rotation to avoid students to work with the same partner and to promote communication and team work skills.

The periodical projects were subjected to a presentation where students were required to explain and defend their solution. We experienced two difficulties in periodical project during the 2nd edition: first, it was harder to convince the students that the periodical projects were not for communal working. Students from the 2nd edition were initially very prone to sharing code and solution than students from the first, and we had to strongly emphasise that they needed to adhere to the rules regarding group constitution. We also introduced a written test at the end of the periodical projects to further emphasise that all students must work on their projects. The test was announced as being part of the project

TABLE III
PERFORMANCE OF STUDENTS IN EACH EDITION

	Enrolled	Finished	Approved
Edition 1	22	22	18
Edition 2	20	16	11

presentation.

The second problem was related to the overlapping of the larger periodical projects deadline with the following lessons. This had two effects. First, some of the presentations of the periodical projects would extend for more than one day causing student to be focused on the impending presentation and not paying attention to the class. The second problem was that students would use the time of the following lessons to solve the current mini-project and lose the subjects being taught. To solve this, the planning of the periodical projects was re-thought and we used every available break in classes (holidays, free afternoons, etc.) to minimise this issue.

Some students, in both editions, shown serious difficulties in keeping up with the subjects. Using the daily exercises and mini-projects we were able to keep an up-to-date idea of the performance and difficulties of the students. In the 1st edition we defined individual recuperation plans to those students that were showing less performance. This recuperation plan consisted on a set of materials and exercises specifically and individually tailored to each of this students. This recuperation plan involved some effort on the part of the faculty and was possible only because the course has a relatively small number of students. In the 2nd edition, instead of offering individual recuperation plans, we devised a continuous project that would allow students to incrementally use new concepts while still having the opportunity to revisit older topics and recover from remaining difficulties.

Table III presents the number of enrolled students in each edition of the programme, the number of students that finished the academic part, and the number of approvals. It is evident that the first edition was much more successful than the second, although 4 students failed to successfully complete the academic part, and therefore were not placed in the internships. The second edition had students quitting the studies, and 5 that failed. This is in part due to the capacity and motivation of the students, and maybe in part because of a mismatch between the students characteristics and the pedagogical approach. This is something to be aware of in future editions.

Considering the industrial internship, all students that finished the academic phase were placed in one of the partner companies. The feedback from students and the companies is very positive - interns were very motivated and exhibited good autonomy, requiring almost no further help from the faculty. To the best of our knowledge, from the 18 interns of the 1st edition, all are currently working:

- 2 decided to leave the company before the end of the internship, opting for other opportunities
- 3 were offered a full-time job even before the end of the internship
- 2 moved to other companies at the end of the internship
- 11 were hired by the same companies

We must stress that some of the interns were offered full-time jobs and reassigned to other, more ambitious projects before the end of the internship, which suggests that they were not only successful, but exceeded the expectations, being ready to move forward.

V. CONCLUSIONS

To the best of our knowledge, this course is a unique programme in the Portuguese context. Even though similar courses exist that promote career changes, the particular characteristic of the Embedded Systems theme make it unique in this context. It is characterised by a close relation between Academia and Industry regarding the training of their workforce. Both Academia and Industry present an active contribution to the program implementation. The first edition is now completed while the second just finished the academic phase.

The program final results relating with the two edition so far show that the program is well adapted to Industry partners requirements but a number of adjustments should be done regarding student selection and motivation.

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