Networked Implementation of an Electrical Measurement Laboratory for First Course Engineering Studies

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***Abstract*—A method based on the use of computers to guide and supervise the practical work performed by the students in a basic hardware laboratory is described. The bench computer adds real-time monitoring of the work done by the student, so that most mistakes, improper measurement settings, etc., are detected and immediately fed back. This environment reinforces student motivation. The networked architecture of the laboratory permits the centralized supervision and tracking of the work done at each bench. The use of standard communication protocols allows the extension of the approach to remotely located benches under the supervision of the central server. Internet-based tools are also included in the method to complement the learning process.**

***Index Terms*—Engineering education, graphical user interfaces, laboratories, teaching.**

I. Introduction

THE USE of computers to improve efficiency in the learning process has been proposed since the early 1980s [1], [2]. In recent years, the increase in performance together with their affordable prices made the introduction of PCs possible for different tasks in the engineering curricula, especially in electronic engineering [3]. Moreover, the introduction of networking and the Internet has prompted some institutions to propose the use of these technologies as an essential part of education [4].

The introduction of the PC in laboratory courses has led to the teaching approach that uses these technologies in applications that either simulate the problems [5] or use the browsers as graphical interfacers to follow hypertext format courses [6], [7]. In these cases the computer simulates the "real-world experiment," and the student interacts with a simulated interface [7], [9] that provides a limited hands-on experience with problems such as noise, component value tolerances, temperature derating effects, etc. Although, these methods show clear benefits: 1) lower the cost per unit, since no real instruments are needed; 2) allow a great degree of self-training; and 3) allow the possibility of delocalizing the laboratory, these approaches do not provide hands-on experience to the students with actual instruments and circuits since they do not interact with the "real world."

On the other hand, in the classical approach to a hardware laboratory, the students are arranged in small teams to develop their experimental work on a bench, dealing with real circuits. An instructor helps them to overcome the practical problems they encounter; but, often, there are mistakes that pass undetected because the students themselves must validate their results.

This method has the advantage that the students get hands-on experience in actual implementations; but, as a practical consideration, it requires a smaller ratio of students per instructor. The number of instructors should be increased proportionally as well as that of the students, leading to either a low instructional yield or a high cost.

In this paper, the authors describe a new approach based on the use of "real experiments" (with real electronic components and circuits, using advanced instrumentation) in an environment where instructor supervision is in part substituted by a software application "*Laboratorio de Medidas Eléctricas* (LME)," developed in the authors' department) that runs on the bench computer. The individual progress of each bench is supervised via a server application in a networked installation, and the learning process is assisted by the on-line exercises and additional web resources that reinforce the student's progress.

In this structure the students deal with circuits and instruments, but some of the basic assistance provided by the instructor in a conventional laboratory is provided by the LME. This software is structured in the form of an electronic book that has some degree of assistance and decision-making capability. The measurements are monitored via the general purpose interface bus (GPIB)-controlled instrumentation. The LME then analyzes the obtained results and the experimental conditions.

The application of this method during the last three academic years in a beginner's laboratory in the Telecommunications Engineering curriculum of the Polytechnic University of Madrid is referenced together with the complementary tools that have been developed.

II. Overview

The goal of the telecommunications engineering studies is to provide the student with a high-level background in information technology (IT), i.e.: electronics, computers and telematics, and communication systems and technologies. These studies span more than ten terms ending with the writing of an engineering project.

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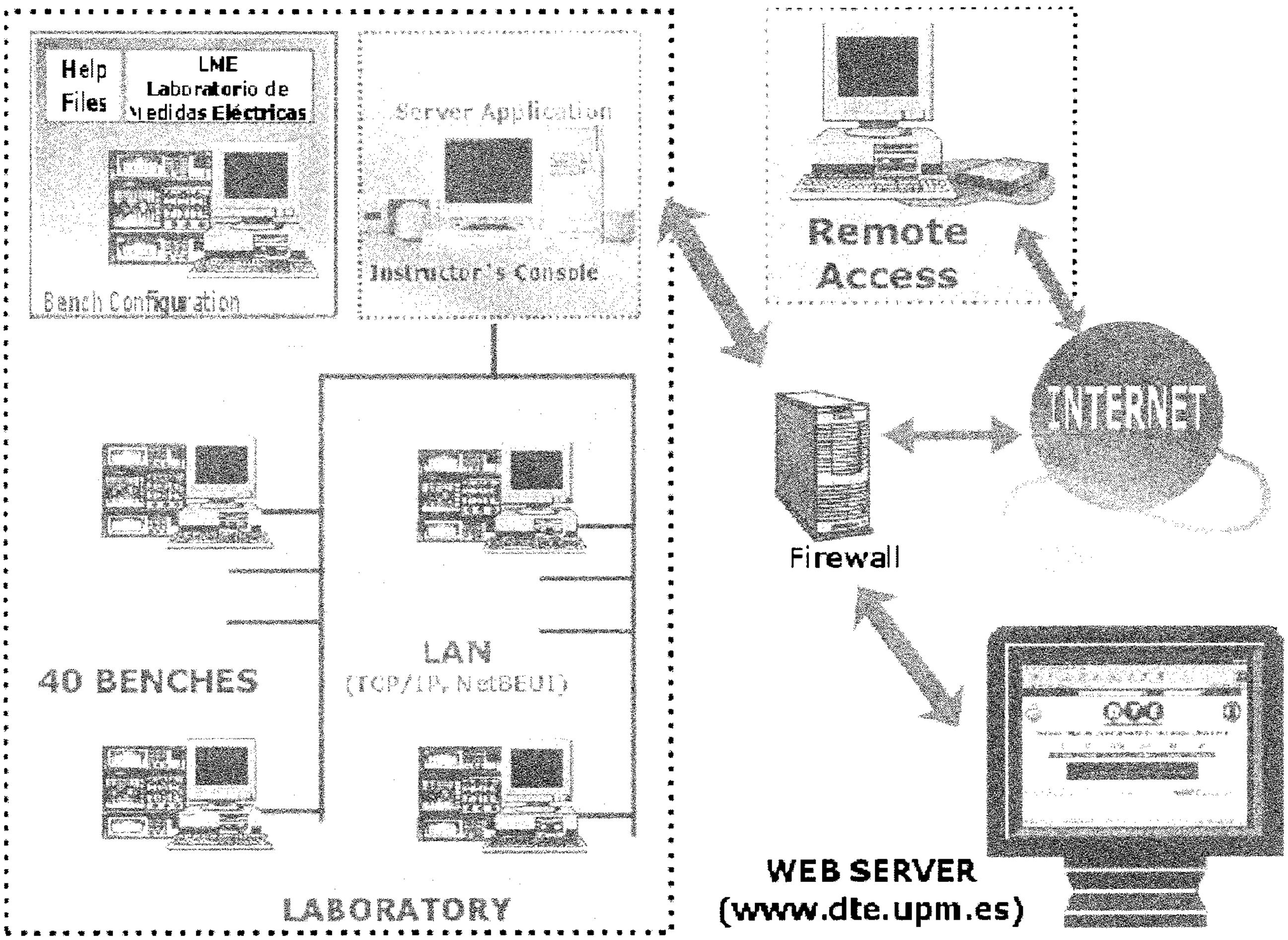

Fig. 1. Networked architecture of the Lab.

The first terms are devoted to providing a basic common level in mathematics and physics while the basic concepts of circuit theory, electron devices and circuits, electromagnetics, and signal theory are introduced.

A special characteristic of the curriculum offered by our School (*E.T.S.I. de Telecomunicación de la U.P.M.*) is that the laboratories follow the theoretical lessons presented in the lecture course on an independent basis instead of being treated as the "standard" lecture-laboratory course.

The laboratory course described in this paper is mandatory for students in the second term of the first year, and it must provide 30 hours of practical work to about 450 students, divided into groups of about 80 participants. The large number of students poses some specific problems that are addressed in this paper.

A. Matter Description

The goal of the laboratory work is to provide the basis of electronic practical work, i.e., the use of basic instruments and measurement techniques, the understanding of the methods used, and the validation of the obtained results. The students also implement simple electronic circuits from a schematic drawing (often for their very first time).

Besides learning how to use the standard instruments in optimal conditions (instrument selection and configuration, minimum loading effect, etc.), they learn how to measure the different parameters of the electrical signals (frequency, amplitude, phase shift, rise time, etc.) and the input–output characteristics of electrical circuits.

The students are evaluated with a mandatory exam made up of two different exercises: one in the lab, where they must be able to take some experimental data using the instrumentation, and a complementary questionnaire on electrical data manipulation and interpretation.

B. Laboratory Facilities

The laboratory has 40 benches in normal service and four backup benches. Fig. 1 shows the bench configuration, each having general-purpose instrumentation (TDS210 digital oscilloscope, HP34401A multimeter, HP33120A function generator, and HP3631A power supply) with GPIB (IEEE488) capability linked to a PC running the LME. The computers on the benches use Windows 95 as their operating system, and they are LAN networked (Ethernet-IEEE 802.3) under the control of a Windows NT Server. NetBEUI (NetBIOS, Network Basic Input Output System, Extended User Interface) and TCP/IP protocols are used. The hardware and software elements of this configuration were the standard ones when the method was implemented (1996–1997).

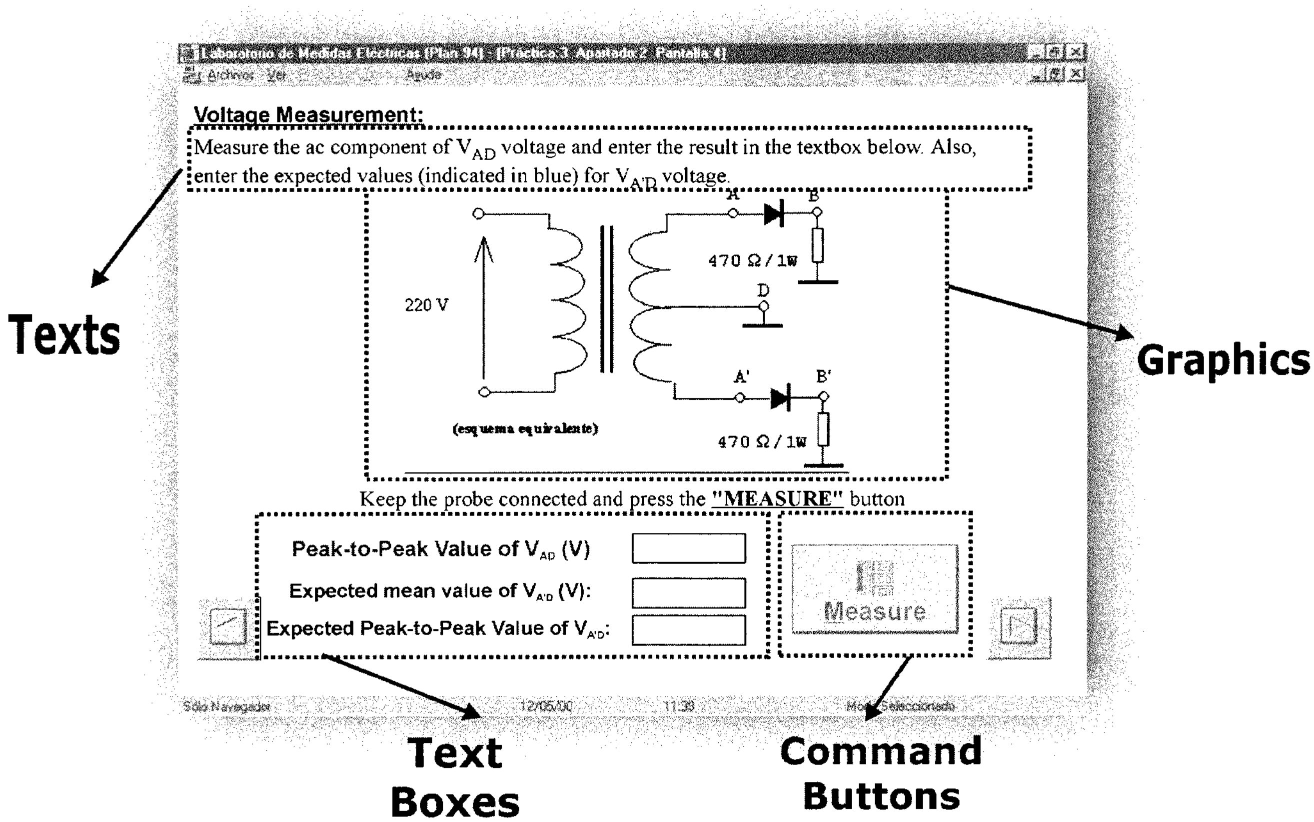

Fig. 2. Example of a screen. The user interface contains text, graphics, text-boxes, and command buttons.

The PCs on the benches had two predefined user profiles, i.e.,:

1) "network administrator," which allows full control of the machine, intended for lab maintenance;
2) "student on the bench," with limited user privileges. The students only have access to the applications that they need to follow during the current practical exercise. In this profile most of the "accessories" and other operating-system tools are removed from the Start Menu in order to preserve the PC configuration.

The server-application developed allows the instructor to follow and control the activity on the benches. This application assigns user privileges on PC start-up, keeps trace of the activities of the benches, and records their partial results. This archiving allows the recovery of the work already completed in the case of bench power failure (not so uncommon in a beginner's laboratory) and facilitates the moving of a group of students to a backup bench in the case of GPIB or instrument failure (usually a protective fuse blow).

III. Experimental Work

In the PC on each bench, the LME controls the session and guides the student through the experimental work assigned. Each session is structured in different pedagogical parts (chapters) which can be entered independently with each part divided into steps leading to an electronic book structure. Usually a step needs more than one sequential page on the screen, for instance: set up of the circuit, initialization of the instruments, gathering of data, and answering to the questions related to it. The possibility of entering the different chapters at will is useful if a student wants to do only a part of the assigned work or redo it.

Fig. 2 shows an example of a typical LME screen. Labels, rich-text paragraphs, text boxes, illustrations, one active measurement command button, and two specific navigational buttons are included to provide the graphical interface. The students write their results in the text boxes and push the button to check them. From all of the LME screens the students have access to links to help files ("Help" in Fig. 2) describing the use of the instruments, specific techniques, or the electronic version of the hard copy Manual. These files are in Windows help format.

A. Application Operational Modes

On start-up, the application takes control of the GPIB and checks whether the instruments are powered and operational. After that, the full screen electronic book is opened; and, if the bench instruments are ready, it can be used by the student in one of the three modes, as detailed in Fig. 3. If the instruments are not ready (unpowered or faulty GPIB connection) only the two first modes are allowed.

These modes are as follows.

1) Browser Only: The program shows, in a sequential and structured form, the contents of each session, including the text, the schematic drawings, and the graphics. The user can follow the instructions given by the computer to carry out the experimental work (electronic book), but the introduced data are not processed. Help files on the instruments to be used and procedures necessary to carry out the work are available.

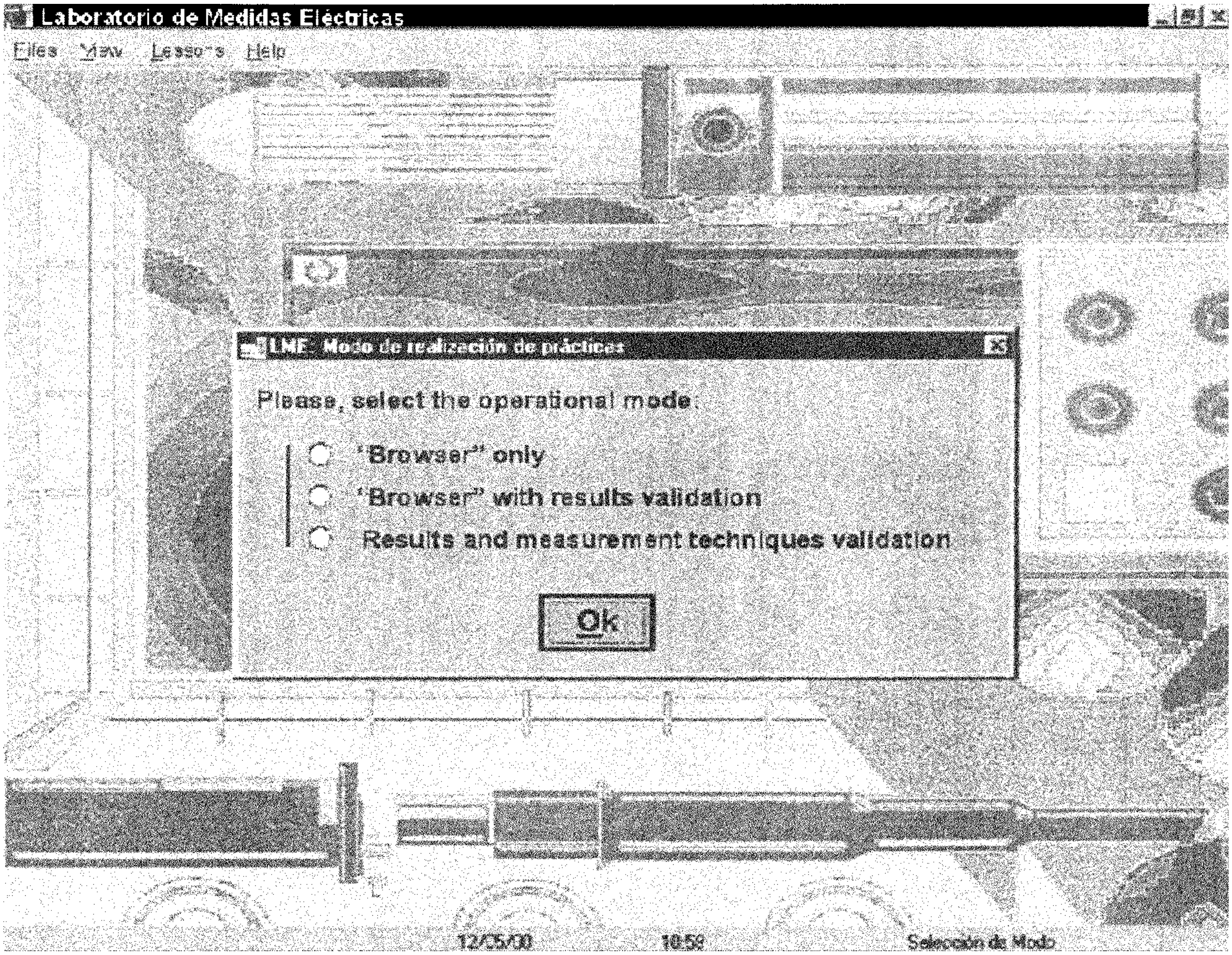

Fig. 3. LME operates in three different selectable modes.

This operational mode is intended for a quick review of the contents of each lesson.

2) Browser With Results Validation: In this mode the user introduces his/her experimental results in each part, and the program validates the data checking them against the values stored in a standard results table. Warning messages, with hints on the most probable source of error, pop up when the data are not acceptable (their deviation from the expected results is higher than a given percentage specific to the exercise being done). If the introduced data are accepted by the program, the next screen is shown.

3) Browser With Validation of Both the Results and the Measurement Technique: This mode was designed to be the preferred operational mode.

In this mode, besides the tasks carried out previously, the program takes control of the instruments, determines the optimal measurement conditions (range, time-base, or sensitivity factor), and obtains the correct data. Thus, the validation of the results introduced by the student implies that 1) the introduced data agree with the expected data; 2) the student has chosen the correct instrument; 3) the student has used the correct measurement conditions; and 4) the student has taken the right readings.

Fig. 4 shows a simplified diagram of the validation process with some examples of the kind of message that LME provides. It can be seen in Fig. 4 that the sequence is 1) the introduced data are compared with the expected data (*there are no mistakes in the experimental setup*); 2) the measurement conditions are resolved; and 3) the introduced data are compared with the actual instrumental readings. If this validation fails, a child window with hints on the possible causes of error pops up proposing that the student repeat the process. When the cause of failure is not adequately spotted, a generic message is shown.

This procedure gives immediate feedback to the student on the obtained results, the setup of the instruments, and the measurement method used, as if a personal supervisor were situated right behind the student.

This mode of operation detects a significant number of errors and mistakes that would otherwise pass undetected, especially when compared to the more classical method. Just as in laboratories where a large number of students work simultaneously with a single instructor helping them, the students should detect their own mistakes. They do the experiments with a general supervision and merely compare the obtained results with a set of given numeric values in order to check their validity.

LME always stores the partial results of each session so that, in case of any failure, data can be recovered, and the work can continue from the last step completed. The recorded files are sent to the server to keep a register of the evolution of the experimental work on each bench.

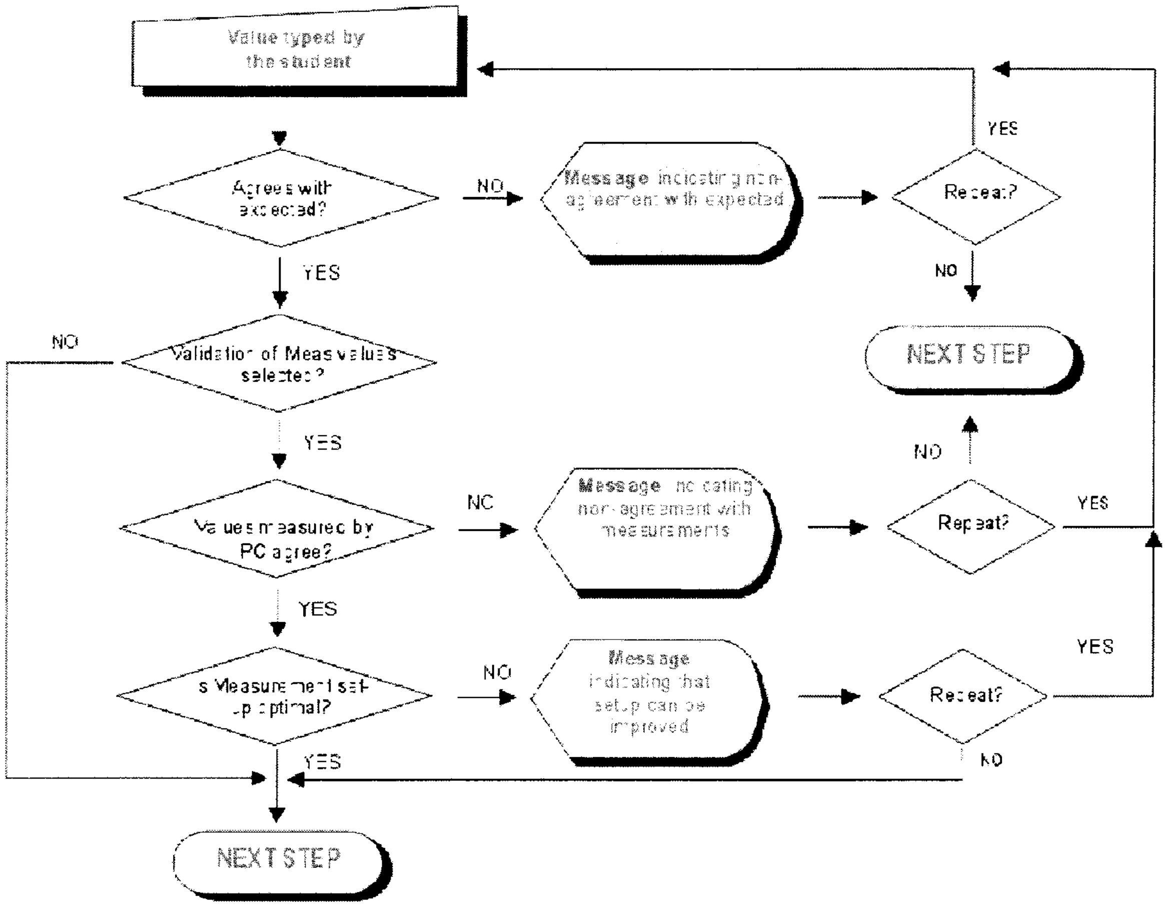

Fig. 4. Schematical representation of the validation flow.

B. Feedback Process

Fig. 2 can be used, as an example, to illustrate the feedback process. On this screen the student must set up the circuit shown on the schematic drawing, visualize the output voltage at the first secondary output on the oscilloscope, measure its peak-to-peak value, and deduce the expected peak-to-peak and mean value in the other secondary output from the schematic drawing.

The corresponding results are written in the text boxes. When this process is finished, the validation button ("*Measure*" on the screen) is enabled, and the results can be checked (a directive to keep the probe connected is given so that the computer may repeat the measurement).

In the operational mode 3, previously described, not only the results of the measurements are checked, but also LME validates the measurement condition. And thus, if the introduced values are correct but the sensitivity factor is not optimal, a message such as "*… reduce your sensitivity factor in order to maximize the deflection of the signal on the screen …*" pops up, giving the student the possibility of repeating the exercise using a more suitable measurement condition/equipment configuration.

1) Improving the Feedback: Currently, the authors can introduce a quiz between any two LME screens. This possibility allows clarification of all critical steps detected and settles the theoretical concepts involved in some specifically long steps (i.e., the measurement of the transfer function of an electrical filter as a function of the frequency) where the students may lose the aim of the exercise.

The quiz is introduced in the form of "*check for the correct options*" or "*select the right answer*" to the question that appears in a child window. In the results window, the students are informed *if* and *why* they are right or wrong in their answers. These tests also increase the motivation of the students because they receive real-time feedback on the progress of their knowledge.

IV. Complementary Tools and Current Developments

In order to be effective, the experimental work needs some previous theoretical preparation, and once the experiments are finished, further study to settle the concepts involved is advisable. The students can do some of this work by the use of the printed manual as well as posing questions to the instructors. Recently, the authors have detected that the number of questions received via e-mail is increasing. Most students have home-Internet access and all of them can be connected using the School facilities. This access has motivated the integration of the Internet as a complementary educational tool.

At a first stage, the authors have developed a set of web-based tools to facilitate both the preparation and the completion of the experiments. Some short quizzes ordered by practical exercises and courses based on CGI scripts in our web server (http://www.dte.upm.es) can be used as self-training exercises before or after the experiments. The underlying application sends to the remote user web pages with several option buttons corresponding to possible answers to the questions to be solved and, in the response, a new web page including the number of correct answers and a brief explanation of the correct options is included.

An example, in Spanish, can be found at (http://www.dte.upm.es/academicas/pregrado/lme/ejercicios.html).

Web services and CGI scripts are also used to publish administrative information and to make reservation of lab benches by the students who want to rerun some of the practical exercises when the lab is not in use by the regular course.

A set of projects is currently being developed in order to improve the method efficiency as well as to extend it to other experimental matters.

As previously said, each experimental session on a bench generates a log file. These log files can be used, together with the results of the self-training exercises, to generate a personal learning profile for each student that will allow the authors to detect the student's weaknesses spots and reinforce the learning process by generating personalized exercises. Although simple in conception, it is not a trivial matter to implement. This implementation will be complemented with a "virtual environment" (a graphical interface that simulates the bench instrumentation and circuits) where more practical exercises could be proposed.

In order to improve the efficiency in the communication between the instructor and the student, the integration in both the server and the bench applications of restricted video-conference capabilities is being developed. These capabilities (image, voice, and alternatively chat), together with the possibility of downloading the bench instruments statuses in the server (instructor console), will allow a better and quicker assistance. These enhancements will also open the possibility to physically delocalize the lab benches, allowing a true remote teaching in experimental matters.

This method can be extended to other experimental matters, not necessarily related with IT. Currently, a modification of the contents (for example, adding or suppressing screens) requires a modification of the program code. In order to avoid this inconvenience, a user-friendly application that allows any user to modify the electronic book contents without detailed knowledge of programming code is under development.

V. Impact and Students Reaction

This laboratory course has been given for the last three years to over 1200 students. From conversations with some them and surveys carried out, the authors can deduce that the students find that the interactive learning is a significant improvement over a traditional laboratory method. They say that this method permits them to monitor the evolution of their experimental work, so that they can validate their results in real time, and feel motivated to continue. Keeping students' motivation alive is a basic aspect in a foundation course and is a difficult task when a large number of them are in the lab simultaneously.

A significant number of erroneous conditions that use to pass undetected are no longer missed. Not only is it possible to detect those conditions but also to help students gain self-confidence when taking data properly.

The complementary web tools that have briefly been described above (self-training exercises, e-mail) have gained wide acceptance among the students and are used together with the most conventional learning procedures. They express a clear preference for the described procedure when comparing it to labs using a conventional method.

Every year a significant number of students are interested in collaborating as volunteers in the development of these tools.

VI. Conclusion

A method to teach experimental matters that has been tested in a first course electronics laboratory has been described. The goal of this hardware course is to permit the student to appreciate the experimental work in electronics. The method has been accepted positively by the students that follow the course.

The method is based on both the use of PCs as bench controller/electronic book and its integration into a local area network under the server/instructor console supervision.

The use of computers allows both real-time monitoring and feedback that reinforces student motivation, so that the student is permanently supervised.

The implemented networked architecture, when combined with the aforementioned tools, allows centralized monitoring of individual work. It also facilitates the obtaining of the learning profiles and permits the delocation of the lab by integration of remote benches.

A set of Internet-based complementary tools have been developed and integrated in the method.

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