PROTOCOL AND MATERIAL FOR THE INTRODUCTION TO THE LABORATORY EXPERIMENTATION

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Abstract
Introducing students in the world of the experimentation has always been a complicated task, since the students are not familiar with the new work place. They have to handle different measuring devices, interiorize the philosophy of the experimentation, measure and estimate uncertainty, graph data, and finally write a report about the results of the experimentation. Students do not know this whole process, and although they delight to do practical work in the laboratory, they do not feel confident of carrying out a proper work.
In order to achieve so, a multimedia material has been elaborated, with an introduction to the laboratory and the experimental techniques which require the implication and the autonomy from the student.
The outcome of this process -students setting the established protocol in practice and achieving competences- has been clearly superior to that reached in previous years.

Workshop Topics
Autonomous learning.

I INTRODUCTION

The laboratory is the place where students observe, measure, demonstrate and understand the phenomena happening in the nature. It is there where students should acquire the habit of working with scientific accuracy. It is a good place to do an experiment. Richard Feymann wrote: *The test of all knowledge is experiment. Experiment is the sole judge of scientific 'truth'* [Feymann, 1964].

When the students begin an engineering or scientific degree, they usually have some quite limited knowledge, skills and abilities about the experimentation work in a laboratory. Nowadays, contrary to previous years, this is a basic formation in the curriculum of the students, since they get some important transversal competences, achieving more integral formation. In the first year of an engineering or scientific

degree, students will have handled different measuring devices which they will continue using in subjects of following years and later in the industry.

Introducing students in the world of the experimentation has always been a complicated task, since the students are not familiar with the new work place. They have to manipulate unknown instruments, interiorize the philosophy of experimentation, measure and estimate uncertainty, analyse experimental data at various levels of sophistication, graph data, and describe the relationships between quantities. Finally they have to communicate results, writing a clear and cogent report [AAPT, 1997]. Students enjoy laboratory work while performing the experiments and they see the laboratory work as a challenge [Hanif et al., 2009]. Even so, students do not know this whole process, and do not feel confident of carrying out a proper work.

We have settled down a work protocol to supervise laboratory experiments when they are carried out. This protocol has been elaborated after analysing the European Higher Education Area and the situation of students of Physics in an engineering degree: the necessity that they should acquire transversal competences such as instrumental, interpersonal and systemic competences like learning in an autonomous way. With this protocol, the students should get confidence about how to move in a laboratory, how to carry out an experiment with accuracy and how to report the final results.

In order to achieve so, a multimedia material has been elaborated, with an introduction to the laboratory and the experimental techniques [Mercadé et al., 2009]. This material requires implication and autonomy from the student. It is gone into detail in Section 3.

This material has been used during the academic year 2008-2009 by the students of Physics Subjects, in degrees of Engineering, in the *Escola Politècnica Superior d'Enginyeria de Manresa* (EPSEM) of the *Universitat Politècnica de Catalunya* (UPC). The outcome of following this protocol has been evaluated, through opinion surveys to professors and students, and taking evaluation tests both on contents and on competences, and it is discussed in Section 4. Finally a summary and some conclusions are commented in Section 5.

II BACKGROUND, GOALS AND OBJECTIVES

The School of Engineering of Manresa (EPSEM), founded in 1942 as a Mining College, is located in Manresa, in the centre of Catalonia, at the Nord-East of Spain. The School offers degrees programs in Engineering of: Mining, Electronics and Automatic Control, Mechanical, Chemical, Telecommunications and Industrial Scheduling.

As a university of engineering education, the role of the laboratory is one of the most important things. In 1958, at the National Electronics Conference in Chicago, a professional group on education sponsored a panel discussion on the Role of the Laboratory in Engineering Education [McFarland, 1958]. They defined the laboratory as the real working area where the student receives an important part of the training which will qualify him upon graduation as an engineering technician.

All the students in the first year at the EPSEM should carry out a Physics course, usually in two terms (Physics I and Physics II), where they should learn the most important physical theories, with insight into their logical and mathematical structure, their experimental support and the physical phenomena that can be described with them[1]. Thus, the engineering students at the EPSEM get their first contact with the laboratory in this Physics course.

The primary goals of introductory Physics laboratories have been evolving over the past century. The American Association of Physics Teachers developed a set of common goals [AAPT, 1997] which can be summarised in: the art of experimentation, experimental and analytical skills, conceptual learning, understanding the basis of knowledge in physics and developing collaborative learning skills. Recently, the tuning project[1] analysed in detail the skills and abilities that the physics students should acquire in the European Higher Education Area. Finally, the UPC mentioned seven generic competences which should be included in the design of the programmes of the news degrees, of which it is necessary to highlight: oral and written effective communication, working in team, solvent use of the information resources and autonomous learning[2]; all of them are very appropriate to be acquired during the Physics laboratory work.

As it is said in Section 1, introducing students in the world of the experimentation is difficult. With this difficulty in mind and thinking of the goal that students should be able to handle different measuring devices, analyse experimental data, understand the uncertainty associated to measurement and, finally, communicate results in a clear and cogent way, and at the same time acquire the competence of autonomous learning, the authors of this paper established a main objective to get: "To elaborate a multimedia material, with an introduction to the laboratory and the experimental techniques."

The material to be elaborated should allow the students to get the knowledge, skills and ability to:

1. Know a protocol to obtain information from the laboratory work.

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[1] The project Tuning Educational Structures in Europe is available at http://www.tuning.unideusto.org/tuningeu/

[2] 'Document marc per al disseny de les titulacions de grau de la UPC' is available at https://www.upc.edu/eees/guia_disseny/fitxers/marc-de-referencia/marc-upc/document-marc-per-el-disseny/

2. Identify and handle measurement instruments carefully.
3. Estimate the accuracy/uncertainty of measurements.
4. Note down a well written measurement log to remember what was measured and what happened during the measurement.
5. Analyse data by calculations and by plotting graphs that illustrate functional relationships between quantities.
6. Evaluate the uncertainty of results, at various levels of sophistication, following the rules of the International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC).
7. Compare the theoretical predictions of physics with the reality we actually observe in the Physics laboratory. Understand the inherent limitations of measurement processes.
8. Communicate results, writing a concise and organised report on the experimental observations and results obtained.

At the same time, setting this material in practice should help students to:

9. Learn in an autonomous way
10. Make decisions; apply the knowledge to the practice and master basic physics concepts.
11. Feel confident of carrying out a proper work

With these goals and objectives in mind the authors have designed a work plan and elaborated the multimedia material.

III WORK PLAN AND MULTIMEDIA MATERIAL

The proposed project should help the students of Physics in first year of engineering degrees of the EPSEM to begin the laboratory work with self-confidence and to acquire the proposed objectives. The following work plan was elaborated with this purpose:

1. Design of the structure.
2. Documental research.
3. Elaboration of the theoretical scripts, exercises and self-evaluation tests.
4. Applets, filming and photos.
5. Elaboration of the final product.
6. Setting in practice.
7. Evaluation.
8. Revision.

Following this work plan, a multimedia material was elaborated which consists of two parts: "The Physics laboratory" and "Experiment 0" (see Figure 1). Each one of these parts contains different subparts which are detailed below. From the name one could say that this material takes the student near to a Physics laboratory, but most of the material could also be used for an approach to another laboratory, (for example: of Chemistry, Biology, Electronics...) as Metrology is basic in any subject.

Figure 1. Introductory page to the website

III.1 The Physics laboratory

It is recognized that the preparation of students for doing an experiment before a laboratory session improves their performance in the laboratory and can lead to meaningful learning [Johnstone at al., 1998]. It is well-known that if students know exactly what they have to do, they are more self-confident and get better results. This is basically our goal in this part of the project.

This part first shows the students what a Physics laboratory is like; it proposes them many experiments to do step by step [Mercadé et al., 2008], which are supplemented with photos. It explains the general rules for the realization and completion of an experiment. Besides, it offers links to other websites with simulations and other helpful information.

The authors emphasize two aspects of the experiment: the preparation and the report. The students are advised to prepare the experiment before hand. They should think what they need to know, what they are going to measure and which devices are going to use. It is useful to make a template of the log book since they should write in it during the experimental session. A list of tips is illustrated in this website.

On the other hand, writing a report is a good way to organize the measurements, to communicate the results and to show the understanding about the process and the results. *Learning how to write a good laboratory report is like learning to ride a bike. Once you've figured it out, you can do it over and over again*[3]. With this comparison in mind, this material also shows students, bit by bit, how to write a high quality scientific-technician report. It should have the following elements: cover page, introduction, experimental methods, data processing, and analysis of results, conclusions, references and attachments. The students are forced to compare reality with theory, to analyse the whole process that has been carried out and to propose future investigation areas.

[3] http://goto.glocalnet.net/ibweb/homepagelink.htm

III.2 Experiment 0

This second part familiarizes the students with measurement techniques and data analysis.

This material especially emphasizes in a great deal the habit of measuring with accuracy and precision, since this skill should be part of the individual's scientific formation. If students do not consider the fact of getting a small error between the measured value and the true value very important, they will neither pay attention nor care to the process of measuring. Students should interiorize the importance of working with accuracy. Due to the fact that working with accuracy is highly valued by the industry, the university has to prepare students in this way, to have a successful and immediate entry into the labour market.

Subsequently this material illustrates how students should measure correctly, how they can estimate uncertainties, and how they can write the final result of the measurement, following the rules of the International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC) since these rules will be those that they will probably use on their future job industry (Kirkup and Frenkel, 2006). It also teaches them how to create a graph and describe the relationships between quantities, and it provides tables of units, of physical constants,...

Finally, it teaches the students how basic measurement instruments work, using applets that allow them to train as if they were really using these tools (see Figure 2).

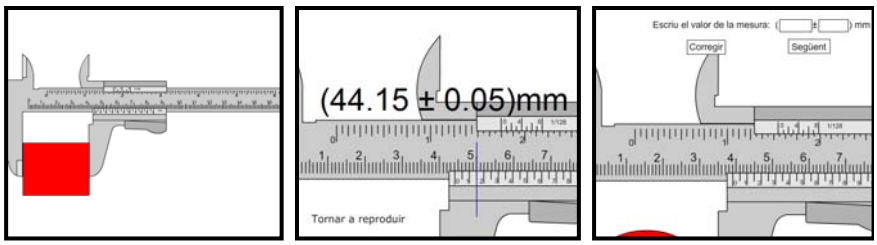

Figure 2. Sample of an applet about the working of a calliper

Some sections of this study have been classified to two levels of difficulty: the elementary one, for the students who begin the engineering studies, and the higher level, for the students who have already learned the elementary level. In this way, the students will gradually learn the whole protocol. The whole material is thought for an autonomous learning of the students. The students can know their learning level answering the proposed self-evaluating tests.

IV SETTING IN PRACTICE, RESULTS AND DISCUSSIONS

This entire material is available in http://www.epsem.upc.edu/~practiquesfisica/ and it is linked from the virtual campus of the university (called Atenea), which uses the Moodle platform. This campus has virtual classrooms where a discussion forum between the students and the professor can be established. This method allows the student to improve in its learning and in the acquisition of the proposed protocol.

This material began to be used in September 2008, by the students in first year of Engineering, so at the moment we can analyse the results of one academic year.

A survey form was designed in order to know the opinion of the students about the material (see Table 1). They should tick the box which best reflected their opinion, in nine items: not at all (1), a little (2), sufficiently (3), quite a bit (4) or very much (5).

Table 1. Questions of the students' opinion survey.

1.	Does preparing the experiment in advance help you in your execution in the lab?
2.	Is it useful to have websites available with information about how basic measurement instruments work, with applets that allow you to train with them?
3.	Have the tests that appear in the website helped you to understand better the concepts of measurement, uncertainty, graphs, etc.
4.	Does a correct writing of the experimental measurements and the results show the importance of working with accuracy?
5.	Do you think that in a first year of Physics laboratory the experiments, the measurement rules and the writing report guide should be very ruled and clear?
6.	Does the writing of a report help you to understand the experiment better?
7.	A report should allow you to communicate your experimental work. Do you consider that you have learned what a high quality report is like?
8.	Do you think it is convenient that all the subjects in the degree have the same rules about writing measurements, evaluating uncertainties, doing graphs, writing a report...?
9.	Will the knowledge obtained in the experiment zero and their application in the other experiments allow you to have more skills and abilities to work in the industry?

The averages of the responses are quite positive as can be seen in Figure 3. Students evaluated positively the possibility of self-learning, and they appreciated the establishment of a rigorous protocol for the realization of an experiment. They believe that they have learned how to write a report and they would want to use the same protocol in other subjects of the career.

In question 10 (not shown), they expressed that this material makes them feel confident in the laboratory environment, knowing what they are going to do and how to carry the experiment out.

The professors evaluated how the elaborated material works and its usefulness very favourably, both for the presentation in the classroom and for the students' autonomous learning.

The outcome of this process -students putting the protocol into practice and achieving competences- has been clearly superior to that reached in previous years.

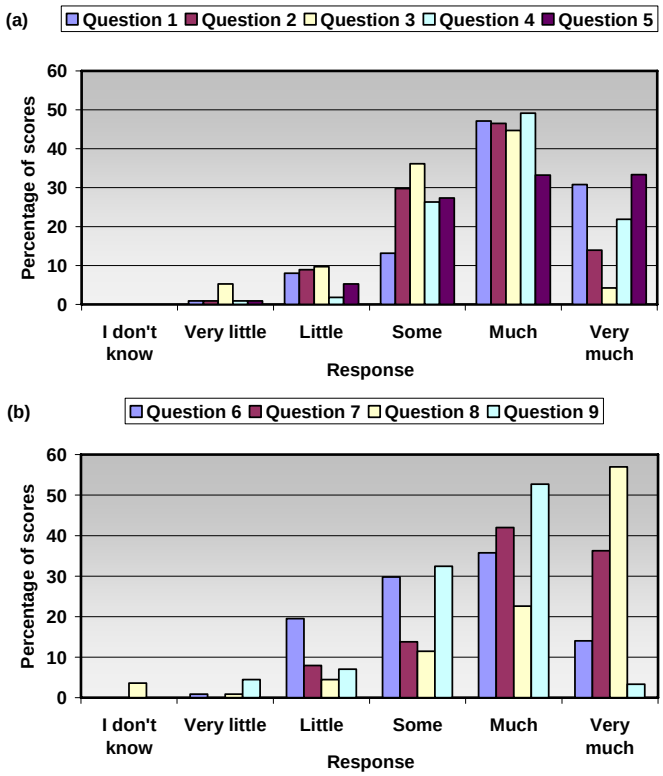

Figure 3. Percentage of scores of the opinion survey of the students. (a) Questions 1 to 5. (b) Questions 6 to 9.

V SUMMARY AND CONCLUSIONS

A multimedia material has been elaborated to introduce students in the world of the experimentation. It establishes the whole protocol to follow when carrying out a laboratory experiment, independently of the subject. This material requires implication and autonomy from the student.

The students showed their satisfaction after using this material and they achieved higher qualifications that those that other students had achieved in previous years.

The professors evaluated the utility of this material very favourably, both for the presentation in the classroom and for the autonomous learning of the students.

For these reasons teachers and students would like to continue using this material and to implement it in other subjects of the engineering degree.

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