Challenges and Solutions from an Embedded Programming Bootcamp

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Abstract

Due to the proliferation of IT companies developing web and mobile applications, computer programmers are in such high demand that universities can't satisfy it with newly graduated students. In response, some organisations started to create coding bootcamps, providing intensive full-time courses focused on unemployed people or individuals seeking for a career change. There is, however, a different set of skills that is becoming increasingly required, but is not addressed by those courses: embedded programming. In fact, the Internet of Things is connecting every device to the internet, thus making knowledge on hardware and C/C++ programming very relevant skills.

A group of computer science and electrical engineering university teachers, in collaboration with several industry stakeholders, have promoted an embedded systems programming course in C and C++. This course is based on an intensive project-based approach comprising 6 months of daylong classes followed by 9 months of paid internships. After two editions, thirty embedded programmers, with no relevant previous programming experience, have been placed with the partners' working force.

In this paper, the course organisation and pedagogical methodologies are described. Problems, challenges and adopted solutions are presented and analysed. We conclude that in spite of the intense rhythm and demanding nature of the subject matter, it is possible to find the structure and solutions that keep students engaged and motivated throughout the course, allowing them to gain the required competences and successfully transition into a new career path.

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1 Introduction

The increasing demand for specialised workforce in the Information Technologies (IT) industry, due to the digital transformation process that has been gradually taking place in recent years, has resulted in the shortage of highly skilled professionals. This led to the proliferation of short courses and bootcamps focusing in IT skill development, with varying degrees of success [11, 3, 10]. These courses are often concerned with web, mobile or desktop development, whereas embedded systems programming is not usually addressed. In fact, this area requires highly specialised hardware and software development skills, which can be challenging to

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acquire in the typically short time frame of these courses. However, there is a growing demand for this type of professionals, due to factors such as the digitalisation of the automotive industry and the Internet of Things (IoT). To meet this demand, a professional re-qualification course, the *Apostar em TI* (AeT) programme [1], was jointly created by a higher education (HE) institution (Coimbra Polytechnic - ISEC) and several industrial partners. The course is highly focused on the skills and competences identified as priority by the industrial partners, and is targeted at highly motivated, full-time students with previous HE experience (i.e., have at least been enrolled in an undergraduate programme). No prior IT background is required or expected.

Having now successfully completed two editions of the course, some key issues were identified and addressed. In this paper, we describe the challenges both students and staff faced, some solutions that have been applied and lessons learned, dealing with the intense and demanding rhythm, short time frame, diverse student's background and qualifications, and the relatively steep learning curve of the subject matter.

The remainder of this paper is structured as follows: Section 2 provides a description of the course. Section 3 describes the results of both editions, lessons learned and adaptations made when transitioning from the 1^{st} to the 2^{nd} edition, and employer feedback. Section 4 presents the main conclusions.

2 The Apostar em TI programme

The *Apostar em TI* (AeT) programme addresses two areas of expertise: Programming (C language [4], with some notions of Software Life Cycle [8] and C++ [9]) and Embedded Systems [5] (Digital Systems, Computer Architecture and Organization, Interfaces and Communication, Real-Time Systems). The complementary internship training guarantees that students achieve a full integration with industrial environment and practices required by the partner companies. In the next sections the AeT programme is presented.

2.1 Goals of AeT

The global market for embedded systems has evolved considerably in recent years. This includes the technology and the industries served. With the advent of IoT and Industrial IoT (IIoT), embedded systems technology has become a central facilitator for the rapidly expanding industries dealing with smart ubiquitous devices and IoT.

Professionals specialised in embedded systems are currently in high demand and most of the regional companies in this sector are actively looking for those professionals, and in many cases are unable to fulfil their needs. In fact, this scenario has specifically been pointed out by our industrial partners and is a key motivation factor for their participation in this project. On the other hand, many other areas are experiencing a decline in demand due to automation and changes in the global society aspects, e.g., Civil Engineering and Chemical Engineering. This creates a large body of professionals looking for an opportunity to change career and for courses that enable them to obtain the required new skills. Computer related engineering is currently one of the most active areas and it is no surprise that professionals from other areas are looking to change specifically to computer related professions.

In this context, one of the main goals of AeT is to offer an opportunity to candidates looking to change their careers to the IT industry. AeT offers the opportunity to acquire the required skills and support for initial placement in the industrial partners. The other goal is to meet the industry needs for IT experts by providing new professionals with the skills in demand.

2.2 Learning outcomes

This course aims at training students into understanding C and C++ programming concepts as well as Embedded Systems usage and implementation mechanisms. Moreover, it aims at developing social and working skills in students, such as teamwork, resilience, communication, time management or responsibility.

2.2.1 Programming/embedded

At the end of the course students should be able to program a microcontroller with a number of peripherals.

Students must learn how to program in C language, including all the normal language structures, constructs and libraries, and also low-level operations, such as the manipulation of bits and registers, which imply the notions of digital numbering and encoding.

For Embedded Systems, students should be able to program both simple microcontrollers, such as 8051s, and more complex ones, such as STM32 ARM architectures. They should also understand and use a number of peripherals such as Accelerometers, ADCs, Led Arrays, among others.

As special requests from the industrial partners, students should also understand the object-oriented paradigm and be able to write simple programs in C++. They should also understand the basic principles of real-time programming, as well as some software engineering practices, including software testing and version control.

2.2.2 Soft skills

The development of soft skills is highly required by the industry, so this programme was organised in a way where students could find an environment similar to a company. So the school assigned one classroom for exclusive use of this course, meaning that students can stay all day long in classes and are free to manage they schedule and study time, which contributes to improve their self-management soft skills. It also encourages a significant shared environment allowing multiple students to remain on their own for extended periods of time, promoting collaboration and competition.

2.3 Structure

The AeT programme is developed in two phases. The first is a lesson-based period where students learn programming in C and C++, embedded systems using 8051 [6] and the ARM-based STM32 [7], and real-time operating systems [2]. The second part consists on an internship in one of the industrial partners.

1. Academic Phase held at ISEC's premises:
   - duration of twenty weeks, between February and July;
   - lecture of 200 hours of theoretical-practical classes by ISEC teachers;
   - 300 hour tutorial training by teachers and instructors;
   - presentation of workshops from partner companies and other guests;
   - execution of a 3 weeks final embedding system project.
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;
   - intermediate and final presentations at ISEC for all participants on the programme about their internship ongoing work and final results.

This course does not confers a degree. However, students who successfully complete the academic phase will be awarded a diploma by ISEC.

2.4 Pedagogical methodology

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 expected workload from students is 36 hours per week, summing a total of 720 hours of effort, corresponding to 28 ECTS credits.

The lessons and scheduling of the subjects of the course were carefully thought and planned, with the close participation of the partner companies. It was decided to have two subjects being taught at the same time, meaning lessons related with Programming and 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.

Each day was organised into three parts:

- During the **morning** the lesson was basically theoretical, but always supported with practical examples and demonstrations.
- In the **beginning of the afternoon**, the first two hours (it could vary from one day to the other) was devoted to exercises for practice.
- **Later in the afternoon** exercises for grading were given to the students.

The students were accompanied by one instructor that was present every afternoon, to clarify doubts and help solving impediments. Instructors were recruited PhD students and professionals with proven high skills in Programming and Embedded Systems.

The evaluation of the students was essentially continuous, based on the quality of the work developed and presented. Each assignment has a set of deliverables that were submitted to GitHub and immediately evaluated, promoting continuous improvement. To encourage engagement, attendance of the students was measured and taken into account for evaluating purposes.

Each student was assigned one teacher as a tutor. This tutor would be responsible for a more direct contact with his assigned students, making sure that their specific difficulties with the subjects, or other individual pedagogical requirements were listened to and taken care of.

All necessary devices, instruments and bibliography are provided by ISEC, however, each student was encouraged to have his own laptop.

2.5 Recruitment

The process of recruitment involved one of our industrial partners and the faculty. The industrial partner supplied the know-how of its human resources office, interviewing candidates using their own psychological and psychometric tests. The faculty also interviewed each candidate to understand their motivations and assess their logical thinking abilities. These interviews always had one teacher and the psychologist from the industrial partner. The results from both parties were confronted towards a combined opinion. The evaluation resulting from each interview were later analysed in a meeting involving all the faculty and the outcome was the result of a consensus. In the second edition, a supplementary programming test was also created to decide on the cases where the faculty was not sure on acceptance or rejection.

Table 1 Profile of initial candidates to AeT.

	Academic degree			Previous studies in STEM?		Gender		Age		
	no	Bac	MSc	Yes	No	M	F	< 30	< 40	≥ 40
Edition 1	19%	55%	26%	54%	46%	78%	22%	43%	46%	11%
Edition 2	20%	65%	15%	51%	49%	80%	20%	34%	40%	26%

3 Outcomes and discussion

The first edition of AeT started in February 2018, and the second edition in February 2019. At this point the first edition of the programme is complete, and the second edition ended the academic phase. This allows us to extract useful information about the recruitment process, lessons' management and students' performance, obtaining some insights for future editions.

3.1 Candidates and recruitment process analysis

Despite the short marketing and application period (about 2 months), 162 candidates applied to the first edition and 74 to the second. This difference may be justified by the better economic situation in Portugal by the end of 2018 than in the same period of 2017 (7% vs 8,9% unemployment).

The fact that Coimbra region is experiencing a period of increase of new IT companies demanding for professionals, and that there is a surplus of former students from other areas coming from the many higher education institutions in the region, results in a dual motivator for AeT candidacy: a surplus of people from areas with less employability, knowing that they will be easily placed in the work market as soon as they finish the programme.

As expected, the profiles of the candidates was very diverse, as can be seen from Table 1.

The original area of the candidates was very diverse ranging from affine engineerings to completely unrelated activities such as psychology or even social animation. This diversity suggests that initiatives such a AeT not only are relevant to a very broad public, but also that they are needed as an opportunity for people wanting to radically change careers.

Their academic degrees ranged from Master (or even PhD - 1 candidate included in the MSc column of Table 1) to Bachelor (*Licenciatura*, in Portugal) or even without any degree; their areas of study were both in Science, Technology, Engineering and Mathematics (STEM) and non-STEM (e.g. in Psychology, Management, Sports or Nursing); they were aged between 21 and 49.

As observe, the majority of the candidates already had an academic degree, although about 20% did not finish their Bachelor. Interesting is the fact that half come from non-STEM areas. Almost half of the candidates are aged between 30 and 40, and a few are more than 40 years old. As can be traditionally observed in any STEM-related programme, the majority of the candidates are male. It was also noted that a large percentage of the candidates (35% in the 1st edition and 25% in the 2nd) had a job and nevertheless were applying for this programme. The main reason was that they were not satisfied with their working conditions. For the purpose of candidate selection, we resorted to the help of a company specialising in Human Resources management, with a history of close collaboration with some of our industrial partners. This experience was leveraged for the benefit of the candidate selection process. After an initial period of publicity and marketing, candidate applications were received and the candidate selection process ensued, following these steps:

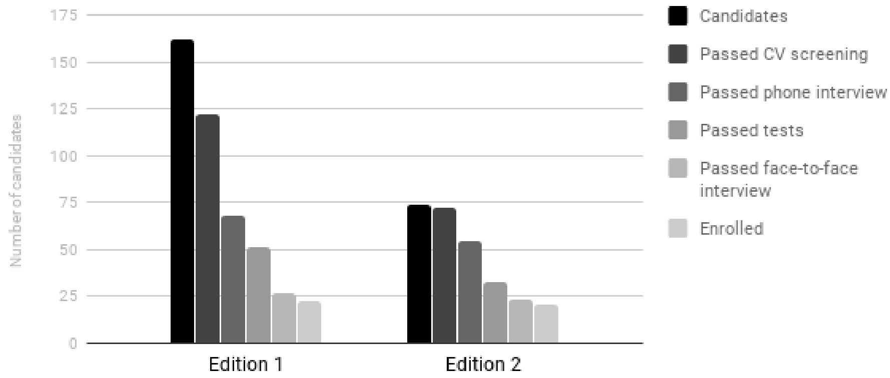

Figure 1 Candidates in each selection step.

Table 2 Profile of accepted candidates.

	Academic degree			Previous studies in STEM?		Gender		Age		
	no	Bac	MSc	Yes	No	M	F	< 30	< 40	≥ 40
Edition 1	15%	62%	23%	65%	35%	85%	15%	52%	44%	4%
Edition 2	22%	61%	17%	61%	39%	69%	31%	52%	29%	19%

1. *CV Screening:* An initial CV screening eliminated candidates that did not meet the requirements.
2. *Phone Interview:* A phone call interview allowed clarification of candidate profile and motivation, allowing further pruning of the candidate pool.
3. *Tests:* Selected candidates were invited for a session of psycho-technical tests and team exercises.
4. *Interview:* Finally those candidates that passed the tests went to a face-to-face interviews with a HR (Human Resources) specialist and a professor associated with the course.

In these tests and interviews, candidate capabilities, motivations and expectations were assessed. Candidates could also understand what was expected from them, if they were selected. Figure 1 shows the number of candidates that passed each step of the selection process. Starting from 162 and 74 candidates, respectively in the first and second edition, 26 and 23 were selected, from which 22 and 20, respectively, formally enrolled in the programme.

Despite the larger number of candidates in the 1st edition than in the 2nd, the number of accepted candidates was quite similar. It seems that the number of initial candidates makes little difference when selecting only those that are apt for the course. Taking a look at the profile of the candidates of both editions in Table 1, they are very similar. We then checked the profile of the accepted candidates (see Table 2), and compared with the initial candidates Table 1.

There seems to be no significant difference regarding their academic degree and gender, meaning that these factors do not influence the probability of a candidate being selected. However, candidates with previous studies in STEM seem to be in an advantage: about 25% of the candidates with STEM background from both editions were selected, as opposed to 16% of the candidates without such background. Also younger candidates look like having a higher probability of being selected.

3.2 Results from first edition

We received 22 highly motivated students, that were ready to work hard every day to achieve their goal of getting an internship in one of the partner companies. Some of them even dropped their stable jobs for a career change.

The instructors proved to be an invaluable piece to keep the pace of the course. They also responded to the exercises that the students submitted to the GitHub platform, providing a fast feedback. 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 exercises where organised 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).

Student's grading was based on three elements:

- **Daily exercises**, specific to the subject addressed in the morning, for individual solving
- **Periodic projects**, specific to one subject, in teams of two, rotating for each new project
- **Final project**, executed in 3 weeks by teams of two, at the end of the academic phase of the programme.

The periodical projects were subjected to a presentation where students were required to explain and defend their solution. During the programme, many difficulties where faced and some important decisions where taken to overcome them. Some of the major difficulties and consequent decisions were:

- The pace of the programme was very intense, leading most of the students to manifest exhaustion. The pace had to be slowed down and pauses were introduced (like Easter break) to provide extra support to the students. Nevertheless, the planned syllabus was fully achieved.
- Some of the students showed serious difficulties in keeping up with the subjects. Using the daily exercises, it was possible to keep an up-to-date idea of the performance and difficulties. Individual recovery plans were defined for students showing less performance. This plan consisted of a set of materials and exercises specifically and individually tailored to each of these students.
- There was no break in lessons for the students to execute the periodic projects. The intention was to have the students to attend classes and do daily exercises in parallel with these projects, forcing them to manage their available time and keeping pressure. What frequently happened was that the students used the time they should spend in the daily exercises to solve the periodic project and disregarded the subjects being taught. To solve this, the periodic projects were rescheduled and every available break in classes (holidays, free afternoons, etc.) were used to minimise this issue.

At the end, (Figure 2), from the 22 enrolled students 18 passed (82% approval rate) which was quite good, considering that the majority of the students had not had any previous contact with programming. Nevertheless, better results were expected due to the nature of the programme and the motivation of the students.

From the first edition of AeT, the following conclusions where drawn:

- The introduction of new topics and its consolidation must be carefully balanced, so the students are able to assimilate them (through daily exercises) without burning out;
- Periodic projects help consolidating the subjects, but need time;
- A final project motivates students, and allows them to have better results. However they can work around difficulties, avoiding challenging subjects. Final project cannot, thus, replace the periodic projects.

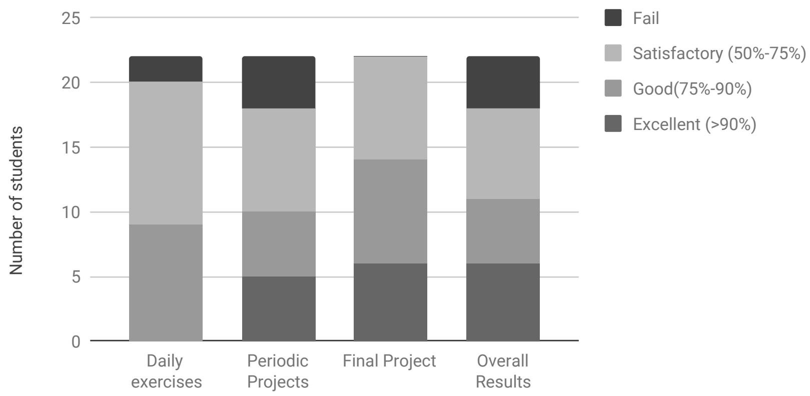

Figure 2 Students results – 1st Edition.

3.3 Results from second edition

Learning from the first edition experience, another approach was sought that would keep up the pace without over-stressing students and instructors with the daily evaluation. Three important changes were made:

1. We kept the daily exercises, but instead of using them for grading, they were only used for practice and feedback (students were required to submit them so the instructors could examine the code and provide feedback).
2. We introduced small 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.
3. The students were given exclusive time (usually one week) to execute the periodic projects.

First of all, it is necessary to stress that students are always different, and a direct comparison of the results from the two editions with such small figures cannot be conclusive. After a few weeks, it was noticed that the commitment from the 2nd edition students was quite lower than what was observed from the 1st edition. It was understood that since the students did not have the daily exercises for grading, they did not push their studies so hard, and started getting behind the imposed rhythm. Another observation was that they shared too much of their code, going beyond a healthy teamwork and discussion. Attending this, we decided for a fourth change, as a way to force them to study and to better assess their individual knowledge:

4. After each major topic, the students had to answer a written test (no computer).

This was quite the opposite of the initial idea of project-based learning. However, this was effective in motivating the students to continuously study and acquire the necessary competences.

Due to diverse reasons, four students abandoned the programme during the academic phase. One wasn't able to keep up with the pace. Another tried to simultaneously keep a part-time job in spite of being advised against it, and ultimately failed to cope. Two other students abandoned after prolonged absence due to health issues. The latter three could not have been anticipated in the recruitment process and can be considered fortuitous failures somewhat unrelated to the specifics of the course.

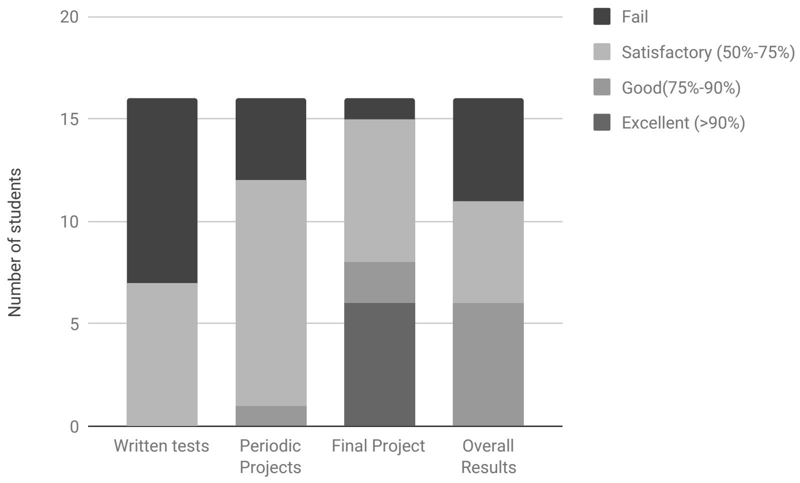

Figure 3 Students results – 2nd Edition.

Table 3 Students preferred internship location.

Location	Aveiro	Aveiro	Coimbra	Coimbra	Coimbra	Coimbra	Porto	Porto	Braga	Lisbon	Castelo Branco
Partner	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Edition 1	1	0	12	1	1	2	0	0	0	1	0
Edition 2	-	-	8	-	-	-	1	-	0	0	2

3.4 Placement and employees feedback

The 1st edition of AeT started with 11 industrial partners, that committed to receive at least one of the students in a professional internship context, offering a total of 35 internship proposals. The 2nd edition started with 6 industrial partners that proposed a total of 22 internships. The partners agreed to internship proposals that were in accordance to the programme contents.

Most of these industrial stakeholders operate in Coimbra but some internship proposals have been presented to Porto, Aveiro, Braga and Castelo Branco, outside the region of Coimbra. The industrial partners played a relevant role in trying to attract students to their internship proposals. At the end of the academic phase, the students had the opportunity to choose their preferred internship, with those with better grades being able to be the first to choose. The aim of this methodology is to make industrial partners pitch for the better classified students. Table 3 describes the students' placing by industrial partner as well as their location for both AeT editions.

The first conclusion from Table 3 is that there is a clear preference for Coimbra located internships. Within the Coimbra placements, the clear student preference is for the partners that offered the best perspectives of future integration and additional training and support. At the time of partners pitches, this was a clear students' concern. Students queries to industrial partners representatives where often related with further training opportunities. It's also relevant to point out that industrial partner #11 made a quite different approach to its pitch from Edition 1 to Edition 2 with clear results.

4 Conclusion

From this experiment, and observation of the results of both editions of the course, we learned the following lessons:

- Students need to be pressed – a strong pace, many exercises and frequent feedback pushes the students to work harder and learn faster.
- The high intensity nature of the course makes it necessary to continuously track and monitor student progress. This demands faculty to be highly available and supportive, making strong staff commitment crucial for success.
- Strategies must be found to maintain the strong pace consistently throughout the course, while ensuring that stress levels are under control and the workload manageable, both for students and staff.
- Grading is a strong incentive – the ultimate goal of the students is to get an internship in a good company, and eventually get a job there. The open box environment fosters both cooperation and competitiveness in day-to-day activities, while high priority in internship selection (because students choose internships in descending grade order) offers a longer-term incentive.
- A strong student motivator is the personal financial commitment to the course. This can be established by direct comparison with the motivation levels of students in courses of similar nature where tuition fees were sponsored by a third-party such as re-qualification grants.
- Although the selection process was in a large measure successful, it didn't take long after the course started to identify that a very small number of the accepted students would find it very difficult to meet the demands of the course, suggesting that the recruitment process could be improved.

The AeT course provides competences identified as priority by our industrial partners. A significant majority of students that attended the course have shown the ability to acquire these competences and were integrated as full-time collaborators. Although it requires significant engagement from both students and staff, AeT's primary objective, opening up new or better career opportunities for students, as well as addressing deficient supply of qualified professionals in the area, has been fully met.

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