

## ABOUT CONCEPTUAL AND METHODOLOGICAL APPROACHES IN REMOTE LABORATORY\*

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Received September 6, 2013

*Abstract:* The significant development of the information technology, including the high quality transmission of data over the Internet, is going to change the traditional way to develop the practical skills of the students. The activity in conventional real laboratories from high schools and universities may be alternatively completed with a new generation of educational systems, based on the concept of the so called Remote Laboratory. This new educational tool provides to the students opportunities to collect remotely from distance, real experimental data from very complex and expensive machines, running on real research laboratories. The main conceptual and methodological approaches related to the Remote Laboratory tool are presented together with a complex application in case of a real experiment involving the remote recording of the magnetization reversal by a High Magnetic Field Measurement System working in the VSM, located at the National Institute of Materials Physics. The obtained experimental data are subsequently interpreted in frame of an accessible quantitative model. Finally, the importance of this type of experiment for transmitting complex information to high school students and to familiarize them with the most modern experimental techniques, even if remotely, is emphasized.

*Key words:* remote laboratory, conceptual and methodological approaches, case study via magnetometry.

### 1. INTRODUCTION

Once the computer has become widely used and the internet allowed to large pieces of information to be shared between interconnected computers, a major change in the educational process was ready to occur: an evolution from the traditional methods to the computer-assisted teaching and learning. In this way, the

\* Paper presented at the Annual Scientific Session of Faculty of Physics, University of Bucharest, June 21, 2013, Bucharest-Magurele, Romania.

computer assisted education (CAE) becomes a didactic method enforced by the informational society; it capitalizes the principles of programmed teaching, in the context of the newly developed communication and informational technologies [1–3].

Physics is a science based on experiments, observations and facts found experimentally. The experiment is the one providing evidences underlying the scientific knowledge and plays many roles in science. One of its major roles is to test theories and to provide the foundation for scientific knowledge. It may also open the way to a new theory by showing that the current theory is outdated.

Since one of the main methods of physics is the experimental method, also the teaching-learning process in physics must be based on experimental practice. Experiments are indispensable for students, since they must trust in the laws of physics and must be encouraged to test their limits. As an active method, the experiment has a more convincing force than any other method and open greater possibilities to influence the formation of students' scientific concepts about the nature [4].

The psychologist Jean Piaget pointed out long time ago that progress in knowledge is generally rooted in tactile interaction with objects in their environment [5] whereas Nersessian goes even further, stating that experiment with own hands is the heart of learning science [6].

Laboratory lessons for scientific and engineering education play an important role in developing students' practical skills, contributing substantially to their professional development. On the other hand, existing laboratories in primary and high schools are not enough well equipped in order to familiarize the students with the most modern experimental techniques (the corresponding costs of such facilities being very high for the educational system). Fortunately, the intense use of the computers in educational process together with the Internet facility and the appearance of new software packages for simulation and data acquisition opened the way toward very effective alternatives such as the so called virtual laboratory (LV) and remote laboratory (RL). No doubt that the real experiment is irreplaceable, but there are definitely some issues making difficult and in some cases (e.g. education at distance) even impossible, it's exclusive implementation.

This work deals with a comparative presentation of the main conceptual and methodological approaches related to the Remote Laboratory tool as well as with the presentation of some applications of the Remote Laboratory in case of different experiments (e.g. experimental recordings of the magnetization reversal by a High Magnetic Field Measurement System working in the VSM mode and located to the National Institute of Materials Physics in Magurele-Bucharest). The way of data interpretation as well as the importance of such tool for an early familiarization of the students with modern experimental techniques and concepts is also presented.

## 2. REAL, VIRTUAL AND REMOTE LABORATORY

The first alternative to the real laboratory is the virtual laboratory [7–9]. Virtual laboratories imitate the real laboratories by computer simulation of the experiments. They offer a good pedagogic experience via virtual models suitable for the simulation of the difficult to understand processes. On the other hand, such models are only approximations of the real processes and can not fully replace real experiments. Being designed mainly for the accessibility of understanding difficult concepts, they are also clear and without experimental errors. Similar to real experiments, virtual experiments allow data acquisition and processing, graphical representations and so on. The main advantages of these experiments are the reduced involved infrastructure (relying just on appropriate software installed on the computer) and the certainty that no error coming from the experimenter will affect the experimental device. The main disadvantage is related to the total absence of experimental errors which in many cases represent the first step in developing perceptual phenomena. Another disadvantage is related to the inability to improve the experimental design, which in turn could lead to the loss of ability of controlling and correcting the experiment, if the situation requires.

A second alternative to the real laboratory is the remote laboratory [10–12] which allows performing experiments remotely via the Internet, using real performing equipments belonging to specialized research departments (allowance and mutual agreements are required in this respect). RLs contribute to a better understanding of complex systems, are much less expensive and do not impose major time restrictions as compared to real experiments. As compared to a virtual laboratory, RL involves the access to a real experiment, even remotely, with all the specific advantages. Oppositely, VL can have some pedagogical advantages over the real and remote teaching and must be taken seriously into account when pedagogical aspects are important [13]. It also provides a safe environment for learning and conducting experiments [14], which in reality would be dangerous (high-pressure gas, flammable, toxic or radioactive medium etc.).

In conclusion, all three laboratories have both advantages and disadvantages, the students having their benefit by using them complementary, depending on the situation. The advantages and disadvantages of the three types of labs that students have at their disposal to gain practical experience are resumed in Table 1:

*Table 1*

Comparative advantages and disadvantages of the three types of laboratories

Laboratory type	Advantages	Disadvantages
Real	<ul style="list-style-type: none"> <li>• real data</li> <li>• Interaction with device real experimental</li> <li>• Teamwork</li> <li>• Interaction with supervisor</li> </ul>	<ul style="list-style-type: none"> <li>• restrictions in space and time</li> <li>• require an appointment</li> <li>• high costs</li> <li>• supervision required</li> </ul>

Table 1 (continued)

Virtual	<ul style="list-style-type: none"> <li>• good explanation of the physics concepts</li> <li>• no restrictions in time and space</li> <li>• interactive medium</li> <li>• low cost</li> </ul>	<ul style="list-style-type: none"> <li>• ideal data</li> <li>• lack of collaboration</li> <li>• no interaction with a real device</li> </ul>
Remote	<ul style="list-style-type: none"> <li>• interaction with a real experimental device</li> <li>• real data</li> <li>• no restrictions in time and space</li> <li>• low cost / average</li> </ul>	<ul style="list-style-type: none"> <li>• only "virtual presence" in the real laboratory</li> </ul>

### 3. REMOTE LABORATORY – A NEW WAY OF RENDERING COMPLEX INFORMATION

#### 3.1. ACCESSIBILITY OF EXPERIMENTAL DATA BY REMOTE LABORATORY TECHNIQUES

An advanced experimental technique, which can be fully explained on the basis of the notions learned in high school, is the vibrating sample magnetometry (VSM) [15]. In a vibrating sample magnetometer, the magnetic sample is connected to a rod which vibrates harmonically in an uniform magnetic field generated by an external magnet (superconducting or electromagnet), along the z axis, for example. The frequency of the periodic movement, generated via an electro-mechanical vibrator, is of tens of Hz and the amplitude is of the order of mm. Since in the presence of an applied magnetic field, the sample is characterized by its overall magnetic moment (proportional to the magnetization), it induces outside an alternating magnetic field. Two collecting coils are placed around the sample. The alternate magnetic field induces in the coils an alternate magnetic flux, which according to Faraday's law, induces a current proportional with the flux variation and hence with the time variation of the magnetization. The electric signal is collected and then integrated, resulting in a signal proportional with the overall magnetic moment/magnetization/specific magnetization of the sample. It is to notice that the two coils are specifically connected in order to add the electrical signals generated by the vibration of the sample and to compensate parasitic signals connected to the thermal shifts. The proportionality constant between the magnetic moment of the sample and the voltage collected at the coil output is determined by a calibration with a sample of standardized magnetic moment. It is to notice that, these measurements allows the determination of the evolution of the magnetic moment as a function of the applied magnetic field (magnetization measurements and hysteresis loops) or its evolution with temperature. The mentioned dependences offer important information on the magnetic properties of the studied substances and on the microscopic mechanisms responsible for these properties. An important way to transmit such complex information to the students during the

classes is to use the remote laboratory technique. A remote laboratory corresponds to the situation where the control and the observation of a real physical instrument are mediated through a computer. An adequate remote access to that computer is provided through a specific communication network, for example the internet (Fig. 1).

Hence, a remote experiment represents a step forward versus a virtual experiment, because in this case the students interact with a real device and can participate at a real experimental activity, in a real laboratory, even from distance. Remote laboratory can be used complementary to the educational resources offered by real laboratory [16], providing basically a remote monitoring of an experiment.

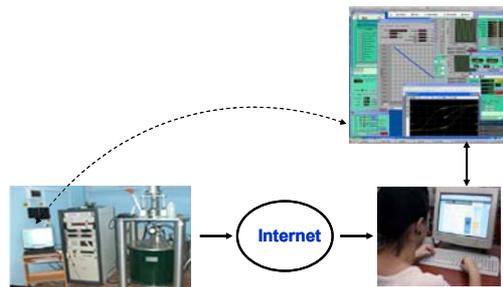


Fig.1 – The connection between the computer from the classroom and the computer control block of magnetometer VSM.

An example of such an experiment which allows to record the magnetization reversal obtained in a High Magnetic Field Measurement System working in the VSM mode (Cryogenics Ltd) and located at the National Institute of Material Physics in Magurele-Bucharest, is shown in Fig. 2. The on-line connection to the control block of the real device is made via Team Viewer program that allows both the visualization of the real measurement (see black window bellow illustrating the magnetization reversal process in relation to the applied magnetic field) and the control of the device parameters.

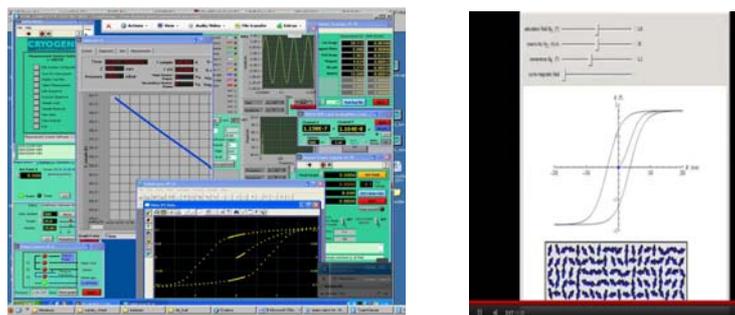


Fig. 2 – Print screen representing the magnetometer VSM command block, accessed via Team Viewer program that allows observation and control of a real measurement. An animation illustrating the observation of the magnetization reversal process [17] is also present in the right.

### 3.2. INTERPRETATION OF THE ON-LINE OBTAINED EXPERIMENTAL DATA IN ORDER TO HIGHLIGHT MICROSCOPIC PARAMETERS IN MAGNETISM

In the following will be exemplified the mode to download and interpret real experimental data obtained with the VSM magnetometer on two thin films of different areas, in two different experimental geometries, namely: (i) with the field applied normal to the film plane (perpendicular geometry) and respectively (ii) with the field applied in the plane of the film (plane geometry). Two Fe films deposited directly on the Si substrate were obtained by RF sputtering in argon atmosphere and at a power of 100 W of the radio frequency source. According to previously reported data [18], films with amorphous structure (non crystalline films with disordered Fe atoms in the solid structure) are obtained in these conditions. Therefore, just for comparison, one of the amorphous Fe films was supposed to a thermal treatment in high pressure of hydrogen following also the procedure described in [18], in order to obtain a Fe film of crystalline body centered structure (Fe atoms are periodically arranged with the base unit of the structure keeping the symmetry of the crystal, consisting of Fe atoms in both the corners of a cube and in its center). The thickness of each film was obtained by total interferometry contrast (TIC), as described in [19]. Characteristic images of the step and of the complex system of interference fringes corresponding to the amorphous Fe film are shown in Fig. 3.

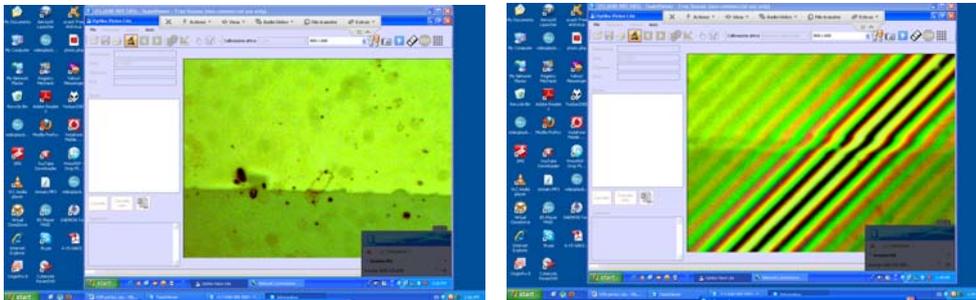


Fig. 3 – Image of the step (left side) obtained by optical microscopy ( $M = 500\times$ , bright field) and corresponding system of interference fringes obtained by TIC microscopy (right side), on the as prepared film.

Thicknesses of about  $50(2)$  nm were obtained on both the amorphous and crystalline Fe film, from the relative shift of the central (black) interference fringe at the step position, with respect to the patterns outside to the step position. Two different samples have been prepared from the amorphous and crystalline Fe films with surfaces of  $7.2\text{ mm}^2$  and  $20\text{ mm}^2$ , respectively (quasi rectangular shapes were cut from the Si substrate supporting the Fe films and their corresponding sizes were

carefully measured). As exemplification of the RL tool, the magnetization reversal (hysteresis loop) was obtained remotely (from school laboratory) on both samples in parallel geometry (field applied parallel to the film) and in perpendicular geometry (field applied perpendicular to the film), just on the crystalline Fe film. In the second case, the VSM measurements have been performed just in low fields (a specific power supply was used in this respect, providing maximum 280 Oe), in order to increase the field accuracy of the measurements. In Fig. 4 are illustrated images captured on the personal computer connected to the command block of the VSM magnetometer via the Team-Viewer program, during the data acquisition process of the magnetic reversal process in the crystalline film, in parallel geometry. Similarly, images captured during the data acquisition process on the same film, but in perpendicular geometry, are shown in Fig. 5.

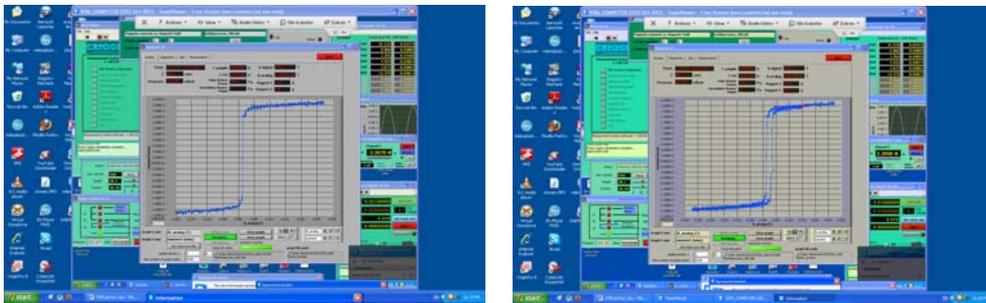


Fig. 4 – Print screen during the data acquisition process with VSM magnetometer, on the crystalline Fe film, in parallel geometry: towards the end of the first branch of the loop (left side) and towards the end of the loop (right side).

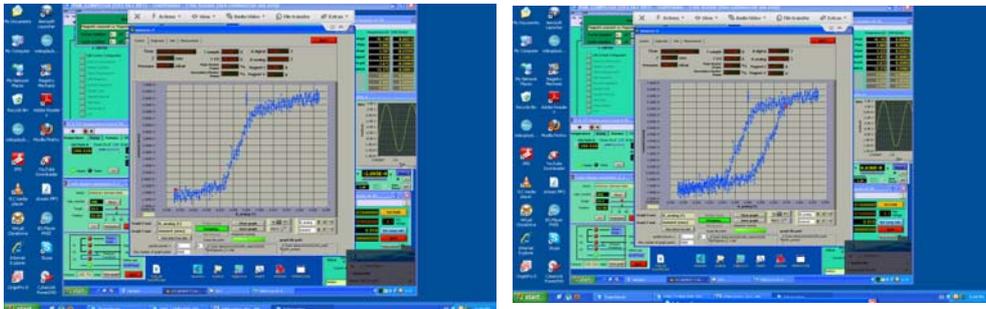


Fig. 5 – Print screen during the data acquisition process with VSM magnetometer, on the crystalline Fe film, in perpendicular geometry: towards the end of the first branch of the loop (left) and towards the end of the loop (right).

The experimental data are finally remotely saved in ASCII type files, which properly processed (averaging, reformatting, etc.) can be imported in special graphic programs and then interpreted in frame of theoretical models in order to

extract the parameters if interest (the file transfer can be also remotely performed). Accordingly, Fig. 6 illustrates the final hysteresis loops, obtained on both amorphous and crystalline films in parallel geometry, after processing and importing the data in the in Origin program.

In the following, an application that can be addressed to high school students, namely the determination of the magnetic moment of Fe for the two samples (crystalline and amorphous Fe), will be presented. The values of the overall magnetic moment of the two samples at saturation can be straightforwardly determined from the graph above at  $1.9 \cdot 10^{-3}$  emu and  $5.8 \cdot 10^{-4}$  emu, for the crystalline and the amorphous film, respectively. Having in mind that to each magneton Bohr,  $\mu_B$ , (seen as an elementary unit for the magnetic moment), corresponds  $9.27 \cdot 10^{-21}$  emu, the magnetic moments carried by all Fe atoms in the two films are of  $2.0 \cdot 10^{17} \mu_B$  and  $6.3 \cdot 10^{16} \mu_B$ , respectively. It remains just a problem to evaluate the number of Fe atoms in each film in order to straightforwardly deduce the magnetic moment carried by one Fe atom. The number of Fe atoms can be on the other hand easily assumed by considering the above mentioned values for

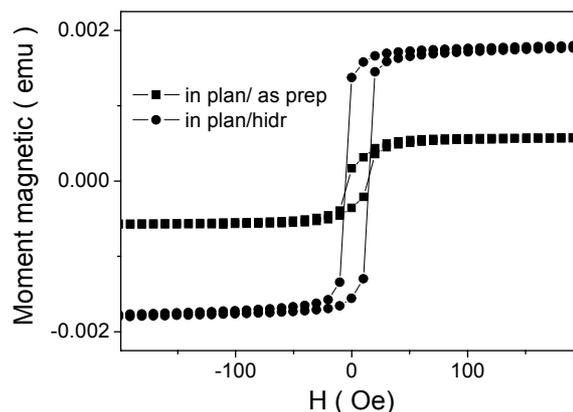


Fig. 6 – Hysteresis loops obtained in parallel geometry, on the two analyzed samples.

the film thickness and surface (the film volume,  $V$ , can be computed), the molecular weight for Fe,  $\mu = 56$  kg/kmol and a theoretical density for the Fe films,  $\rho = 7850$  kg/m<sup>3</sup>. Accordingly, the number of Fe atoms, given by the formula  $N = v \cdot N_A = (\rho V / \mu) \cdot N_A$ , with  $v$  the number of mols and  $N_A$ , Avogadro's number, is of  $0.82 \cdot 10^{17}$  atoms in the crystalline film and  $0.29 \cdot 10^{17}$  atoms in the amorphous film. Hence, the magnetic moment per the Fe atom in the crystalline film is nearly  $2.4 \mu_B$  whereas in the amorphous film is nearly  $2.2 \mu_B$ . Even at a first view such results suggest a higher magnetic moment of the Fe atom in a crystalline thin Fe film as compared to an amorphous one, such a statement should be considered with high care, due to inherent errors involved in the experiment and related mainly to the regular shape of the films and the accuracy of determining the corresponding sizes

as well as on the assumption of a similar film density for both films, approaching the theoretical value of the bulk like phase of body centered cubic Fe. However, the both obtained values for the magnetic moment of the Fe atom, approaches within the experimental errors, the typical value of  $2.2 \mu_B$ , corresponding to the metallic Fe phase.

#### 4. CONCLUSIONS

Complex physical phenomena can be understood more easily if using computerized information techniques instead of traditional educational tools. Such techniques allow the simulations of physical phenomena, which can be subsequently visualized through attractive and suggestive animations. The new types of laboratories developed starting from the computerized information techniques, namely the virtual and the remote laboratory were comparatively discussed with respect to the traditional laboratory. Among the most modern computerized resources, remote laboratory (RL) technique shows great importance because it allows the access of the students, to high performing research activity, even if remote.

The following characteristics of the RL technique can be resumed:

(i) It presents a comprehensive pedagogical and methodological structure while students, after going through a theoretical material, can perform simulations of an experiment and finally realize the remote experiment. This gives them a true understanding of complex theoretical concepts and practical realities. However, in spite of the fact that students appreciate learning autonomy, feel motivated and consider RL a good tool for collaborative learning, they do not consider that RL laboratories must completely replace traditional laboratories which develops also specific aptitudes.

(ii) It allows a higher flexibility of the study and a better time management while generally there is no need for a supervisor to perform experiments remotely. These experiments are not limited in time or space. An automatic booking system may realize the record of the student in a database and may permit the access to the experiment at the desired time.

(iii) It has a good economic value while it does not involve investments in expensive experimental equipments and maintenance. In some cases, RL allows that facilities in well equipped laboratories of a given university to be shared by hundreds of students from that university as well as from other universities and high schools in different countries where previous agreements exist, the cost of education per student being much lower than in case of a real laboratory. Alternatively, agreements with advanced research laboratories can be done, allowing the access of the students to real experiments of great complexity.

It is to mention at the same time that a similar high care should be given also to the traditional ways of teaching - learning. In their absence important skills of the students, such as making and solving problems, extracting ideas from a text, the desire to read and patience for careful study and thought. etc., can be lost. It is also worth mentioning here the very important role of the teacher in guiding students' thinking (formation of a particular logical system specific to the approached domain, formation of a certain moral system) and competent guidance in selecting information. In fact, in case of such computerized information techniques, the teacher's role becomes even more important than in classical pedagogy, the accent being put on the formative, logic and educational side.

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