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Development of a virtual laboratory on the internet as support for physics laboratory training

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Abstract

A virtual physics laboratory is being developed in the Escuela Técnica Superior de Ingeniería Informática of the Universidad de Valladolid (UVA). This laboratory will be accessible via the internet, and its main aim is to provide support for the real physics laboratory. In this paper we describe the main steps taken to develop such a laboratory. This virtual laboratory is currently accessible from `http://cawdor.fa2.etit.uva.es/laboratorio/index.html`.

Se está desarrollando un laboratorio virtual de Física en la Escuela Técnica Superior de Ingeniería Informática de la UVA. Este laboratorio será accesible a través de internet y su principal finalidad es servir de ayuda al laboratorio real de Física. En este artículo describimos los principales pasos seguidos para el desarrollo del mismo. Actualmente este laboratorio es accesible desde `http://cawdor.fa2.etit.uva.es/laboratorio/index.html`.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The vast majority of physics teachers consider that physics teaching must be strongly based on experimental observations made by their own pupils. However, we can find many cases in which the relative weight given in physics to laboratory work seems to be insufficient. In many cases the cause lies in the budget. Providing suitable funds for a laboratory, with a sufficient number of adequate training experiments may prove very expensive and, moreover, such a laboratory may require more teaching posts than classroom lectures do. In addition, well taught laboratory experiments with few pupils and individual attention require, in general, a great amount of work on the part of the teaching staff in charge. Finally, we ourselves sometimes

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fail to communicate properly to our pupils the importance of their own experimentation. As a result, many of them see laboratory training merely as a more or less difficult step to pass the subject, a point of view that we ourselves are partly responsible for. An interesting discussion of the importance of the laboratory in the science curriculum can be seen in the introduction of [1] and in the references cited there.

The aim of the project that is shown here is to heighten the interest of the pupils in physics laboratory training and, at the same time, to make the most of the pupils' time in the real laboratory. The way in which this project is developed, using web pages, aims to reduce the economic and teaching staff problems that individualized pupil attention in the laboratory would entail. Pupils will work individually in the virtual laboratory, after which they ask their teachers about any doubts or problems that may have arisen. This laboratory will allow the students to perform virtually the experiments which they will later find in the real laboratory. In this way, they will have to study and analyse the experiments before being faced with them directly. It must be emphasized that this virtual laboratory must never replace the pupils' work in the real laboratory. The virtual laboratory only aims to provide support in improving the benefit obtained from the work carried out in the real laboratory. This virtual laboratory may now be accessed from `http://cawdor.fa2.etit.uva.es/laboratorio/index.html`.

This virtual laboratory is the main part of a set of utilities that are being developed and whose main aim is to help in the teaching and understanding of physics at the Escuela Técnica Superior de Ingenierá Informática of the Universidad de Valladolid (UVA). This set of utilities will also include the following: first, a set of downloadable simulation programs to study some specific physical problems. Second, a set of topics of a general physics course including theoretical explanations, easy Java-based simulations to illustrate some examples of each subject and solved problems so that the students can self-evaluate their understanding. Thirdly, a series of films made by teachers from the Departamento de Termmodinámica y Física Aplicada (DTFA) of the UVA, showing and explaining some physical phenomena, or even showing how some laboratory experiments should be done. A more complete description of all of the utilities can be seen in [2].

2. Description of the virtual laboratory

Let us see how the virtual laboratory has been developed.

The virtual training web pages must have a structure that is as close as possible to an actual laboratory training procedure. They must not only parallel the look of the actual devices that the students will find in the laboratory but, more importantly, must also involve an identical procedure to that found in real training. In addition, each page must contain all the information that may be necessary for the virtual training to be carried out and it must be as easy as possible so as to help those pupils who may not be familiar with internet tools. In this way, the pupils will be able to work independently in all the training web pages.

An outline of a virtual training web page may be seen in figure 1. The successful completion of the training should be done following the parts of the corresponding diagram in a clockwise manner. The page `Beginning` is only an introduction of each virtual training task, containing information on the web page programmers. The next step for carrying out the training would be the `Explanation`. This part describes how the virtual training works, that is, how the virtual measurement devices must be handled, how different graphs may be obtained from the measured data and how a report on the obtained results may be written. This report will later be sent to the teacher of the subject. Different ways of compiling and sending this report are discussed in section 2.1. This report must focus on the physical meaning of the obtained results more than on their numerical values. The next step `Theoretical basis of the real training work` is devoted to explaining the real training that is imitated by the virtual training with which the pupil is working. As has already been mentioned, virtual training is a complement to the actual training that must be performed by the pupils and, as a result, training in both real and virtual laboratories must be related. As the greatest interest

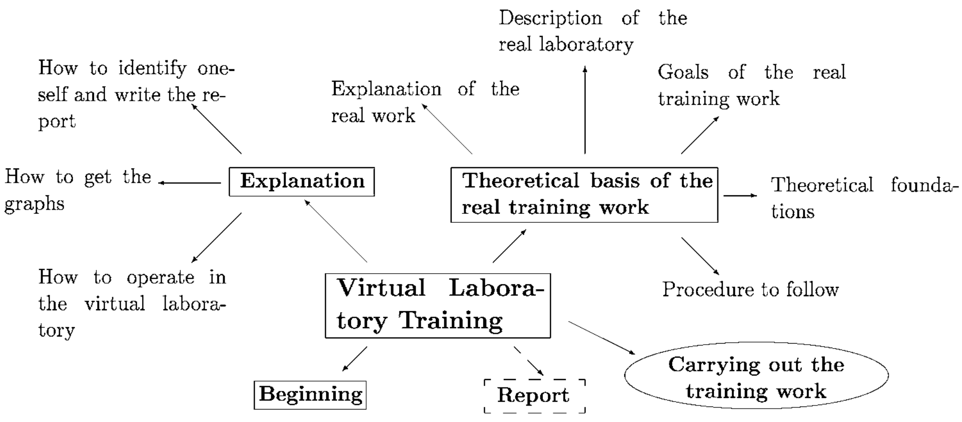

Figure 1. Diagram showing the structure of the web pages of each training task of the virtual laboratory. The correct way to work in this virtual training task would be to follow this diagram clockwise.

of this virtual laboratory lies in improving teaching in the real laboratory, we have decided to initially include only reproductions of the real training that the pupils will encounter in the real laboratory. Therefore, each virtual training task includes a section containing information on the material and procedure of the equivalent real training. This information includes a guide to the real training procedure, a description of the physical phenomena involved or analysed as well as a description of the necessary material. We have attempted to show material that is as similar as possible in the virtual training to strengthen the similarity between virtual and real training and to improve the learning process.

The next stage, that is shown inside an ellipse in figure 1, is the carrying out of the training. In this part the necessary elements for performing the training are shown as similar as possible to those in the real laboratory. Two examples of virtual training are shown in figures 2 and 3. In these figures the necessary elements, power sources and measurement devices of each training task are shown. The pupil can interact with these elements using only the computer mouse. In this way, different elements may be connected, the parameters of other elements may be changed or even the values of the different measurements performed by the measurement devices may be included in the data tables.

With regard to how these measurements are given, we can distinguish two different cases. On the one hand, there are training tasks in which the pupils must verify generally simple physical laws that are well symbolized, with more or less complexity, by known mathematical expressions. There are also training tasks in which the pupils must analyse the behaviour of some devices (for example, diodes, transistors, PTC or NTC resistors . . .) whose behaviour depends both on the specific materials of which they are made as well as on the environmental conditions (such as laboratory temperature). In order to illustrate numerical results to the pupils in the virtual measurement devices we work in the following ways. For the experiments of the first type mentioned previously we take as the *initial numerical values* those given by known mathematical laws. For the experiments of the second type, and as we try to reproduce the real laboratory training, we use the real values obtained in the laboratory. That is, firstly we have performed the real measurements of the behaviour of those devices for different conditions. The results of these measurements have been fitted to simple mathematical laws or to polynomials, according to different parameters, and these functions or polynomials have been programmed in the virtual laboratory so that these fitted functions will give the *initial numerical values* for the experiments of the second kind. In neither of the cases mentioned are these *initial values* shown directly in the virtual measurement devices. In order to give physical credibility to the virtual laboratory the *initial values* are modified in random quantities that are

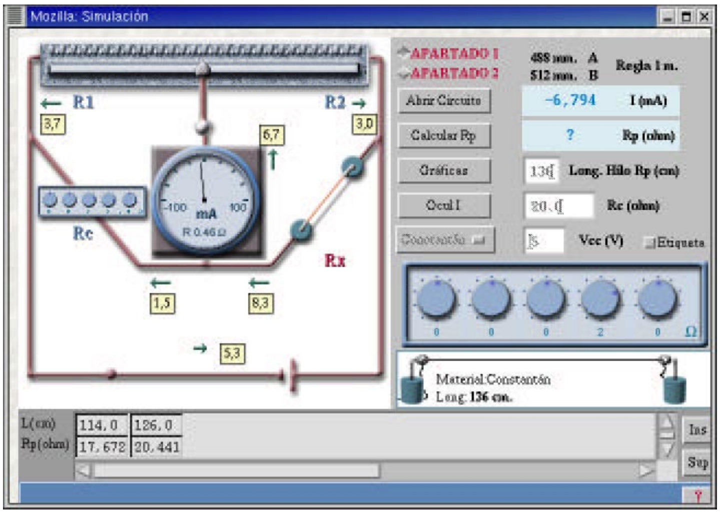

Figure 2. Detail of the experimental arrangement shown in a virtual training task devoted to the measurement of the resistivities of different conductors using the Wheatstone bridge. In the figure the components of the current are shown when the bridge is not balanced. The students can study different behaviour, changing the study material, its length and section. They can also change the value of the resistance of the box and they can displace the point of connection of the cursor along the bridge in order to balance it, as is done in real training.

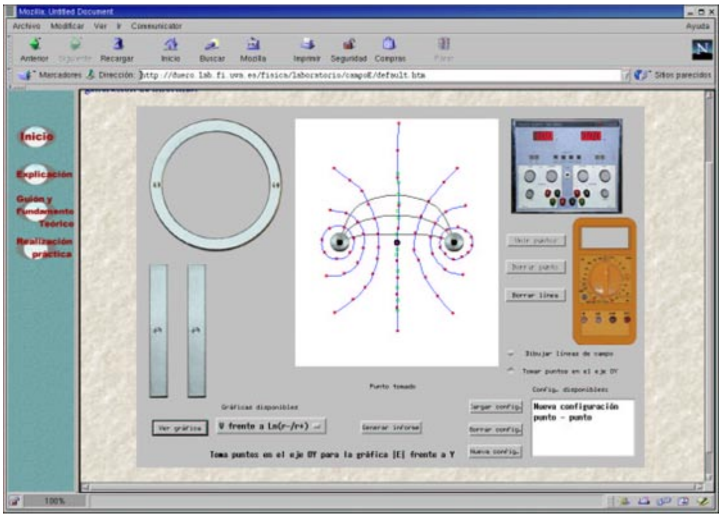

Figure 3. Web page showing part of the measurement of the electric field and electric potential distribution due to two given electrodes as would be obtained in the real laboratory. On this page some equipotential curves obtained in the virtual training can be seen together with some field lines obtained from them. The students should obtain electric field and potential distributions for several electrodes (shown on the web page) using the cursor as a measurement probe to measure the potential (that would be shown in the polymeter screen) at every point of the surface containing the electrodes. From the measurements obtained the students should analyse some dependencies of the field and the electric potential for several electrode characteristics and positions.

obtained from the experimental errors that may be obtained in the real laboratory, knowing the accuracy of the real measurement devices used. In this way greater physical realism may be given to the virtual results and, moreover, numerical coincidences in the results obtained by different pupils are avoided.

Some video clips have been introduced in some virtual laboratory training. These video clips are controlled by the web page applets. The aim of introducing these video clips is to show some phenomena that may be observed in the real laboratory and that are very illustrative if observed directly, but are not so descriptive if reproduced with drawings or animation. An example of this kind of phenomena is the visualization of the heating and light emission of a conductor depending on the intensity of the electrical current passing through it. In this example, the web page applets allow forward or backward movement of the film shots depending on, for example, the value of a variable resistor placed in the studied electric circuit.

The last part that may be seen in figure 1 is the `Report`. Although anybody with access to the internet will be able to do the virtual training, only those who are pupils of the subjects taught by the DTFS at the ETSII will be able, after being properly identified, to send a report to their teachers analysing the obtained results.

2.1. Sending the report and evaluating the work done by the pupils

As has already been mentioned, this virtual laboratory has been envisaged to provide help for students so that they can benefit more from their work in the real laboratory. It may help them to get used to real laboratory procedure before working in it, or even when remembering details after they have worked on it. In our case, we have contemplated the possibility of evaluating the work of our pupils in the virtual laboratory. Of course, this evaluation must not assess the numerical results obtained in the virtual laboratory, but rather the effort made by the pupils and, mainly, the pupils' thoughts and ideas on the physics of the problems shown in the different training of the virtual laboratory. Reflecting on the physical problem may help them more than simply knowing how the real devices are handled or which devices or arrangements they will be faced with in the real laboratory. By performing this virtual training and reasoning a brief report on it, pupils must think about the results they may obtain in the real laboratory before working in it. What is more, the comparison of the results of these 'ideal' virtual experiments with those that they will obtain in the real laboratory will show them how difficult it is to perform an experimental measurement correctly. In some sense, doing this virtual trainings plays a similar role to the concept maps of [1] because the aim of both is giving up a 'traditional' way of teaching, in which pupils are perceived as passive receivers of knowledge. With this virtual laboratory we try to change the pupils' attitude and force them to have an active behaviour in the learning process.

As has already been pointed out, sending a report will only be possible for those users of the virtual laboratory that have been properly identified as pupils of our subjects. In order to be identified, the pupils will have to enter their username and password before sending their report. In order to validate the identification, the server that holds the virtual laboratory must contain a database with both the pupils of each subject as well as the teacher of the subject. Each teacher will thus receive only the reports of the pupils of his/her subjects.

Sending this report may give rise to some problems. The simplest format for sending a report is that of an e-mail. However, it is difficult to include in an e-mail the graphs of the results to which the pupils must refer when drawing up their reports. Another option may be the use of ASP pages with which the results are stored in a database. However, the ASP protocol belongs to Microsoft, limiting the kind of server that holds the virtual laboratory to one working within Windows. In our case we decided to create HTML documents for the reports since in this way they will require little space in the server that will store them for correction by the teachers. In fact the required space may pose a problem if other formats are used, especially if there are a large number of pupils, each of whom must perform several training tasks and send the corresponding report including graphs. On the other hand, with

HTML reports the server itself can generate the general structure of each report and it would only be necessary to include the numerical data obtained in the training together with the text typed by the pupil. As a result, the volume of data sent to the server for each report is very small. When a teacher decides to correct his/her pupils' reports he/she will access a private part of the server where the report data are stored and classified. In order to generate the graphs again the server must contain an additional application that will reconstruct the graphs from the numerical data received in each report. This application may, in fact, be the same as the one that shows the obtained graphs in the virtual training to the pupils.

With regard to client–server communication for sending the reports, we have studied two possibilities. First, communication based on servlets and, second, communication based on sockets, both of which could initially prove suitable. From the programmer point of view the servlets solution is simpler, but it has the disadvantage that if one uses the solution based on servlets, several pupils might profit from the training of just one of them and each send a report using the data and graphs from training done only once by one of them. However, with socket based communication, the virtual laboratory can ensure that every report originates from a different user who has completed the virtual training. This condition convinced us to use socket based communication. Finally, just as an additional note, we decided that together with the HTML report stored in the server, an automatically generated e-mail should be sent to the teacher when any of his/her pupils finish the virtual training and send the report.

As a final technical detail, we have decided to show the virtual laboratory applet in a window independent of the internet navigator window. If it were in the navigator window the pupils might press the `'next'` or `'back'` navigator buttons and lose all the data obtained in the training. By showing the virtual laboratory in a different window, the pupil could continue the navigation and the independent applet would keep the obtained data. Figure 2 shows the independent applet containing the virtual laboratory for training on the Wheatstone bridge. Figure 3 shows the virtual laboratory for training on the measurement of electric fields and potentials in the navigator window as was done initially.

3. Improvements and conclusions

The virtual laboratory shown is not a closed project. Its contents must change according to the changes made in the real laboratory. Moreover, the results obtained each year with regard to the interest and participation of the pupils must be used for improving the virtual laboratory. Ongoing improvements, both in software and in quality and speed of internet connections, will enable us to enhance the virtual laboratory with new elements. Some of these new elements might include, for example, 3D worlds to show how different devices applied in physics experiments work or the inclusion of multimedia elements in the virtual training, as has been done by including a video filmed in the real laboratory. These multimedia elements might be used to enable pupils to take virtual measurements using the videos filmed in the laboratory or allow mixing Java applets and video film to measure positions, distances, etc on the video as is done in [3].

Clearly, the greatest limitation of this virtual laboratory comes from external elements. Firstly, as is obvious, there is the speed and accessibility of the net which it is said will increase rapidly over the next few years. Secondly, the problem of net security. In view of possible external attacks the only solution is to take steps to ensure that any possible attacks do not succeed.

Finally, we must remember that this virtual laboratory simply provides help in supporting the benefit obtained from the teaching of real laboratory training. The virtual laboratory must never replace the real laboratory. The main utility of the virtual laboratory is to make the students think about the physics behind the training they will receive without actually substituting for it. When doing the training in the real laboratory, students will encounter not only the physics of the experiment that is being done, but other problems that they must also learn to solve.

Acknowledgments

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