Teaching Software Engineering for Embedded Systems: an Experience Report from the Manaus Research and Development Pole

1Vicente Ferreira de Lucena Jr., 2José Pinheiro de Queiroz-Neto, 3Isaac Benjamin Benchimol,
4Andréa Pereira Mendonça, 5Valteir Romão da Silva, and 6Mário Ferreira Filho

Abstract - The number of microprocessors and microcontrollers being applied to modern computational systems is growing exponentially. Nevertheless, it is not easy to find engineers with the necessary skills for developing software for such devices. In fact, the creation of official undergraduate courses to fulfill this modern demand proved not to be the best solution. This paper describes an inter-universities training program specially created for embedded systems organized by CEFET-AM, a technical college, and carried out by Genius Institute of Technology, a research and development company, both located in Manaus – Brazil. After a restrictive selection process, 24 senior students coming from 8 of the most important universities of the region started their studies. Eleven theoretical modules distributed in 300 hours of training were given. Afterwards, the students started an industry oriented project. One major assignment was given to the whole group. They divided themselves in sub-groups responsible for specific parts of the project which involved distributed systems programming, communication process development by using M2M, web services planning and MMI design by using diverse devices. The joint venture of theoretical studies conducted by a school of technology together with the practical side of a research company resulted in a well succeed experience.

Index Terms - Embedded Systems Education; University and Industry Collaboration; Educational Experience.

INTRODUCTION

Manaus, located in the center of Amazon Forest in Brazil, was once the most important rubber production center worldwide. It went through a long period of decadence up to the 60’s when it became the home of the largest global free trade zone for the production of electronics and the Brazilian main manufacturing production center of analog and digital television sets. The eighth largest city in Brazil, and the largest industrial park of its kind in South America, Manaus is a microcosm for political, economical, and social transformations implicated in recent debates over digitalization, including Digital TV [1,2].

Because of its history and characteristics, Manaus has many contrasts being the host of the oldest Brazilian University (UFAM) [3, 4] and, at the same time, facing big difficulties in keeping a good level of education for the children. Nowadays in Manaus we can count on several universities, technical colleges and research development institutes which are responsible for professional formation and technology development in embedded systems, among others sciences, to support the companies settled in the local industrial pole.

Nevertheless, the academy has been facing many difficulties in following the fast changes of technology, for example, to keep up-to-date in areas such the embedded systems. The curricula and the contents of the actual majors are not adjusted to attend the research institutes settled in Manaus in recent years due to an incentive law, as well as the new demands of classical electronic industries. On their side, the research institutions and the electro-electronic companies neither dispose of time nor of budget to train the professionals they need to compete in the global market. In this paper we present a collaborative project among some universities located in Manaus, the source of professional man power, and a research center, build to produce innovative solutions for the global market and with great interest in the embedded systems world.

Indeed, the particular discussion about embedded system education has shown some important solutions, as presented in [5]. Considering that collaborative projects present great possibilities of success [6], two recognized institutions in Manaus decided to join its know-how: The Centro Federal de...
Educação Tenológica do Amazonas (CEFET-AM) [7], a federal technological college who has almost a century in technological education experience, including graduate and under-graduated courses; and the Genius Instituto de Tecnologia (Genius Institute) [8], a non-profit Research and Development (R&D) center, established in Manaus in November/1999, focused in software technological innovation, embedded software, electro-electronics, and microelectronics.

EDUCATIONAL PROGRAM CHARACTERISTICS

One of the biggest problems in the industrial pole of Manaus is to find professionals who have all the necessary requirements of the employers. The experience of bringing professionals from other cities of Brazil has shown inefficient and expensive. People who come from other cities do not adapt easily to Manaus, because of its weather and its distance from other poles. Manaus is located in the middle of the Amazon Rain Forest, about 800 km away from the next important city and has an average temperature of 32 grades Celsius and a humidity factor over 80%. Recently, a reasonable solution being adopted is the direct participation of the industries and institutes in the curricula of the local universities and colleges, encouraging the formation of local technicians. This motivated the accomplishment of the program with a partnership between the CEFET-AM and the Genius Institute.

This partnership aims to integrate the academic and the practical learning in a real company, with the advantage of counting on the CEFET-AM experience in education and the Genius Institute know-how in software development and technological solutions creation. The program intended to specify the minimum curriculum for the formation of professionals interested in software development for embedded systems established in C, C++, Linux, Java and J2ME and still established an institutional training program that enables students to work with these technologies, with objective to develop projects with real embedded systems applications.

The main objective of this project was to deal with software engineering teaching and training. Since the beginning of the project we were aware of classical problems, such as the ones described in [9, 10, 11] and tried to provide an effective solution to those.

The Training Program in Development of Software Applications for Embedded Systems selected students from several universities and colleges in Manaus, including public institutions, considering the students from majors as electrical engineering, computer engineering, computer science, or other similar. Although positive experiences using robots to teach software engineering were already presented in the literature and applied in Manaus [12, 13, 14, 15], it would not be the most appropriated approach, since the students came from different schools with different backgrounds.

In fact, the domain of the technologies related to the world of embedded systems will be the main ability learned by students at the end of this institutional program. To obtain success, a learning model is necessary to improve the learning of programming languages, as presented in [16]. Therefore the program uses a proper methodology divided in two steps: in the first step they have a basic level of knowledge on programming languages and laboratory tools; and in the second one the students are involved in the development of real software projects at the Genius Institute. The two phases are detailed as follow:

1- Theoretical training of the students (three months). Initially, 24 students were involved in this program and were trained in the chosen technologies. The training was applied by specialized professors from CEFET-AM. During the training, the students were submitted to evaluations in each new topic, to determine the students who would be able to continue in the training program.

2- Implementation of real projects (three months). The selected students were divided in work teams develop their part of the project, oriented by the professionals from Genius Institute and CEFET-AM.

In the following sessions, we will show more details about the project itself and about the two phases of the training program.

LABORATORY AND EQUIPMENT RESOURCES

The fundamental idea of the project was to gather the best Information Technology (IT) related students of Manaus in a single class group and teach them the basic technologies associated to the embedded systems world.

The Genius Institute was responsible for building the necessary infrastructure and for proposing a final task to be implemented by the students. The CEFET was supposed to invite students from other colleges and to select the best ones to participate in the project. The CEFET professors were also responsible for the creation of a basic curriculum and for teaching the classes themselves.

The researchers from Genius Institute applied to a government agency named FINNP to construct a laboratory and to equip it with modern computers and sophisticated embedded devices. The resources were obtained promptly proving the quality of the proposal and the strategic importance of the project.

After six months of hard work the Genius Institute could open up the Anísio Teixeira Laboratory. The choice of the name of the lab is a reference to a former Brazilian researcher on education related topics who became a major reference in innovative methods of education in Brazil. He was also rector of the University of Brasilia and worked as associated professor in many American universities during the last century. Anísio Teixeira died in 1971.

Selecting the students was not an easy task. The first step was to verify the graduate courses that could contain students with the necessary profile. In Manaus there are three public universities with courses in majors including electrical engineering, computer engineering and computer science.
These public schools are well known and have a good reputation. Additionally there are in the city about 12 other new private colleges offering diverse courses on computer science and other Information Technology related majors. The problem faced was how to select good students from this diversity of background choices and how to avoid privileging one school against the others.

The solution was to fix common criteria that could be fair for each institution: The students should preferably be at the last year of their graduate studies; They should not have more than 2 fails in their academic history; They should prove basic knowledge of the English language; They should also prove basic knowledge in one or more programming languages; and at last their participation in under-graduated scientific works had to be proved.

The invitation to participate in the project was announced via newspapers and directly in the schools. Since the early phases of the project the expectation was to receive many candidates but the final results were much optimistic than one could realize. As there were only 22 places available and there were 84 candidates inscribed, it meant that there were more than 3 candidates for each place.

At the end of the selection process the professors from CEFET and the researchers from Genius Institute worked together. Among the 22 selected students there were 6 different courses and 8 different schools. Well known colleges obtained not more than 5 approved students; even CEFET obtained only places for 4 of its students.

Another important characteristic of this project is that no fees were paid by the students. They attended the classes in the afternoons, four hours a day and five days per week. This meant that they were involved in intensive work for six months. The professors were paid by another research foundation named CNPq. This agency belongs to the Brazilian Ministry of Science and Technology and supported the whole project.

**DESCRIPTION OF THE COURSE**

As described above the course was divided in two different phases: The first covering the theoretical aspects of embedded systems and the second comprising the construction of a real embedded system. In the next two sections a detailed description of the activities developed in these phases is going to be presented.

**Phase 1: Background Technologies**

The first phase of the training program consisted of 11 theoretical modules totaling 300 hours of intensive class work. Table 1 shows each module and its corresponding duration. Next there is a brief description of the themes discussed in each module.

<table>
<thead>
<tr>
<th>Module</th>
<th>Duration (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedded Operating Systems</td>
<td>32</td>
</tr>
<tr>
<td>Object-Oriented Programming</td>
<td>20</td>
</tr>
<tr>
<td>UML</td>
<td>20</td>
</tr>
<tr>
<td>Basic Java</td>
<td>32</td>
</tr>
<tr>
<td>Design Patterns</td>
<td>16</td>
</tr>
<tr>
<td>J2ME</td>
<td>40</td>
</tr>
<tr>
<td>XML</td>
<td>16</td>
</tr>
<tr>
<td>Java TV</td>
<td>32</td>
</tr>
<tr>
<td>C Programming Language</td>
<td>40</td>
</tr>
<tr>
<td>C++ Programming Language</td>
<td>32</td>
</tr>
<tr>
<td>Java-C Integration</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>300</strong></td>
</tr>
</tbody>
</table>

- Embedded Operating Systems – This was an introductory module on embedded Linux. An overview of the operating system was shown; including basic commands, tasks control and system administration basics. Next, it covered the embedded issues such as running Linux in embedded devices like mobile phone, PDAs and set-top boxes.
- Object-Oriented Programming – This module described the basic concepts of object-oriented programming, enlightening the differences and relations between classes, objects, methods, inheritance, polymorphism, abstraction and encapsulation. It also reported important differences between object-oriented languages such as C++ and Java.
- UML (Unified Modeling Language) – This module covered the use of the object-oriented modeling technique UML to produce documentation artifacts. It covered the analysis and design documentation from software systems as well as the documentation of users and system requirements. Special attention was given to the use of UML associated to the Java programming language.
- Basic Java – The Basic Java module provided a general introduction to programming in Java. Developing Java programs from basic applications to mildly complex programs was the goal of this practical course. Indeed it covered topics from the fundamentals of the language until data base access using Java and its APIs.
- Design Patterns – Here the students had the opportunity to study object-oriented design patterns. This module focused on known solutions for specific modeling problems showing the students professional approaches to solve classical problems of software design.
- J2ME (Java 2 MicroEdition) – This module provided an understanding of software development for embedded devices such as PDAs and cell phones. J2ME has become a popular option for creating small embedded systems.
applications, as they can be emulated on a PC and easily uploaded to the target device.

- XML (Extensible Markup Language) – The key goal of this module was to understand the basic concepts of the general-purpose markup language XML. The students have gained experience in storage, description and data exchanging which are skills desired for Web software developers.

- Java TV – To meet the demand for Digital TV emerging interactive applications, this extension of the Java language was released by SUN. Here the students had the chance of using the functionalities of Java TV API.

- C Programming Language – A structured programming language used in many different areas of application: C’s power and fast program execution was treated in this module. Students gained a strong structured programming basis here.

- C++ Programming Language – More programming tasks, this time using C++, one of the most popular commercial object-oriented programming languages. Object-oriented principles were used throughout this module.

- Java-C Integration – This module discussed integration issues in attempt to interoperate C and Java codes. The Java Native Remote Invocation and other ways of mixing Java programs with C were presented and exercised in this module.

All modules were achieved in a very practical basis. Classes took place in the laboratory where two students shared a computer. As the professor explained the topics and related examples, the students could immediately explore the subject more deeply by solving the following exercises. This approach meets the “Learning by Doing” pedagogical focus normally adopted by CEFET.

Evaluating the students was a matter defined personally by each professor. Minimal grade required in each module was 7,0 (in a scale from 0,0 to 10,0). Students who failed in two or more modules were not allowed to proceed to phase 2. Although the training program occurred together with the normal academic semester, some students faced some difficulties to succeed in both engagements. Nevertheless, all of them met this situation by doing extra work to achieve the desired grades and could continue to the next phase.

**Phase 2 : Development of an Industrial Project**

The second phase of the project was planned to put the students in contact with the industrial know-how. In fact this phase was mainly oriented by the researchers from Genius Institute. The goal was to follow a real industry development process, by accessing its documentation and following the same phases used by real projects.

The staff from Genius played the role of customers, demanding a product, while the students and the professors from CEFET played the role of the project development teams.

**Session S4C**

The project developed by the students followed the main phases of the conventional life cycle of development of a product: a) Requirement development; b) Architectural design; c) Implementation; d) Tests; e) Packing and delivering.

Students generated and delivered work artifacts during each one of these five phases as follows:

- Requirement development: creation of the technical requirements specification document, starting from the customer’s requirements;
- Architectural design: elaboration of the technical solution document for the development, taking into accounts the time, scope and available resources;
- Implementation: implementation of the technical requirements in a specific programming language and according to the desired architecture;
- Tests: elaboration of the test plan, tests cases, execution and fixing of bugs;
- Packing and delivering: generation of the final product baseline and the product delivery report to the customer.

Like a real project development, the students had to adopt the development process and the documentation templates from Genius Institute of Technology. The work of the students was evaluated considering not only the quality of the delivered documents but also the capability of being on schedule.

**Team composition method**

Before the beginning of the development activities, the Genius Institute and the CEFET researchers presented the project scope to the students, its three components, and the main technologies involved in the development of each one. After this presentation, each student received a questionnaire, where it was requested that they put in a decreasing order of priority the component that the student would like to develop. They should also explain the reasons for their priority choice and relate the choice to their university course. These questionnaires, together with the student's grades in the theoretical modules were used for the team composition. Indeed, the following three criteria were adopted: a) amount of people necessary to develop each component; b) the students’ skills and the technology involved in the component development; c) student accomplishment in the theoretical modules. This procedure tried to align the students’ interests and skills with the technical demands of each project’s components, contributing with students’ motivation and accomplishment. At the end four work groups were formed, each of them having 4 to 6 students. The number of group members varied in accordance with the level of difficulty of the assigned task.

**Project Scope**

The Genius Institute, playing the role of a customer, requested to the students the development of a System to Manage Public Transportations (SMPT). For this purpose the Genius Institute gave the students just one set of documents containing the customer's system requirements, and the
development schedule with the desired date to finish the project and the partial deliveries.

Purpose of the project was to create a software system and other components to be embedded in electronic devices, like cell phones, PDAs, and M2M devices. The M2M (Machine to Machine) device could be installed in the buses, subways and trains, in order to automate the exchange of information among moving devices and fixed points. These transmissions and the receptions of signs, and the processing of them all should result in a system capable of delivering to the real users some actual information about the public transportation system, like: a) Buses’ schedule for seen; b) Suggestion of the best route for the passenger’s demand; c) Bus line list with the places the line covers and which line goes by in a specific place. The public transportsations users can access this information through a web page, cell phones and PDAs.

Transportation System

The system was divided in three components: 1) Client Unit; 2) Client; 3) Server. Figure 1 illustrates the architectural design and shows the parts of each component.

![System Architectural Design](image)

Client Unit Component

The system should acquire through sensors the position of the public transportation vehicle when it stops or goes by one station, so the M2M device sends a signal over GPRS for a database manager to process the data, and stores the information in a database server. Basically the sensors acquire the station identification and the number of passengers that got in and got off the vehicle.

The first group of students was assigned to develop this component. They received a commercial development board containing sensor units and a reception device. Their task was to integrate the whole system. Sensors, receptors and M2M devices should be programmable from scratch. They should also synchronize the development with the other groups and communicate intensively with groups that share common interfaces. Part of their work was developed by using the C language and the integration was done in Java.

The public transportation users should be able to access the system’s information by three different ways:

- Through a Consultation Terminal: Special devices positioned at strategic places in the city, where the users could access the information available.
- Through a Web Browser: Using personal computers with internet connection, the users could access the system’s web site and find the information they needed.
- Through Mobile Devices: The systems should also admit that users accessed the information through cell phones or PDAs. This could be done for example, sending a short message (SMS) or accessing a specific application embedded in the device.

A consultation terminal was the task given to the second group of students. They received a 9 inches touch panel terminal and a microcontroller based board. They were supposed to implement an embedded web server and communicate directly with the server database in order to offer actual information for the transportation clients.

The third group should develop the consultation system using mobile devices. They received some cell phones and designed a system based on the services provided by regular telecommunication companies. The concept involved a TCP/IP connection to the server, WAP surfing and SMS sending and receiving information.

The task of the fourth group was to develop the server side of the whole system. They should develop and implement the database access and a web application offering to the users the Web Browser option. This group should also communicate intensively with the others in order to keep the interfaces aligned and coherent. Their work was basically done in normal PCs and was the less related to embedded systems.

Real-time constraints should be observed for every group. Indeed the desired system is typically a real-time system and the students were supposed to prove their ability to deal with such requirements.

Each student group had a tutor from CEFET and communicated directly with a researcher from Genius Institute. The most relevant problems were solved together with these two professionals. Both the tutor and the researcher oriented the development of the system to the schedule and emphasized to the students the importance of following the desired requirements and a pre-defined schedule. The cost impacts of missing deadlines as well as the benefits of keeping them were demonstrated during the work.
RESULTS AND CONCLUSION

At the end of the project the students needed to assemble a mockup to simulate the system and to present the work results. The mockup was composed by toy trains, cell phones, a computer and a database server. There were two stations mounted with M2M devices in the track and there were affixed transponders in the trains. As the trains went by the M2M devices, the train identification was sent to the server keeping the real-time data up-to-date.

The project was supported by the Brazilian government and proved its value by the obtained results. A second group of students was able to conclude the training successfully. They learned a lot about technologies related to embedded systems and learned how to develop software in a real world approach. Four of them were directly hired by the Genius Institute and the others could easily find jobs related to software development for embedded systems.

The group of professors from CEFET learned a lot by working closer to the industry. The experience with students with quite different backgrounds was also a positive point of the project. On their side the researchers from Genius Institute could work closer to students and could cooperate with the teaching force.

Teaching software engineering for embedded systems is not an easy task. It may cover a set of technologies and knowledge that could not be covered by only one subject. That’s why we had a joint venture of technical college and local research institute what granted the success of our experience in Manaus.

In fact, there is no novelty on the program adopted in this project; the modules and the sequence of their presentation obey a classical approach. The originality of our experience laid on the fact that we could join together students from 8 different schools and quite different backgrounds. The division in two phases, where the second was clearly oriented to the development of a real product is also a innovative contribution of our work.

The project was supported by the Brazilian government and proved its value by the obtained results. A second group of students is about to finish their work. This time they develop a software system for a digital set-top-box TV.

REFERENCES