TOWARDS THE ACQUISITION OF SOFT AND SYSTEMIC SKILLS: A PROJECT BASED LEARNING EXPERIENCE IN MASSIVE LABORATORIES ON ELECTRONICS

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Abstract — *The Career Space Consortium provides an 'industry demands' perspective that must be taken into account when designing University curricula for Information and Communications Technology graduates. Not only the scientific and technological base needs special attention, but also the acquisition of **soft** (behavioral) skills, including a systemic view of technology that accounts for the relationship between the specific learning topics and the systems. Under these considerations, Project Based Learning (PBL) is one of the most attractive instructional strategies to be applied, especially in the area of practical learning. In this paper we describe our experience, during four academic years, teaching massive PBL laboratory courses on electronics in the Telecommunication Engineering Studies. We describe how our implementation of PBL is able to provide students with the required soft skills, including also the results of a comprehensive evaluation of our experience both in terms of acceptance from the students (3.7 in a 1-5 scale) and their performance (on the average, they get 76.3% of the maximum grade)..*

Index Terms — *Soft-skills; Career Space Consortium recommendations; Project-Based Learning; Education tools; Instructional strategies; High student-to-faculty ratio.*

INTRODUCTION

In the context of the European Space for Higher Education [1], the Career Space Consortium (CSC) provides an 'industry demands' perspective that must be taken into account when designing University curricula for ICT graduates [2]. Within these recommendations, not only the scientific and technological base needs special attention, but also the acquisition of soft (behavioral) skills, including a systemic view of technology that accounts for the relationship of the specific learning topics to the systems in which they are found.

In this scenario, Project Based Learning (PBL) [3] is one of the most attractive instructional strategies to be applied, especially in the area of practical learning. The student-centered strategy applied in PBL, fosters student initiative and other skills (apart from theoretical knowledge): time planning, resources management, assumption of responsibilities, negotiation and social abilities. All these

soft and systemic skills are very well in line with the Career Space Consortium recommendations.

In this paper we will describe our experience, during four academic years, teaching PBL laboratory courses on electronics in the Telecommunication Engineering Studies.

The paper is organized as follows: first, we introduce the recommendations of the Career Space Consortium in what respects to the required acquisition of soft and systemic skills by ICT students. After this, we describe the main ideas regarding the PBL approach. Next, we present a short description of the laboratory course on which we have applied the PBL strategy, describing how we faced the demands of the CSC. Then, we briefly summarize some of the additional strategies and tools that we have implemented in order to efficiently deal with PBL laboratory courses with a high student-to-faculty ratio, and we finish with some results on the evaluation of the course quality and the conclusions of our work.

CAREER SPACE CONSORTIUM RECOMMENDATIONS

The Career Space Consortium (CSC) is a consortium of major ICT companies, plus the European Information and Communications Technology Industry Association. CSC has defined a set of guidelines for designing ICT curricula, based on existing good curricula together with information and suggestions from the companies and associations. Their proposal is providing a basis for universities and technical institutions to review and revise relevant courses.

CSC states how ICT graduates need a solid foundation in technical skills from both the engineering and informatics cultures but, as indicated by Peter Revill in his notes regarding situational learning and the explicit acquisition of behavioral skills in [1], "it is not sufficient just to learn about technical and other issues and pass exams; the techniques need to be used in real situations. This is particularly important to emphasize the connections between different aspects, to encourage a broad systems view and to illustrate the practical, technological and human constraints of solving real-world problems".

Within the CSC recommendations, the core elements of any ICT curricula should be composed of a scientific base of 30%, a technology base of 30%, an application base and

systems thinking of 25% and a personal and business skills element of up to 15%.

In our case, we are interested in practical learning in laboratory courses on electronics, and our motivation is providing the students with some of the soft, systemic and behavioral skills that CSC recommends, namely:

- The acquisition of a broad systems perspective: the ability to create system solutions
- The ability to take initiatives
- Team working abilities
- Communication and persuasion skills
- Time planning and resources management
- Readiness to understand fully the needs of the customer and their project colleagues

PROJECT BASED LEARNING

"Project-Based learning" (PBL) [3] is one of the most interesting instructional strategies, mainly in the field of technical careers [4-6]. The PBL Strategy aims at engaging students in authentic real-world tasks that enhance learning [7]. Students, typically organized in workgroups, face open-ended multidisciplinary projects with the instructor playing the role of facilitator or coach. Every team designs and implements a whole system with more than one possible approach, in an environment designed to simulate professional situations, where the students have to deal with different kinds of knowledge. PBL allows increasing students' involvement in the learning process, obtaining better results in terms of knowledge and habits acquired by the students.

In this environment, the students learn the characteristics of each module and the interaction or interface between them, obtaining a global view of the system. This fact is very important for our laboratory courses in electronics, because we emphasize the idea that electronics is a fundamental supporting technology for developing communication, control and signal processing systems. The comparison to the traditional way of teaching reveals a greater degree of learning in the case of the PBL technique [8], especially when new technologies support this technique [9].

The PBL strategy has also several implementation problems: a greater teaching effort in management and coordination, and a more complex and difficult evaluation process. In courses with a very high student-to-faculty ratio like ours (around 200 teams of 2 students and between 7 and 10 instructors), it is very difficult to supervise and feed back to the students continuously. This fact can cause that both students and instructors may focus on the functionality of the project, setting aside non-functional quality aspects. On the other hand, the relatively high number of faculty members in our course (7-10) must evaluate non-overlapping sets of students; this increases the risk of discrepancy in their evaluation criteria. In order to perform a good supervision and evaluation in massive PBL courses, it is necessary to use automatic tools that help faculty to control and supervise the students' evolution and to analyze the evaluation process.

LABORATORY COURSE DESCRIPTION

We have applied the PBL strategy in a course called LSED (Laboratory of Digital Electronic Systems) of the Department of Electronic Engineering at the Telecommunication Engineering School, of the Technical University of Madrid (UPM).

LSED is a laboratory with about 400 students attending each year. The students have to design, build, test and document a complete microprocessor-based system (both HW and SW), grouped in teams of two students.

The students must carry out the complete analysis of the system (the initial specification is always incomplete) and they must make the design, implementation, testing and documentation. The target system changes every year and the students must develop a completely functional prototype with the associated documentation.

FACING THE CSC RECOMMENDATIONS IN OUR PBL LABORATORY COURSE

In our implementation of the PBL strategy in the LSED course, we emphasize the acquisition of the soft skills recommended by the CSC. In order to achieve our objectives, we have introduced several strategies which are described in this section.

The acquisition of a broad systems perspective and the ability to create system solutions

The laboratory assignment we propose every year consists of a simplified version (both economically and in terms of time demand) of a consumer system. This way, the students have to face the design, implementation and evaluation of a complete system from the point of view of its functionality. For example, in the 2002-2003 academic year the system proposed was a talking calculator based on the MC68000 and in the 2003-2004 academic year, we proposed a wireless chat with an infrared link.

The starting point is a written description of the system to be implemented, with an extension of about 30-40 pages which includes the functional specifications and requirements of the system. Given the relatively low experience of our students regarding the architectural design, in the laboratory assignment document, we propose a simplified modular description of the system and a detailed description of the main subsystems.

In this scenario, our students need to integrate their knowledge from different disciplines: communication, control and signal processing theory, apart from electronics.

The ability to take initiatives

Some of the specifications that we include in the laboratory assignment document are open to the student creativity. In

order to reach the maximum score, students must implement optional functionality improvements on the basic proposed system. These improvements accounts for more than 15% of the total score, which means an additional motivation for students to take initiatives.

Some of these improvements are suggested in the assignment document (but not thoroughly described) and most of them are fully analyzed and designed by students themselves. This strategy has proved to be very effective for fostering students' initiative: our experience shows that more than 80% of the teams provide some new functionality to the basic system we propose.

Team working abilities

The laboratory assignment is carefully designed so that the amount of work required to achieve the course objectives corresponds to teams of two students. This way, students must organize themselves.

Communication and persuasion skills

We carry out the evaluation of each student team in two steps:

- The first one is the evaluation of intermediate reports during the semester. These reports help instructors to verify the evolution and originality of the work.
- The second step is the final evaluation based on the complete documentation of the system and an oral examination.

In both cases, the students must develop their communication skills, both in written and oral forms. Apart from the technical aspects, we evaluate the capacity of each student to explain the obtained results, in order to determine his/her degree of participation. Additionally, we also consider the technical writing quality, the skills for oral communication, teamwork capabilities, etc. All these factors are carefully recorded in one detailed evaluation sheet per student team.

The development of persuasion skills is not explicitly addressed in our methodology, but it must happen along the course: our students have to negotiate with their partners regarding the adoption of design decisions, the implementation of improvements to the basic assignment, etc.

Time planning and resources management

In the laboratory assignment document we also include a tentative planning to help the students on how to organize the different laboratory sessions in order to achieve the objectives in a professional-like environment. The planning is organized according to the achievement of given milestones, related to the fulfillment of different system requirements, but with loosely-defined timing restrictions.

This way, the students are faced to a typical scenario in a real-world project, while they are the ones to decide on the amount of time to devote to each milestone.

We also make special emphasis on getting the students to understand the importance of a careful design, taking into account some resource-saving considerations. Our strategy is rewarding the students with higher scores if they make explicit design decisions regarding the optimization of hardware or software resources.

Readiness to understand fully the needs of the customer and their project colleagues

Although this aspect is not explicitly addressed in our courses, it also happens along the course, as the students need to understand the requirements stated in the laboratory assignment document. Moreover, these requirements are sometimes not tightly defined (especially regarding the optional improvements), so that they have to contact the instructors in order to get additional information that refines the decision process they undertake.

TOOLS FOR IMPROVING THE MANAGEMENT OF PBL LABORATORIES

As stated above, dealing with a PBL laboratory with hundred of students implies a greater effort in management, coordination and evaluation. In order to ease these processes, we have designed and implemented a set of computer based tools according to the client-server-paradigm. In our case we considered web management tools, tools designed to capture relevant data for improving the progress-monitoring processes, tools designed to help in the evaluation processes and for feeding back the students on their designs quality, and tools to perform cheating detection.

Web management tools

Our web tools can carry out the following tasks:

- Managing the students enrolment and the assignment of weekly laboratory slots (time schedule), because it is necessary to have a list of students and teams (in order to automate the progress monitoring process) and several e-mail distribution lists (for electronic tutoring and for Frequently Asked Questions)
- Linking the examination of each team to an available instructor on a certain date
- Providing the students with additional services: extra-slot reservation or electronic access to grades
- Managing the final anonymous survey through the web: in order to evaluate the competence of each instructor and some aspects of the course quality, automatically.

Data acquisition tools

The basic management tools are not enough to efficiently run a PBL laboratory course with a high student-to-faculty ratio. They need to be complemented by a web tool to get monitoring data from students' progress at given dates:

- To verify the attendance of students to the laboratory in their pre-assigned slots or in extra ones.
- To estimate their degree of achievement of the functional objectives according to the time plan proposed by the instructors.
- To collect intermediate electronic deliveries that contain the software developed until that date. Typically in a semester students must carry out four or five partial deliveries and a final one, with three purposes: early detection of bad programming habits or errors (before it is too late to fix them); to deter students from plagiarism: a case of partial or full software copy is easier to detect by analyzing the history of deliveries and the coherence of the sequence, and the evaluation of the final software delivery is one the key points of the final grading (along with the oral examination, the final written report and the monitoring data). By using these tools, one can get a great deal of measurements to help the instructors in grading.

Tools for automatic software quality analysis and feedback

In the LSED course, the core of the project is the development of an assembly program for a Motorola microprocessor [10]. We have also developed an automatic tool to analyze the style of the assembly programs and to estimate its quality. This tool, based on statistical pattern recognition techniques, computes a feature vector with up to 48 basic characteristics from each program.

From the data collected in previous academic years, we have studied the correlation between the values of the features and the grade assigned by the instructors to the program (with the instructors being used as a source of expert knowledge). The data has been properly normalized to avoid differences resulting from the size of the program and the laboratory assignment that changes every year. With this analysis, we obtained the relevance of each parameter regarding the grade and we have tuned an automatic tool that helps both the instructors and the students to evaluate the software quality throughout the semester. The automatic tool is also used to guide (feedback) the students. The instructors can get information on the quality of students' software and advise them not only in terms of the functionality they have achieved (as reported by the monitoring tools), but also in terms of the way they code it. The use of this tool has greatly improved the software quality statistics when compared to the previous academic years (e.g., in the 2003-2004 academic year, there were 54.7% more subroutines per program, with 48.7% fewer lines per subroutine and an increase of 43.6% in the use of the more complex addressing capabilities).

Tools for plagiarism and cheating detection

In courses with a large number of students, most of them have to develop the same basic system (instructors are not able to specify and monitor different assignments for different teams) so that a certain degree of information sharing between students is not only admissible but also advisable. Nevertheless, students must achieve the educational objectives on their own, so most of the work must be based on original solutions. In our software based laboratories, we have developed automated tools to detect copies in the source code developed by students (standard similarity-detection programs are not useful as they are not fully adapted to dealing with assembly programs smartly modified by students). Given the high computational workload required to make full comparison among students we also use the monitoring data we collected (intermediate reports). By comparing successive files and routines from the same team, we can detect situations of sudden changes that are not usual in evolutionary prototyping. Although in our experience, plagiarism is not high in a PBL course (less than 5%), it is important to deter students from cheating (the rumor that plagiarism is easy can make PBL a failure).

Strategies and tools for improving the process of students' progress monitoring and students' advising (to focus instructors' tutorship on the teams with slower progress and to generate alerts on problematic evolution of the PBL course).
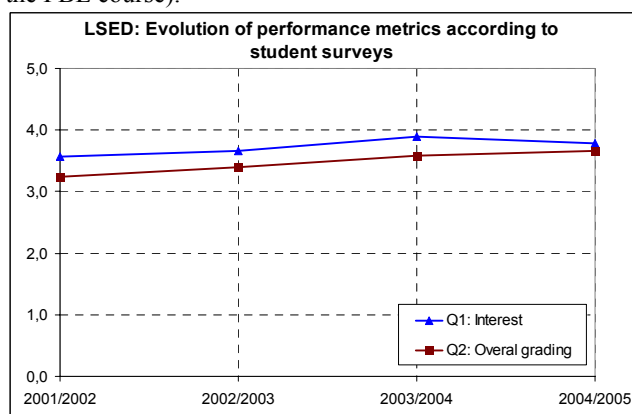

FIGURE. 1
PERFORMANCE METRICS USING STUDENT SURVEYS.

EVALUATION

During the past four academic years, we have been closely monitoring the grades of our students in order to evaluate their degree of achievement of the courses' objectives. Aggregating grading data from 2001/2002 to 2004/2005, we can show that:

- Almost 98% of our students passed the course.
- 35% of them got grades strictly over 80%.
- The average grade was 76.3%, very high in our academic environment.

We have also evaluated different aspects of the course quality, from the perspective of the student, by means of student surveys. Among all the possible performance metrics we measured, we have chosen two of them as the most

appropriate ones, linked to the following statements presented to our students:

- [Q1] The course has been interesting
- [Q2] The course is globally a good one: it is a measure of the course overall perception, as perceived by the students.

To answer these questions, every student had to choose among five different answers with a numerical value: I fully agree (5), I agree (4), I partially agree (3), I disagree (2) and I fully disagree (1).

In Figure 1, we plot the evolution of the two performance metrics between the 2001/2002 and 2004/2005 academic years. The main results are:

- Regarding [Q1], the students gave an average value of 3.73, with a minimum of 3.57
- Considering [Q2], the average value has been 3.47 with a minimum of 3.2

Both metrics and their evolution clearly show how the general tendency is improving and a very good acceptance from students.

CONCLUSIONS

Project-Based learning (PBL) is one of the most interesting instructional strategies in technical careers, fitting very well to the Career Space Consortium (CSC) guidelines. The CSC recommendations consider that the acquisition of soft (behavioral) skills is fundamental in the graduate curricula. In our PBL laboratory, we emphasize on the acquisition of the main soft skills recommended by the CSC. From our experience, we have learnt that it is not sufficient to devote part of the grade to these skills because students still perceive them as secondary in a PBL laboratory. They are confident on passing the final exam by making the system work. In order to foster the students to acquire these skills, it is necessary to demonstrate them that instructors can measure and evaluate the performance in each skill. With these measurements, the instructors can supervise and feed back the students along the course, and these skills can be included (in an objective way) in the grading process.

We have also presented a set of strategies and tools designed to face the problems when applying a PBL strategy in laboratories in electronics with a high student-to-faculty ratio. This set is a very good workbench where we can easily design and test ideas about different teaching strategies for PBL laboratories. Our proposal has been the result of four academic year's experience.

In our case, a very good example has been the software quality analysis tool. Although during the years, we have devoted part of the grade to the software structure and quality (systemic point of view), the students were focused in making the project work, leaving aside the design and structure of the software. The students had the feeling that software quality was a very subjective aspect, difficult to evaluate by the instructors. When we introduced the software quality tool for feeding back and evaluating, the students realized that the instructors reach this information in an easy and objective way, spending more time in these aspects. This lead to an impressive improvement in software structure.

The evaluation of the laboratory course shows that the suggested strategies and tools actually work in terms of student acceptance (on average, student grade the laboratories as 3.73 on a 1-5 scale) and in terms of student performance (on average, they get over 73% of the top grade). These figures show a remarkable success, especially if we take into account that our laboratory assignments are much more complex than assignments in standard guided laboratory courses.

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