An Experience of a Multidisciplinary Activity in a Biomedical Engineering Master Degree

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Abstract- **Training Biomedical Engineers presents major challenges because of the different backgrounds they are coming from. These activities should stimulate the student's professional skills and, in the particular case of a Master Degree, this is even more complicated. It represents a higher educational level where students should increase and improve their ability to solve problems related to very different areas such as the engineering and biomedical. The Biomedical Master Degree shared between the *Universitat Politecnica de Catalunya* and the *Universitat de Barcelona* has students coming with extremely different backgrounds, from the medical or biological to the engineering profile. Taking into account this situation, we have developed a *4-days multidisciplinary charge activity* in a particular course of Biomedical Devices. It is focused on the amperometric sensors and in the conception and application of biopotentiostat amplifiers. Regardless the student's profile the activity is focused in such a way that everyone has to work actively in the experience. This paper presents a proposal based on co-operative learning strategy and the feedback that students give to the learning process as a first approach for future improvements.**

Index terms: Biomedical Engineering Education, Workgroup teaching, Analog electronics teaching.

I. INTRODUCTION

The Bologna process in the European Union (EU) has been defining, since 1999, a new conception of the Credit measurement [1-3]. This European treaty that should be concluded in 2010 is the configuration of the European Higher Education Area. It brought a reformation in all the European Countries involved, in order to establish qualification comparability criteria for all the higher education institutions in Europe.

This new credit, defined by the European Credit Transfer System (ECTS) must be a measurement of the full student's work [4-6]. This conception imposes a more practical approach in the learning process, and it is of particular interest in technological disciplines where technical practices are essential for a complete learning. This was one of the main reasons to develop this activity, as a different approach to classical laboratory experiences. In the case of a Master degree in Biomedical Engineering, in the University of Barcelona [7], is even more important taking into account that the profile of the students covers several areas, and the conception of the curricular courses is a key point for their professional's future.

This Master degree is conceived with 120 ECTS credits which are distributed in 4 semesters.

As it was mentioned before, due to that this Master degree is cursed by students of different degrees, like Biology, Biochemistry, Pharmacy, Medicine, Veterinary, Ontology, Electrical, Electronics, Mechanical, Biomedical Engineering, Physics, and Chemistry, the students should follow different schedules depending on their previous knowledge. Students coming from Biological and/or Biomedical area can just overcome 60 credits to obtain their master degree. On the other hand, students coming with engineering, physics, and chemistry backgrounds must complete 5 ECTS extra credits.

In this paper is presented the conception of a specific experience in the course of Biomedical Devices, designed to an optional subject in the curricular formation of the students.

II. BACKGROUND AND INTEREST OF THE ACTIVITY.

The particular problem we have encountered has been how design an activity that allows students with different profiles work together ***actively*** in the lab, and an initial cooperative work has been followed. Interesting approaches have been presented in [8-9].

The key aspect is the design of one activity that allows to put to work in the same laboratory students as heterogeneous as we have found, being a completely new experience for teachers and also for students.

For this course, the theory is designed to cover several topics to understand, design and work with basic biomedical devices. Firstly, there is an introduction to the measurement systems, focused on devices and instrumentation for measurements of temperature, pressure and flow. Also there is a basic explanation of different types of sensors and biosensors such calorimetric, potentiometric, amperometric, optical biosensors, immunosensors and bio-optoelectronics, and to finish the students learn concepts of Electrochemical techniques, like voltammetry and Electrochemical Impedance Spectroscopy [11-13].

In particular, in the field of sensors and biosensors, the introduction to the concept of Potentiostat Amplifiers, and their applications with biosensors, has been used to design such activity for students that either have an electrical engineering profile or for those who are coming from other areas and could have a weak background in electronics.

Different objectives are pursued in the design of the experience. One is the development of an integrative laboratory that promotes inquiry, relevance, and hands-on experience for students with different profiles [14]. We do not want groups where just only some students work actively in the lab, depending on the type of activity. The scope of the activity is that everyone work and participate actively. In this experience the students must applied their skills in math, science and engineering. The key aspects of the ABET EC 2000 criteria have been followed [15]. The students take measurements and interpret their results.

This experience is based on a traditional master class, but it is just one more element in the process. Thanks to the activities in the classroom and the laboratory, some other aspects are reinforced, like the communication and team work between the students, working in a multidisciplinary team, and a more hands-on approach to learning is developed [16-18].

An important aspect is the cost of the laboratories for the biomedical engineering education. The Biomedical Devices lab is organized in teams of two or three students, in ten full equipped tables with standard instrumentation equipment. In our case, a portable low-cost potentiostat amplifier has been designed for each table. In the classroom some commercial biopotentiostat amplifiers are presented, from different commercial suppliers, like a high performance amplifier from TekNet Electronics [19], or an educational potentiostat like the Voltalab 06 [20]. These equipments are quite expensive to be placed at each table. Through the designed equipment students have an approach to this type of equipments at a low cost for the University. These kinds of equipments are compared with our discrete amplifier at the end of the sessions. The discussion arises in terms of the trade-off between their performances and cost, where the commercial ones are much more expensive than our low-cost PCB design, (30 USA$ vs. more than 3000 USA$ for each commercial device and worktable). Following these approach we can also incorporate in our laboratory an experience to provide students with hands-on, real-world application.

The presented activity, that is centered in a cyclic voltammetry, is designed in order to work different aspects related to the students activities (ECTS credit transfer), and to work specific objectives in the course, which are the interest to present the feasibility to carry out electrochemical experiments controlled by a PC, and make noticeable how works the instrumentation used to interface the electronics with the experience.

III. DESIGN OF THE ACTIVITY

The activity is focused on the presentation of the potentiostat amplifier and its use to control a cyclic voltammetry. There are different techniques to define a Cyclic voltammetry [21-23]. In our case, it is an electrochemical technique based on a triangular scan of the potential of the working electrode. As the potential of the working electrode is scanned in one direction, any electroactive species in the sample will undergo reduction or oxidation (depending on the direction of the scan). As soon as the direction of the potential scan is reversed, the species will undergo the opposite reaction (oxidation or reduction, respectively). These electrochemical reactions give rise to redox currents, which are recorded as a function of potential. The current-potential graph is the cyclic voltammogram, which gives quantitative and qualitative chemical information.

The selected biopotentiostat setup uses a three electrodes sensors configuration [24-26] which are a) the working electrode (WE), which serves as a surface on where the electrochemical reaction takes place; b) the reference electrode (RE), used to measure the potential at the WE, and c) the counter electrode (CE), which supplies the needed current required for the electrochemical reaction at the WE.This amplifier controls the voltage between the WE and RE electrodes to a control input voltage (Vin). In order to keep this condition the current at the RE electrode should be ideally zero and no current should flow through it.

The potentiostat amplifier design has a very low-cost structure which is depicted in Fig.1. This structure is based on four operational amplifiers (Opamp) and two resistors. OP4 is the transimpedance amplifier, which defines the virtual ground voltage of the WE electrode and provides current-to-voltage conversion. The key characteristics of the transimpedance amplifier, in terms of its input impedance, very low input leakage current and offset voltage, are some of the elements that the students must work in the activity, working their thinking critical skills**.** The gain in theI/V conversion is defined by an external resistor. OP3 is used to ensure minimal current flows through the RE electrode. It senses the voltage difference between the RE and WE electrodes, that is measured between the RE voltage and the virtual ground. This difference is used by OP2 and compares this voltage with the desired Vin voltage, changing the voltage at the CE electrode and defining a current trough the cell in such a way that the voltage difference between the RE and WE electrodes follows the defined Vin signal that polarizes the sensitive cell.

The activity is divided into four different parts, which are programmed in two weeks, as is represented in Fig.2, where are also indicated the inputs for the student's evaluation. The total work for the students is estimated to be around 10h, which are equivalent to 5/6 ECTS, for this activity. Five of these hours represent practical work done by the students in the faculty, and the remainder of the hours represents their individual or group work out of the classroom and the laboratory. It is important to emphasize that the students can contact their supervisors/teachers by e-mail for tutorship if needed.

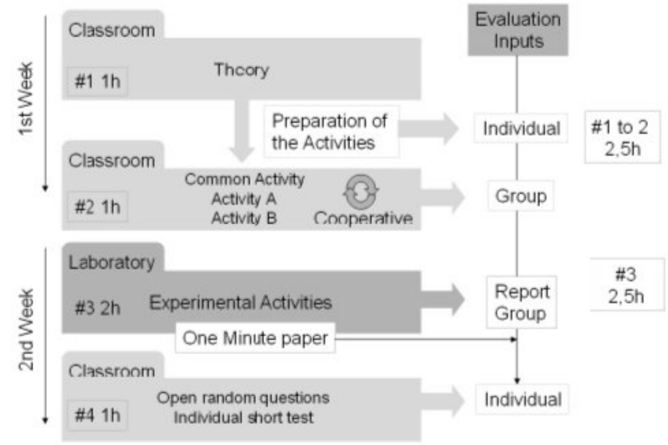


Fig.2: Schedule of the activities.

Team groups are formed by two classmates at least, where both are coming from different study areas but at least one of them should have engineering background. Ideally, a team of three members is preferred.

A work in the classroom is planned to present the circuit and experience, which is the first part of the program. The concepts of the potentiostat amplifier and the sensor are introduced in this section. The second class is devoted to a *cooperative task*.

In order to develop the work in the lab the students must prepare a theoretical previous work, which is developed here. This work is focused into three main activities, as a previous lab work, which programmed in terms of the student's profile.

This common activity for all the students is divided in two categories A and B. Activity A is oriented to students with an engineering background (A Student), and Activity B for the rest of them (B Student).

These activities must be read and prepared by the students before the class time. The common activity is based on the visual analysis and identification of the components used in the design of the potentiostat amplifier, of the designed PCB, which is depicted in Fig.3.

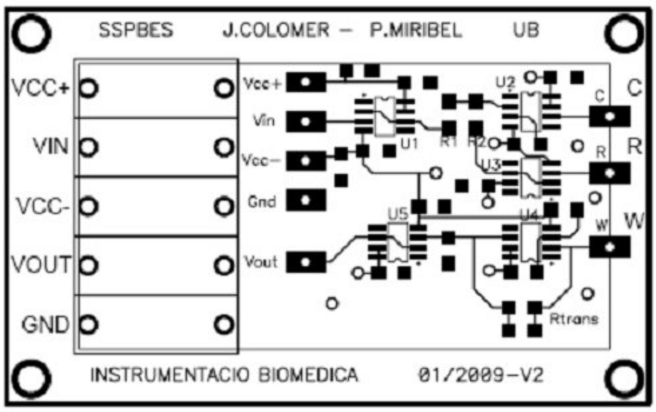


Fig.3: PCB representation of the biopotentiostat amplifier.

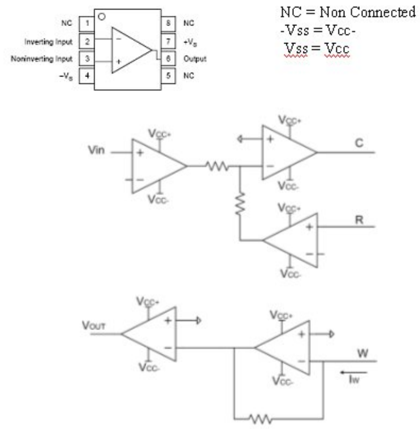


Fig.4: Caption of the exercise.

They must identify the different amplifiers that define the potentiostat amplifier, and find out the connections between the different elements, Fig.4. Following this technique all the students have a first contact with the PCB implementation before their experimental activities in the laboratory. The scheduled time for these activities, two hours, are more focused to run the different programmed measurements. This will make better time in the lab.

Activity A is focused to find out the mathematical expression that describes the relationship between the Working (W) and the Reference (R) electrodes with the input signal (Vin).

Also, for the students with an electric engineering profile, some more specific activities are programmed, and are used in order that they explain to their classmates the main reasons to select one amplifiers, and no others, for this design. The selected operational amplifier is the OPA 656 from Texas Instruments [27], which presents good parameters in terms of input impedance and offset voltage. They are requested to search the datasheet of this amplifier and compare it with some other amplifiers with worst and better characteristics like the LM741, LM725, LF411 and OPA124.

Fig.5: The instructor works with one group defining the CV measurement using Labview © interface of the programmed CV.

Activity B is focused to find out the sensor that has been used. The students only have the reference of the supplier (BVT Technologies) [28]. They must find its datasheet and identify the electrodes and their characteristics, and also will work the principles of the chemistry redox.The second part of the practical work is developed also in the classroom (second day), to work in a cooperative way. Previous activities concerning to each class are delivered, individually, to the teacher before the class, using the e-learning Moodle resources or e-mail. These are essential tasks for the individual evaluation of the students. Also, the students must indicate an approach to the time needed for them to complete the activities, which are estimated by us, around 2 hours and a half. Thanks to this work, out of the faculty, we are placing the students to prepare these activities before the work in group. If one of them fails, the whole qualification fails in the cooperative stage.

Following a three-step interview methodology [29-31], they must discuss the common activity and work on it together, the electronic background student (A student) should explain to the other students (B Student) its activity, in a basic academic language to be well understood for the rest of the group, and the B students introduce their research of the sensors to the A students. By the end of the class they should deliver a common report of the activity. Without this work finished and delivered to the professor before the laboratory activity, they can not go ahead with the activity, which is translated to a negative qualification.In the lab, part three, they proceed with the experimental measurements which are indicated in the student's laboratory manual. These activities are carried out during the second week. Work in the lab promotes interaction between students and the -laboratory equipments, with groups up to 20 members. In Fig.5 the instructor is working with one group, while they are taking a CV measures using LabView© interface.

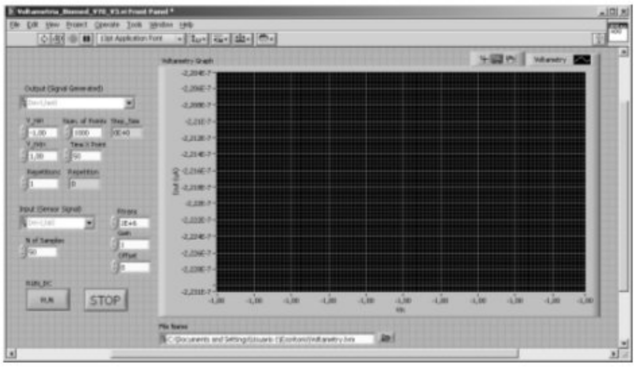


Fig.6: Interface of the programmed CV using Labview.

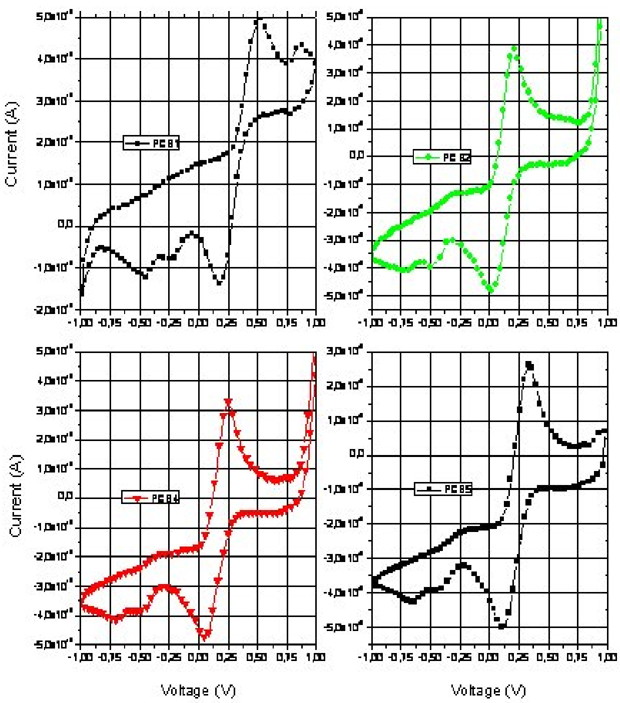


Fig.7: Different measurements programmed CV using Labview by the students.

During this session they are focused on the experimental part of the activity. The students work with a LabView©

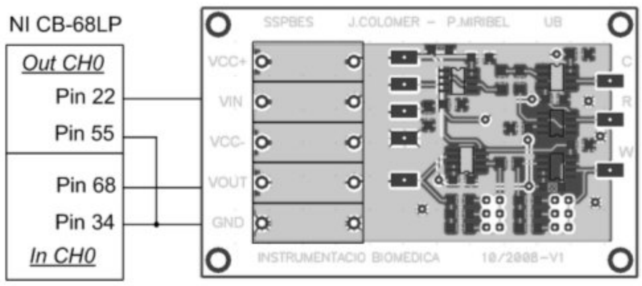


Fig.8: Interface connections between the PCB and the acquisition board.

Fig.9: Introduction review at the beginning of the lab session.

interface used to program and obtain the Cyclic voltammogram response (CV), defining the maximum (V_max), and minimum (V_min) voltage levels, time acquisition, in terms of the numbers of points (Num.of.Points), and the defined time of measurement for each point (TimeXpoint), Fig 6. The number of iterations for each CV can be defined (Repetitions) as well. They learn how the electronics are used to control the electrochemical reaction, basis of the electrochemistry. The CV, in terms of the current vs. the cycle voltage is depicted online in the panel, and the results can be browsed for their analysis, as shown in Fig.7. In the student's laboratory manual is described the right way that must be followed to bias the circuit, and the channels interface with the acquisition board, from National Instruments© (PCI-6014), as it is depicted in Fig.8. The instructor presents an introduction at the beginning of the session, Fig.9. Then, the students must prepare a report based on their measurements and some final questions. Reports are programmed to be presented to the professor before the next class, one week later. Also, the students must indicate the time needed by them to complete the report, which is also estimated around 2 hours and a half. At the end of the lab experience the monitor asks for a one minute paper [30]. That is a traditional technique followed in cooperative learning, and it is used in our case as a feedback measurement on where is the student's understanding of the material. Questions like: What was the most important or useful thing you learned today? Which three important questions do you still have? In the next class, the professor asks to the students following different strategies based on the feedback process: open random questions or short individual written examination. Also half of the class is used to solve the main student's doubts

IV. FEEDBACK FROM THE ACTIVITY

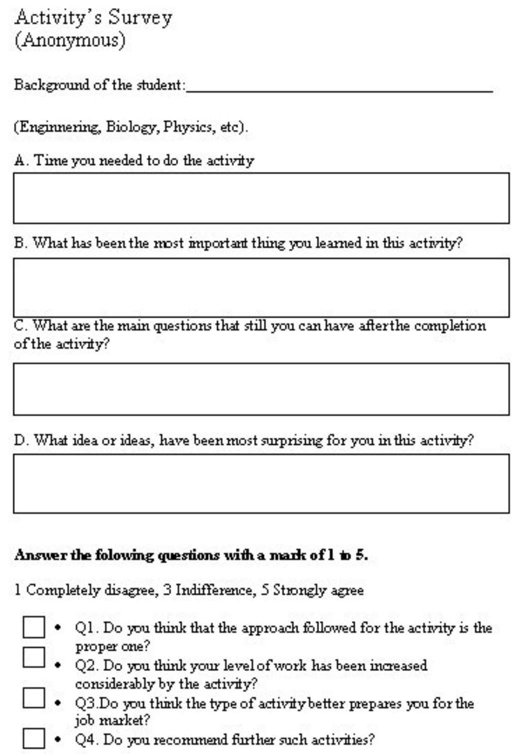
An interesting study has been also carried out between the students, which are not very keen on this type of activity. For this academic course we had 22 students, divided in four groups, as is indicated below in this section.

Figure 10 presents the survey used to know the opinion of the students about this activity. During this first experience we asked to them about their feeling about cooperative learning. From these surveys among them, we have analyzed their opinion and views on the full activity. These questionnaires are adapted from [33]. By using a defined scale, from 1(never) to 5(always), or 1 (strongly disagree) to 5 (completely agree), we have recollected the strengths and weaknesses of the activity.

In order to analyze these inputs, the curricular background of the students is required in the form.

The study was divided into four main groups depending on the background of students: Electrical & Electronics Engineering (7), Computer Engineering (4), Mechanical Engineering (2), Physics (4), Chemistry and Biology-Medicine (5). All students remark the interesting fact to know how they can relate the experience of a chemical reaction with the use of electronics' instrumentation for experiences that are the basis of spectroscopy.

Basically, the students with an electric and electronics engineering profile have an excellent comprehension of the involved electronics, and they focus their main interest in the experience, according to surveys, to the use of electronics in the functioning of the electrochemical experience. They highlight the fact that a potentiostat amplifier can be used in the measurement of chemical reaction and its biological applications. Their main concerns are related with the chemistry in the experience as it could be expected.


Activity's Survey
(Anonymous)

Background of the student:________________

(Enginnering, Biology, Physics, etc).

A. Time you needed to do the activity

B. What has been the most important thing you learned in this activity?

C. What are the main questions that still you can have after the completion of the activity?

D. What idea or ideas, have been most surprising for you in this activity?

Answer the folowing questions with a mark of 1 to 5.

1 Completely disagree, 3 Indifference, 5 Strongly agree

- Q1. Do you think that the approach followed for the activity is the proper one?
- Q2. Do you think your level of work has been increased considerably by the activity?
- Q3.Do you think the type of activity better prepares you for the job market?
- Q4. Do you recommend further such activities?

Fig.10: Survey's form.

In the case of the rest of engineers, and for students with a degree in Physics, they have some difficulties with the electronics but they can cope with them with success. They have the same difficulties with chemistry linked with the laboratory experience.

As examples, these are some interesting answers of the students.

From question B of the survey: *What has been the most important thing you have learned in this activity*, they responded: "The use of chemical sensors, which I had never seen one, and I had no idea how they were and how they could be used, and thanks to the experience I have a first approximation.", by an Electrical and Electronic Engineer.

"I learned a visual and practical use of an electrochemical instrument", by a Mechanical Engineer.

For question C, *What are the main questions that still you can have after the completion of the activity?*, they say "My main doubt is related to the electronics", by a biologist. This answer is common in the group of chemistry, biology and Medicine students.

"My main problems were when I has to analyse the electronics", by a Physicits.

"The voltammogram response is a bit difficult for me to understand", by a Mechanical Engineer, very similar with comments by other students with an engineering brackground: "I do not understand very well the measured curve", by a Computer Engineer.

For question D, *What idea, or ideas, has/have been most suprising for you in this activity?,* the say: “The fact that an electric current is generated by a redox reaction and it is converted to a voltage that can be measured and processed.” by a Computer Engineer.

“The use of the electronics with the chemistry and sensors in the field of the introduced application and its use”, by a biologist student.

“It is for me the most surprising and new idea that I have learn from this experience that you would be able to measure biological concentrations using electronics”, by a Computer Engineer.

“The current detection by the electronics which is produced by the redox reaction”, by a Physicist.

“The application of electronics in biomedicine in general seems very important.” by an Electrical and Electronics Engingeer.

There are also some comments which are very grateful for the lab professors, like: “The attitude and involvement of teachers surprised me positively”, which is a great reward for teachers. In terms of the proposed experience, in general, and especially for the majority of students with a deficiency in training in electronics, the method has a high score, as it is shown for the different groups for question Q1, Fig.11.

What has been a great surprise is the average of indifference in terms of the work load for the students, question Q2. We expected a general sense in terms of an increase in the hours needed for the experience to be completed by the students.

Question Q3, designed to check the practical impact of it, in terms of a real job training approach, we have very different answers. In the particular case of the mechanical engineer’s profile, they mark this question with an average of “2”, which is a “disagree” opinion. Computer Engineering students and Biology-Chemistry and Medicine students have a good perception of this activity as a nice preparation for a real job.

Finally, question Q4 indicates a good perception of the students with this type of activity, which indicates a success in terms of the implementation of this kind of co-operative activity in this particular field.

The ECTS work of this activity represents 1/6 of the total activities of the students in this subject. Our first estimation was planned to be a total average of 10 hours. Thanks to the feedback collected from the students the real average time is around 12h.

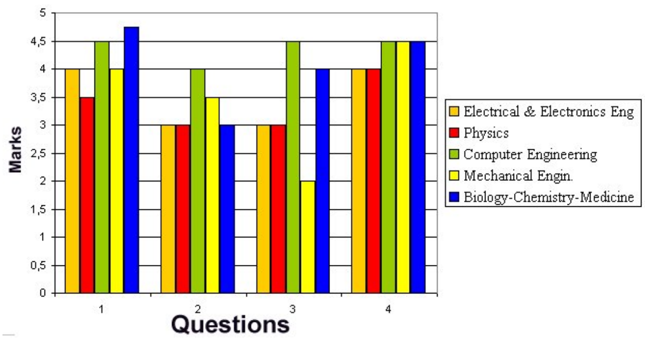


Fig.11: Mark’s report for survey questions Q1 to Q4.

V. Conclusions and Future Work

This activity has been conceived to provide students with real hands-on experience. The focus of the activity was achieved for all students, regardless of their profile. They worked actively in the activity, having a good understanding of the experience, difficulties in more detailed aspects, but with success in the entire experience.
The students are introduced to one type of sensors and they work with the electronics involved in the design of a potentiostat amplifier, in its basic architecture. In this way they are introduced to commercial solutions but working in a design based on discrete components they are able to have an approach to its architecture. Also, in terms of cost it is more economic to have this discrete PCB for each working group that a commercial one. In this activity they work different clue aspects like the application of previous knowledge, the ability to work in multidisciplinary teams, communicate their results, etc ...

Teachers have noticed how all the students have understood the experience and they worked actively on it, particularly students with very weak foundation in electronics have been able to work with the track and understand the experience. No typical passive roles in the labs were present, which was one of the main concerns taking into account the diversity of the students.

Next year we would like to change the followed approach to increase the interaction between the students. The students with and engineering background will work just the sensors and chemical aspects of the activity, and the rest of student will work in the electronics. Then, they will work following a three-step interview methodology. In this case we expect a better interaction. The students will correct their classmates within the fields they have a better understanding and background.

It is also our purpose define new modules of experiences, like the Electrochemical Impedance Spectroscopy (EIS), and the use of lock-in amplifiers in the characterization of sensors and in the measurement of Electro Chemical Impedance Spectroscopy.

More in-depth analysis of the student's ECTS charge and comparative analysis of the qualification of the students following this kind of activity or traditional approaches will be presented in future works.

ACKNOWLEDGMENT

The work has been supported by the Calatan Government through the project "Millora i Qualitat Docent", MQD-2009, number MQD00226.

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