Embedded Systems Education: Job Market Expectations

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ABSTRACT

The embedded systems world has radically changed since the first Embedded Systems Design Master studies were proposed. The spectrum of application areas has increased and the whole industrial ecosystem is changed, having SMEs emerged as major players. For these reasons, it becomes mandatory to reconsider the competences and capacities that should be provided in a Master of Science Program addressing Embedded Systems Design, so as to meet new and diverse requests that come from job market and prospective employers.

In this paper, we present the study we carried out to outline the revised professional profile for young Embedded Systems Designers, and we report the results of our exploration. To infer the competence of an ideal candidate, we carried out two experiments: we analyzed the competences listed in posted job offers and we interviewed a number of potential employers. Results obtained analyzing the collected data, demonstrate the importance of soft skills such as teamwork and communication, and confirm that programming, networking, real time and system architecture know-how are in demand. Our results are an important starting point for updating embedded systems design curricula.

1. INTRODUCTION

In the fifteen years since the first Embedded Systems Design Master studies were proposed at the Advanced Learning and Research Institute at Universitá della Svizzera italiana in Lugano, the embedded systems world has radically changed. The spectrum of application areas has increased beyond any expectation, and the increasing presence of embedded systems in the physical world has led to "cyber-physical systems". Devices tend to become a commodity in many cases, while sensors and IPs acquire a larger share of the market.

When the first curricula on embedded systems design appeared, only large market segments (telecommunications, multimedia in general, automotive, automation) had to be taken into account. Today, availability of an increasing spectrum of sensors leads to cyber-physical systems, emphasizing the direct interaction between electronic systems and the physical world without the mediation of a human user, thus stressesing the relevance of sensors and actuators as well as the necessity of innovative algorithms. This creates the necessity of including in the curricula concepts typical of the control theory world.

Pervasive systems penetrate appliances, commerce, logistics etc.; Internet of Things (IoT) or lately Internet of Everything (IoE) are the new keywords. There is growing emphasis on end-user applications and solutions, as well as on embedded software and on solutions based on reconfigurable devices, dramatically changing the current request which the future system designer has to fulfill.

Finally - and this is not a minor aspect - the industrial ecosystem addressed by Embedded Systems has changed as well, with an increasing presence of SMEs (and in particular of Start-ups), so that both the environment in which the young graduate will find a job and the characteristics of this job are often quite different from what was foreseen a decade ago.

For all the above reasons, it becomes mandatory to globally reconsider the competences and capacities that should be provided in a Master of Science course oriented to Embedded Systems Design, so as to meet new and diverse requests that come from job market and prospective employers.

We addressed this issue during the Future Embedded Systems Education (FESTE) Educational Project, which is presented in this paper together with the achieved results. The project, which was carried out within the Swiss Nano-Tera program (`www.nano-tera.ch`), had the goal of drafting the guidelines for renewed Master of Science Program in Embedded Systems Design capable of meeting the expectations of the job market in the area of Embedded Systems (in particular, although not exclusively, of the European one). The project consisted of three parts. The first part focused on assessing trends in requested skills and hiring patterns both at large corporations and at SMEs inferring them the competences listed in the job offers posted by companies and headhunters. The second part consisted of interviewing a number of managers in a variety of environments (large companies, SMEs, incubators, research centers), to directly dis-

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cuss the requested competences which the ideal candidate should have and tasks which he should complete. Finally, three experimental courses based on results of the first two phases sould be designed and launched within an existing MSc curriculum.

The rest of the paper is organized as follows: in Section 2 we revise the state of the art. In Section 4 the criteria adopted in analyzing the set of job offers are presented, and the results of the analysis are illustrated. In Section 5 we present an outline of a questionnaire used for interviewing experts from industrial and research environments, and summarize the results of such interviews. Finally, in Section 6 we extract from all the previous information the suggestions providing possible guidelines for next-generation Master of Science in Embedded Systems Design educational program.

2. RELATED WORK

The necessity of a specific educational project for Embedded Systems Design was recognized at the end of the twentieth century, when it became evident that by far the largest segment of applications for digital processor was not in the conventional "computing" area but rather in application-oriented solutions (the definition "hidden computers" was sometimes used). Some common guidelines were recognized from the start - in particular, the necessity of a transdisciplinary approach crossing the different areas of ICT and the relevance of project-based activities (see e.g., [13], [8], and [4]).

In [13] the authors further asserted the necessity that "embedded systems designers have knowledge of the complete design process so that they can make global rather than local decisions". Even with this initial (and well-motivated) declaration, it can be seen from the extensive literature on Embedded Systems education proposals that the targeted subjects have been definitely technical, quite often actually restricted to the computer engineering area (a review of US-based programs is given, e.g., up to the year 2006, in [5], the experience of Berkeley university is described in [10], while experience in embedded systems and embedded software education are reported in [7]).

A broader cross-disciplinary approach - encompassing together with EECS also topics in Control Theory and Telecommunication, insofar as these would impact the Embedded Systems Design world - was taken when designing a teaching plan of the ALaRI Masters in Embedded Systems Design at Universitá della Svizzera Italiana (USI) [2] (opened in October 2000), and included also basics in economics, marketing and business plan preparation.

Recently, a new proposal has been developed at European level within the EIT-ICT Labs Master Programs, that includes a Science Major in Embedded Systems Design (see `www.masterschool.eitictlabs.eu`) structured as a set of complementary curricula located in the various collaborating Technical Universities that take part in the experiment. The first year of "Embedded Systems Fundamentals" offered in three "core" locations is followed by a second year (including possible internships) at a different University, strongly focusing on a subject area typical for each location. A "minor" track in Innovation and Entrepreneurship is mandatory. Actually, even the EIT proposal is still related to an industrial ecosystem revolving around large ICT companies, and takes limited notice of the various aspects of evolution of the embedded systems world in recent years.

In this work we aim at updating existing curricula in the light of the changed embedded systems scenario. Works aiming at identifying the specific needs of industry were carried out also in the past. Barry [6] analyzed the content of 242 courses and 11 industry-derived programs to evaluate the extent to which such content adheres to the industry's demand for the focus on specific skills and study areas. His study pointed out shortfalls in key areas deemed to be important by industry professionals.

Surveys were also used to identifying the hiring needs of industry for recent college graduates. McGill [9] used two surveys, one given to industry participants and another given to academic participants to explore the needs of game development industry, asking in particular to rate abilities, technical skills, supporting knowledge areas, and contextual fluency.

Our work combine a carefully analysis of current job offers with a number of interviews to current employers. In this way, we aim at providing guidelines for designing an embedded system curriculum capable of meeting the requirements of the actual industrial ecosystem.

3. FOLLOWED APPROACH

In this section we detail the approach we followed to carry out our analysis. Our analysis consists of two phases: the first one asserts currently requested skills, the second identifies the competences which an ideal candidate should have.

The first phase was addressed by analyzing current job offers. We carried out this analysis on two sets of data. The first set was composed by approximately 400 job offer posted on the the internal database of a Swiss university. The database stored the most recent requests directed by prospective employers to students of a master program on embedded systems' design. This set was selected to represent the expectation of local employers (our study is focused mainly on Swiss job market). The second set was still composed by approximately 400 job offers, but this time collected from dedicated international websites, such as Linkedin or Monster. This second set was selected to represent the larger picture of skills requested to newly graduate embedded systems' designers. For both cases, we considered offers mainly targeting graduated students.

The second phase was addressed by means of surveys and interviews. In particular we successfully interviewed approximately 30 persons. The pool of interviewed people was built in order to be representative of the target population, and included managers working in different environments such as large companies, SMEs, incubators, and research centers. The questions included in the survey and the informal interview which followed the completion of the questionnaire aimed mainly at identifying the main tasks and skills which are immediately requested to the newly hired person, the ones which will be requested in the future, the requested soft-skills, and the difficulties which a prospective employer have to face while searching the right candidate.

Although our study is mainly devoted to the Swiss job marked expectation, the approach we followed (identifying the current needs by analyzing recently posted job offers and identifying future needs by means of questionnaires and interview with current managers carefully selected to be representative of the target job market) is suitable to carry out the similar analysis on different job markets. In the next sections we present the detailed results of our analysis.

4. REQUIREMENTS BASED ON PRESENT EDUCATION

In this section we discuss the first experiment we carried out in order to identify competences currently requested in job offers. We concentrated on two sets of job offers:

- Offers received through the Advanced Learning and Research Institute of Universitá della Svizzera italiana (ALaRI)
- Offers extracted from international sources

The first set of offers is representative of the profiles required in Switzerland (this is coherent with the objective of the FESTE project, which is mainly devoted to the Swiss situation). We focused on the most recent requests directed to the ALaRI Institute by prospective employers, and we examined approximately 400 requests. The second set of offers is also composed by approximately 400 job offers collected from the most recent job offers published by international websites dedicated to the topic, such as Linkedin or Monster. For both cases, we considered offers mainly targeting graduated students.

We analyzed each offer taking into account the following parameters:

- "Core" competences - primary technical competences;
- Other competences - including specific skills, personal capabilities;
- Relational skills, such as team working, problem solving;

The first observation which can be done is related to the source of offers: offers published on international web sites come roughly in equal percentages from perspective employers or through headhunters. Direct offers instead in most instances relate to SMEs or to research centers. From Figure 1 (which depicts the core competences required by the Swiss job market) and Figure 2 (which depicts the core competences required by the general job market) it is also possible to notice that, when looking at "general" core competences, the distribution is roughly identical in the case of the Swiss and of a wider job market.

Interesting enough, against a very basic competence in general programming, followed by networking, architecture and real time, no highly specific technical competence appears as "prevailing": even in the more HW- or SW-related areas, basic general competences on the subjects are favored. Especially education of software needs to be reexamined taking into account constraints imposed on embedded systems design such as low power and real time. Application areas tend to favor telecommunications, a fact probably reflecting on one hand the adoption of distributed (possibly wireless) systems, that require telecom basics, and on the other hand the widespread diffusion of mobile systems in general.

Coming then to personal and relational skills (Figure 3 depicts the Swiss job market while Figure 4 depicts the general job market), basically local (Swiss) and global job markets present again the same requirements: problem solving capacity, project management, teamwork capability and communication ability appear as general preferences, while other capabilities such as e.g., customer relation, documentation, organization skills are not as widely in demand. The main difference between global and Swiss job market is higher request for project management competences for the Swiss job marked. However, as mentioned, the trend and the type of requirements are similar in both cases.

Again, some interesting aspects may be deduced. Non-technical skills most highly valued are the ones that mostly relate to the technical design activity. Capability of teamwork and communication skills are seen as dominating factors even for young graduates, from whom (quite reasonably) involvement in customer relations and organization activities are seldom expected. Project management appears as a relevant requirement, quite distinct from more conventional management skills (a request so rare that it was not considered significant in our statistics). As a further consideration, such personal and inter-personal skills do not appear in any typical curriculum but are obtained at best through collaboration efforts during end-of master projects or in the course of well-managed internships.

5. THE PROSPECTIVE EMPLOYERS' POINT OF VIEW: EXPECTATIONS FOR FUTURE EMPLOYEES

In this section we discuss our second experiment. While job offers analyzed in the previous section basically refer to the education received by present graduates, i.e., they reflect "the past" in educational terms, in order to understand what might be the competences that would-be employers might require of next-generation graduates in the area of embedded systems, a number of questionnaires were distributed among top managers of large companies, high-tech SMEs and of research centers as well as incubators. The target persons were carefully selected to have a set representative of the considered job market. We distributed 60 questioners and 30 were returned back duly completed. The returned questioners were coming from different categories of persons, so still significantly representative of the target job market. The questionnaires which were returned, have been followed by informal personal interviews to further discuss the points addressed by the questionnaires. The questionnaires were mainly consisting of the following questions:

- Which tasks will be assigned to the newly hired graduated student? Will he/she have to attend an extended internal training or will he/she be immediately in direct contact with customers?
- Which competences may your company easily find today on the job market compared to the needed ones? Which positions are in any case difficult to be covered?
- Why is it difficult to find the right candidate for certain positions?
- Which tasks will be assigned in ten yeas to graduate students which will be hired now?
- Which soft skills are needed for that?
- Which are the main technical skills required today? How did they change compared to the ones required 15 years ago? (for instance, is nowadays a digital project mainly a composition of IPs or are low level competences on digital design still required?)

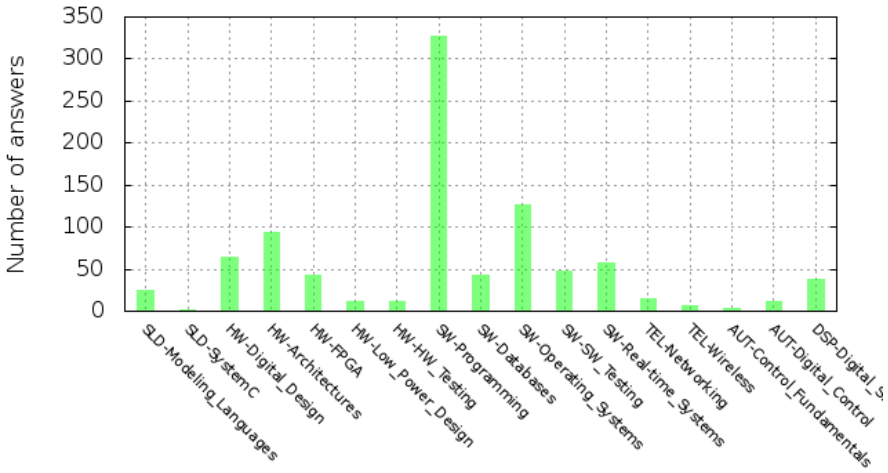

Figure 1: Core competences required in the offers received by ALaRI (mainly related to the Swiss Job market)

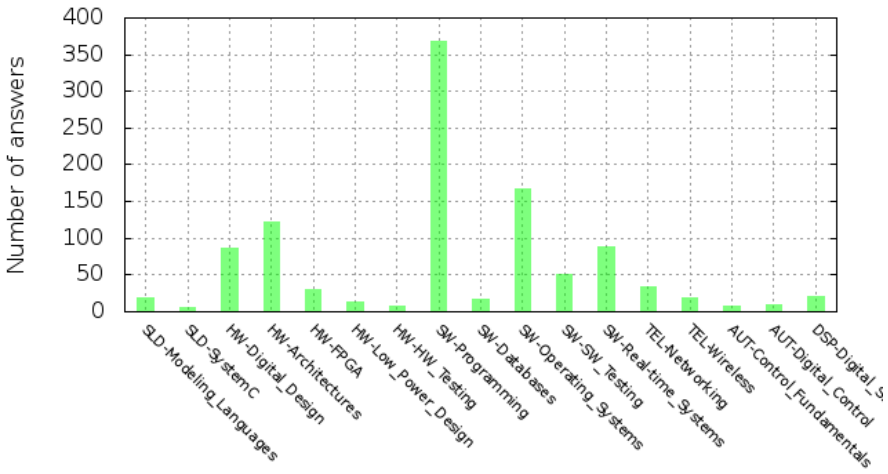

Figure 2: Core competences required in the offers published on international web sites (mainly related to the the general job market)

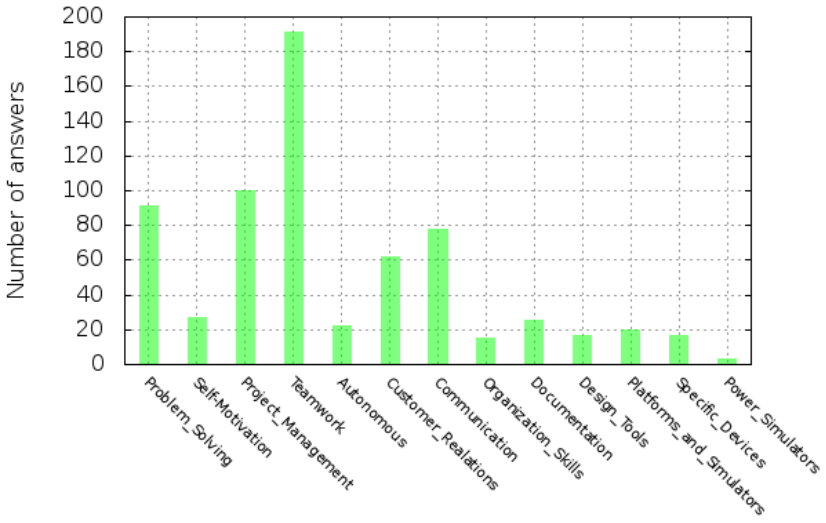

Figure 3: Personal and relational skills (Swiss Job Market)

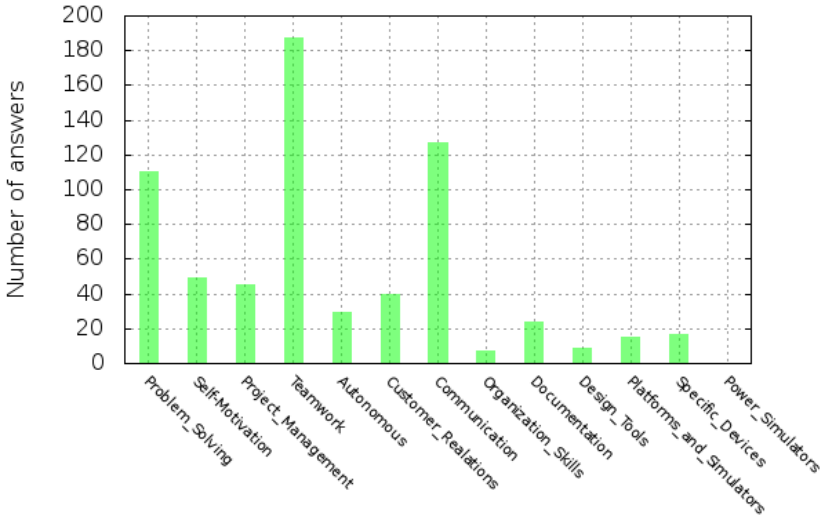

Figure 4: Personal and relational skills (General Job Market)

The detailed list of questions is available at http://nt-feste.alari.ch/, here we will briefly summarize the most relevant results.

The first interesting outcome from the questionnaires is that with very few exceptions, extensive initial training is not foreseen: a "new entry" is expected to acquire training while involved in projects (initially in minor roles, supervised). Even in companies that offer extensive in-house educational opportunities, such offer is seen as the basis not so much for entry-level preparation as a possibility to pave the way for determining future career developments. Internships may allow a faster learning curve; project experience during MSc studies is also relevant. This is a strong difference with respect to the "traditional" approach of big companies (particularly in the ICT area), which included very often an extensive in-house educational period; learning is considered as relating to company approaches, in-house processes and company tradition rather than to technical aspects.

All interviewees emphasize "interdisciplinarity" as a mandatory aspect in education of future ES designers, making it clear that it involves not simply the different facets of the ICT world (e.g., telecommunication, automation, microelectronics, hardware rather than software engineering) but a much wider spectrum, combining hardware-software codesign with a "horizontal" set of disciplines that relate to present and future possible application areas. Several interviewees emphasize that the move towards "cyber-physical systems" and "Internet of Things" scenarios increasingly push in this direction. No very specific technical aspect is taken up: this certainly reflects the continued evolution of the area, such that specific technical knowledge is of necessity related to lifelong-education aspects; on the other hand, the relevance of methodological fundamentals is generally emphasized. Capacity of a system-level approach is a common request (even in the case of silicon companies) - actually, "systems of systems" become a challenge. Capacity of abstracting from problem to model and then moving through the whole design chain down to implementation is seen as characterizing the "ideal" ES designer; embedded software is seen as increasingly relevant. Actually, all this leads to deduce two very important points:

1. Abstraction and use of system-level specification languages and tools need to be part of the background capacities of an embedded systems designer;

2. Given that obviously a widespread interdisciplinarity bridging an a-priori almost infinite set of disciplines cannot be achieved, the capacity of finding a common language with "customers" from any scientific area and of working in an efficient and effective way in multi-disciplinary teams involving experts from such areas becomes essential (in fact, points 1 and 2 are strongly mutually related).

Most interviewees chose to deal in detail with aspects that might be seen as "non-technological" ones. In particular, teamwork and project as well as product management were widely discussed as basic aspects. More in detail, such points were elaborated as follows:

- Teamwork refers to working within teams that are multi-cultural in technological, ethnological, and even geographical terms. This implies not only flexibility, but openness and respectfulness as well; from a technical point of view, understanding different technical "languages" becomes essential. Communication within a team needs to be vertical as well as horizontal - a new entry must be welcomed equally by superiors as well as by colleagues, in order to reach consistent efficiency. In perspective, the capacity of managing teams will be an evaluation parameter.

- Project management is a much emphasized point; Project management is fully relevant as is some understanding of quality process requirements and of the main principles of a supply chain (make/team/buy analysis, procurement, terms of contracts with suppliers, etc.). It is important to know also that companies are operating within regulations and standardized processes (e.g configuration management, safety and security issues, sometimes certifications, formal design methodology often supported by a tooled process, etc.). Today, project management is learned "on the job"; almost all the interviewees emphasized that providing students with its basics during their graduate studies becomes increasingly important. Furthermore, product management should be taght to teach students how to manage a product through the entire lifecycle.

6. GUIDELINES FOR RENEWED MASTER PROGRAMS

Results of the analysis performed in the frame of the FESTE Educational Nano-Tera project allow deriving some basic guidelines for renewed Master of Science programs in Embedded Systems Design. Actually, no criticism was found to be leveled against the present curricula of such masters, which focus fundamentally on technical aspects; an accurate exam of job offers and interviews leads to conclude that requests are oriented towards non-technical aspects rather than towards deepening specific technological competences.

The evolution from autonomous embedded systems towards pervasive networked systems and, by now, towards the Internet of Things, the increasing prevalence of applications in which the electronic system directly interact with the physical world ("cyber-physical systems"), emphasize the necessity of tackling complex problems spanning a large variety of scientific areas and therefore of being capable of a sound "problem solving" approach: a capacity that needs to be developed by coupling methodological fundamentals with hands-on experience. Also ability to combine hardware design with programming (HW-SW-codesign is fundamental and software engineering for embedded systems in which all types of constraints such as power and timeliness must be taken into account will be essential.

Ability in project management is widely advocated (interestingly enough, in a widespread fashion, whether in the environment of large multinational companies or in that of SMEs or even in the case of incubator managers); even more than for complex problem solving, it cannot be taught in a purely theoretical fashion but it must involve practical experience under the guidance of an expert - possibly not an academic one! Even more delicate is the aspect of achieving proficiency in teamwork: in fact, the request of increasing interdisciplinarity in technological terms may be at least partially fulfilled through well-managed work of multi-disciplinary, multi-cultural student teams under the guidance of expert advisors. From this point of view, actu-

ally, an interesting experience is the one developed at ASP (Alta Scuola Politecnica): an advanced post-graduate educational experiment carried on jointly by Politecnico di Milano and Politecnio di Torino, in which students come from the various Departments of Technical Universities (the different areas of Engineering, Architecture, Industrial Design) and projects assigned to students' teams cut across multiple specializations [3].

7. CONCLUSIONS

We have present the study we carried out to outline the renewed professional profile for Embedded Systems Designers. We carried out two experiments. The first one analyzes the current request from the job market by searching competences listed in posted job offers, the second one aims at envisioning the future requests from the job marked by interviewing a number of potential employers. Our results show the importance of soft skills such as teamwork, management and communication, and confirm that programming, networking, real time and system architecture know-how are and will be relevant in future. Our analysis concludes proposing guidelines for updating embedded systems design curricula. As a follow-up to the analysis phases, three experimental courses have been set up within the Master of Embedded Systems Design organized by the ALaRI Institute of Universitá della Svizzera Italiana, dealing respectively with problem Solving, Project management and Teamwork.

8. ACKNOWLEDGEMENTS

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