REMOTE EXPERIMENTS IN EXPERIMENTAL PHYSICS

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ABSTRACT:

Information technology has made experimenting *via* the internet possible. Different from simulations, applets or animations, remotely controlled experiments give students the possibility to experience in reality physical situations and the realistic response to parameter variations. We demonstrate how to measure the efficiency of a solar cell by recording the *IV* curve in the dark and under illumination by an artificial light source. In a second experiment, we determine the hysteresis of a Ferro magnet. Both experiments are completely isolated from the operator; they have been implemented in a large engineering class and were accessed several hundred times in the course of a semester. We also discuss employing interactive learning material in oral examinations.

1. INTRODUCTION

Performing experiments is an essential part of the learning and teaching experience in natural and engineering sciences; it was always part of these sciences. The new media and technologies allow us – within a *blended learning* concept – to increase the experimental part of the education from very early on. Already in the first or second year experiments can be performed remotely which otherwise would not be accessible for reasons of expense, security, or availability. We show at several specific examples how the interaction of students with learning material increases their learning experience and learning success. We also present first examples of how interactive applets and remote experiments can be used in oral examinations.

1.1 eLearning and eTeaching at universities

eLearning and eTeaching have become increasingly important in their contributions to modern education in today's universities. Basic courses in mathematics or the natural sciences taught for large engineering classes often suffer from an audience too large to individually address questions of students during the lecture, let alone allowing each student to experiment with demonstrator equipment employed during the class. Laboratory courses provide the conventional way to get students in contact with reality in form of an experimental setup which needs to be operated, and which produces data to be analyzed by the student or a group of students. The classical disadvantages of the laboratory courses are the relatively large investment on part of the teaching personnel, the more or less fixed experimental arrangement and a somewhat limited amount of different experiments available in a given laboratory. The tendency of groups of students to not each participate with the same intensity and the existence of previous lab notes further reduce the learning effectiveness of such courses.

1.2 Remote experiments

Information technology has provided teaching with novel didactic methods which become increasingly used and positively evaluated by the students. These advances encompass both the access to internet information *per se* and programming tools such as interactive applets, which are available abundantly for most physics problems dealt with in class. Furthermore, situations too dangerous or too expensive for in-class treatment can be taught and the related concepts and contents brought to the student. An example of a too dangerous (and too expensive) realization of a physics situation is the core melt down of a nuclear power plant (Eriksson, 2005), see Figure 1.

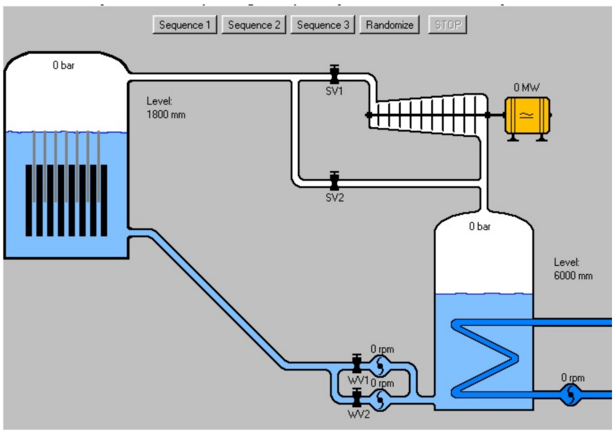

Figure 1: NuclearPowerPlant applet challenging the student to avoid a nuclear melt down following various incidences preventing normal operation. The students get to understand the essential thermodynamic functionality of a power plant. The components are the reactor (*left*), the turbine and the generator (*top right*), and the cooling unit (*bottom right*). Various pressures, water levels, and the power generated are indicated continuously by the running applet. From Eriksson, 2005.

In this paper we present the concept of remote experimenting, which we developed at TU Berlin. Different from the above-mentioned simulations of reality, we feel that it is important to combine the concept of abstract thinking or understanding abstract problems with true experiments for certain physics problems. In such experiments, the true physical setup is located remotely from the operator or student wishing to do the experiment. Our setup is related to a remote controlled action of electrical parts or switches combined with physics questions to the student which force him or her to gain an understanding of the issue presented. We demonstrate our concept at the example of a solar cell and of the hysteresis loop of a Ferro magnet; generalization to other experiments is straightforward.

2. TECHNICAL REALIZATION

Technically, a remote experiment takes places in a location separate from the experimenter. The experimenter may be speaking to an audience and wanting to present experimental results as shown in Figure 2. Or the experiment is located at a distant location where access is difficult or impossible for one or the other reason. A remote experiment consists of two conceptually distinct parts. First of all there is the experiment itself, which is conducted remotely, and secondly there is the method used to provide the necessary remote features. The experiment is controlled *via* software through the internet by issuing commands to an interactive surface, which we shall illustrate below.

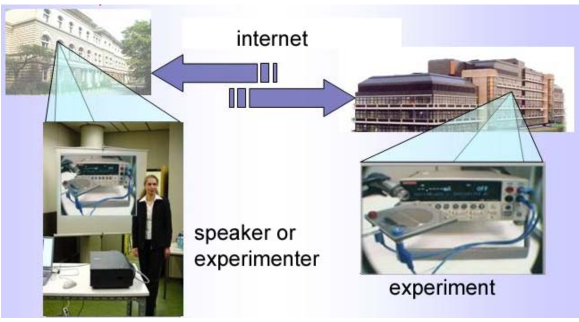

Figure 2: A typical remotely conducted experiment. The speaker or experimenter is in a location different from the laboratory where the experiment resides, *e.g.*, in a seminar room (*left*) and controls a real experiment (*right*). The control of the experiment is mediated to the speaker *via* the internet.

2.1 Solar Cell

We have chosen two simple experiments from the broad field of undergraduate experimental physics to demonstrate the functionality and capability of remote experiments. In the first experiment the *IV*-characteristic of a solar cell can be measured in two states: in the dark and under illumination by an incandescent lamp. This is a common experiment to determine the efficiency of a solar cell (Thomsen and Gumlich, 1998). For the actual experiment we have used an ADVANTEST R 6243 source-meter which enables us to simultaneously measure the sourced current and the voltage drop across the solar cell. The current source can be controlled via a standard GPIB (IEEE 488) interface. The light is switched using the printer port of the controlling computer.

2.2 Hysteresis loop of a Ferro Magnet

The second experiment, the determination of the hysteresis loop in the magnetization of a Ferro magnet, is slightly more complex. The more elaborate setup on the other hand makes it applicable for a wider variety of similar experiments.

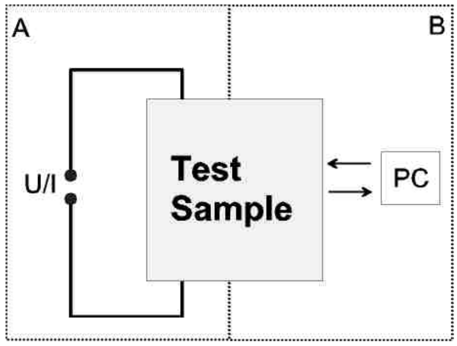

Figure 3: Diagram of the setup for the hysteresis-type experiment. On the left side (Part A) the PC controlled current is pictured. Part B on the right side symbolizes the collection of an arbitrary parameter of the experiment.

Figure 3 shows schematically the setup of the hysteresis experiment. It consists of two parts (A and B). In our case the sample (part A) is an electrical coil which generates a magnetic field when a current is passed through it. Part B is a hall-probe measuring the magnetic field in the hysteresis experiment. The actual interaction with the PC is done *via* a Keithley model 200 multimeter. In a modified setup, part A could be any device which is controllable by a voltage or current. A simple example could be an electric motor. Part B could then be the measurement of the temperature, the rotation frequency or the noise which is being generated.

2.3 Software requirements

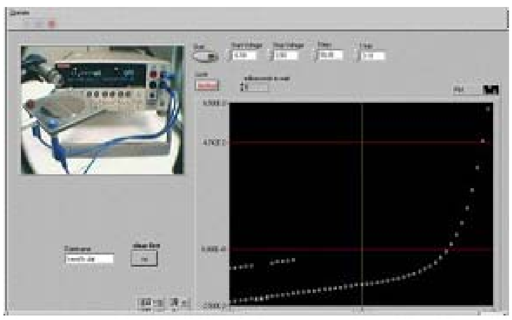

Figure 4: Software from National Instruments used in the remote experiments. The upper left inset shows a video image of the "real" (remote) experiment. One can recognize the current source with a digital display (*back*) and the solar cell (*front*, *left*) as well as the light bulb which simulates the illumination of the solar cell. Various buttons can be pressed and parameter values entered. They are passed through the internet to the experiment. The display area (*right*) contains the control variable (*x*-axis) and the measured parameter (*y*-axis).

In our remote experiments we used National Instruments LABVIEW to control the hardware and collect the experimental data. LABVIEW also possesses a very convenient web-interface which enables the remote-experimenter to perform any adjustments necessary. In order to view or control the experiment, a freely available web-browser plug-in has to be downloaded and installed. With the modular programming structure of LABVIEW remote experiments can easily be combined or extended.

3. USING REMOTE EXPERIMENTS

We describe here how the remote experiments presented can be used effectively in class or by individuals accessing the experiment over the internet. They are particularly suited as extensions or partial replacements of traditional problems in exercise classes. Problems for remote experiments usually cannot be solved simply with paper and pencil, but require some form of interaction with the experiment or with internet information in general. They are designed such that they are easy to use for students, and the learning efficiency is increased substantially by the aspect of playing or interacting with a real experiment, not just a simulation of what “should” happen. Students may use the remote experiment as preparation before class or to complete their understanding and exercise their knowledge gained after class. They also find remote experiments useful for preparing exams. A positive side effect is the increase in IT experience for the students participating in remote experiments.

3.1 The efficiency of a solar cell

One of the educational goals of treating solar cells in physics classes – next to understanding their production and functioning – is to determine their efficiency. The efficiency is given by the ratio of the power of a solar cell delivered under illumination to the power of the incident light (Thomsen and Gumlich, 1998). The power is given by the largest rectangle in between the *IV*-curve under illumination and the coordinate axes for zero voltage and zero current, see Figure 5. The maximum power of the solar cell occurs at an operating voltage of U_{max} and at a current I_{max}. By recording the solar cell in the dark (*upper curve* of Figure 5) and under illumination (*lower curve*) the power rectangle can be determined by the experimenter who is remotely located from the experiment. The software employed directly displays the two curves, proper scaling of the axes occurs either automatically, or predetermined, or by adjustment through the operator. Limiting values may be set to not endanger components of the setup and cannot be exceeded by the operator. Performing two successive voltage scans on the solar cell, one without and one with illumination produces curves similar to those in Figure 5. The maximum power output of the solar cell may be estimated directly from the rectangle in Figure 5, or the data may be exported to other software for further treatment.

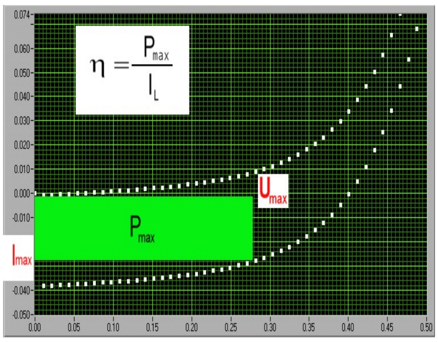

Figure 5: *IV* curves recorded in a remote solar-cell experiment (*dotted lines*). The upper curve was recorded with the solar cell in the dark, the lower one under illumination of a small light bulb. The rectangle between the curves indicates the maximum power of the solar cell.

In this way the efficiency of our specific solar cell was estimated to be around 2%. This experiment was part of our engineering class, and we counted several hundred remote accesses during a period of two weeks. Comments of students on the remote experiment were generally very positive.

3.2 Magnetic hysteresis measurement

Experiments with magnetic material can be an excellent complement to theoretical studies of phase transitions (Jeschke, 2005). We show in Figure 6 what the hysteresis of a magnet looks like. A similar plot can be found in almost any textbook on experimental physics, as shown in the inset to Figure 6, where the magnetization is plotted *versus* the magnetic field, and the remanence and the coercive field are indicated. In the experiment, instead, the outcome of the hysteresis experiment is shown, in which the magnetisation is not directly accessible. The magnetic flux, which can be measured with the hall-probe, is therefore plotted *versus* the magnetic field, *i.e.*, the coil current. Note, that the hysteresis area (*red in the figure*) is rather small as compared to the usual textbook illustrations.

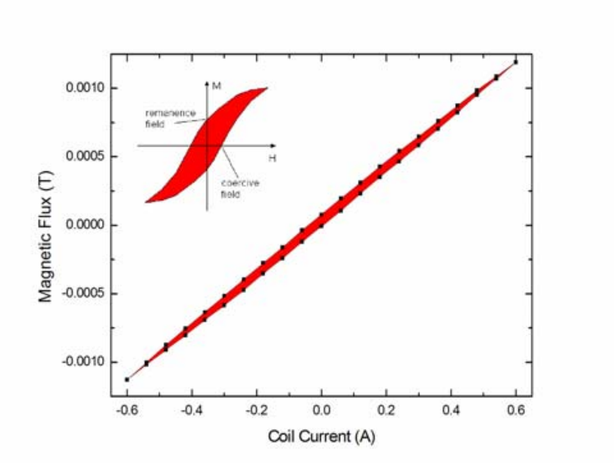

Figure 6: Hysteresis curve of a soft Ferro magnet. We have indicated several important points of the hysteresis curve like the remanence or residual magnetism and the coercive field in the inset which is a typical textbook example.

The student is also able to study the influence of the maximum magnetic field on the remanence and the coercive field within certain ranges only to prevent damage to the coil.

The presented hysteresis experiment can therefore give an important impulse to the understanding of ferromagnetism and the meaning of the three physical values ***H*** (the magnetic field), ***B*** (the magnetic induction or flux) and ***M*** (the magnetization).

4. REMOTE EXPERIMENTS IN EXAMINATIONS

One of the challenges of modern education is modernizing the situation a student is in during examination. Traditionally, an oral exam consists of the examiner asking several conceptual and/or technical questions, and the examinee answering those questions to the best of his or her knowledge. In written examinations a whole set of questions is given, and the student is required to gain as many points as possible by answering those questions in writing. By writing down some starting equation the student can show that he or she has a grasp at least of some of the issues in question; a partial number of points may be obtained. What is not challenged in such exams and what is really an essential qualification in engineering or other applied sciences is the ability to elegantly and efficiently deal with experimental or practical aspects of a problem.

Problem solving in reality encompasses choosing the right tool or instrument, connecting it properly and being able to understand and interpret the result, which may be obtained in form of a data stream output by a computer or by some other form of recording instrument. Recognizing the important and relevant parameters and knowing how to incorporate the data stream in a physics analysis is an integral part of performing an experiment and of understanding a problem. We show how remote experiments can address these issues.

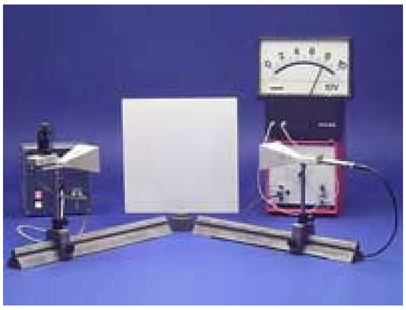

Figure 7: Interactive Screen Experiment (Kirstein, 2005) which allows via mouse movements to vary the angle of the central board, which reflects the incident microwave radiation. The microwave power at the detector is monitored and maximal at an angle of 45°.

4.1 Interactive screen experiments

We began our feasibility study of interactively examining students of first or second year engineering classes which were obliged to pass an exam in introductory physics (Thomsen, 2005). We presented them applets or interactive screen experiments, e.g., that of the simple reflection of microwaves (Kirstein, 2005). In this experiment, the law of reflection may be studied at the example of microwave radiation, see Figure 7. The student, who classically would be asked to write down the law of reflection, is confronted here with the question, what kind of waves are being reflected (microwaves), has to explain what kind of waves they are (electromagnetic waves), has to discuss the size of the reflector *vs*. the wavelength of radiation (they ought to be of the same order of magnitude). He or she is then asked to demonstrate the reflection law by turning the angle of the board and finding a maximum in the reflected radiation. Further issues to be discussed with the student are why the reflection does not drop to zero instantly at an angle somewhat larger or smaller than the maximum angle (wavelength of microwave radiation compared to the geometry of the setup) or how generator and detector of microwaves work.

4.2 Interactive applets in exams

As a second type of experiment we have employed interactive applets in oral examinations. We downloaded them from the internet and found them particularly suited for students to show their understanding by varying the relevant parameters in physics problems. As an example, we show here the molecular model for an ideal gas, see Figure 8 (Hwang, 2005). Here the number N of atoms or molecules, the pressure p in an enclosed system, and the velocity of the particles can be varied; the resulting volume V of the container is read out digitally. The relationship $pV=N\,k_B\,T$ can be demonstrated and the students in the oral examination are asked to predict what happens when one of the parameters is varied (Thomsen and Gumlich, 1998). They are then asked to demonstrate the reaction of the molecular gas with the applet.

As a further difficulty, the relationship between temperature T and particle velocity must be understood when the student is asked to increase the temperature of the gas. Finally, and this particular applet is ideally suited for such a question, the origin of the fluctuations in volume that are apparent in the running applet are to be discussed. The best students are able to show how the fluctuations may be avoided by increasing the number of particles by a factor of 10 or 100 and keeping the volume constant by increasing the pressure. This reduces the fluctuations and gives insight into the averaging qualities of statistical thermodynamics.

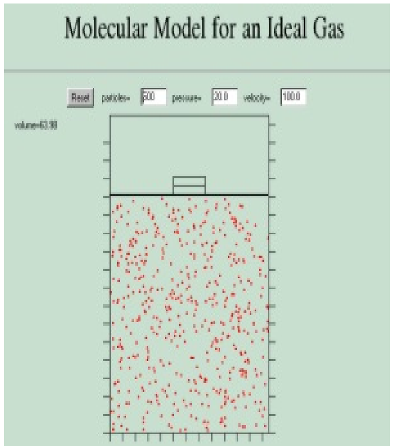

Figure 8: Molecular model for an ideal gas (Hwang, 2005). Students in oral examinations may be asked to demonstrate the ideal gas law or discuss why the piston and the corresponding enclosed volume fluctuate as a function of time.

Remote experiments as described in Sect. 3 are similarly suited for finding out the student's practical understanding of physics or applied sciences. Currently such extensions are being tested in oral examinations.

4.3 Assessment

Our preliminary experience with such extensions of oral examinations to include interactive elements for the examinee is very positive. Many of the students were asked about how they experienced the exam, by an independent person not involved in the exam. Their reactions may be summarized as follows. Generally students were very content with this exam situation. Their unanimous opinion was that they could better present their knowledge than in a traditional exam. They all felt that their fear or nervousness in the exam was much reduced compared to a traditional exam. Having an screen image in front of them was perceived as beneficial in the stress situation; handling the computer was not considered a disadvantage. If an option, they would prefer such interactive components in future examinations.

From the point of view of the examiner, the interactive oral examinations were successful as well. The students appeared to be well in control of what they were asked to do. They could present the proper physics context and adequately treated the problems presented to them with the applet or with the interactive screen experiment. The interactive experiments may be incorporated to various degrees in an oral examination; they allow seeing how the examinee deals with reality-near situations.

5. CONCLUSIONS AND OUTLOOK

In conclusion, we have presented the concept of remote experiments, which are real experiments conducted and controlled through appropriate software through the internet. Such remoteness can be used advantageously to demonstrate a sophisticated experiment remotely during a presentation located far away. Remote experiments offer an advantage as well in situations where access to the experiment is dangerous to the experimenter's health or just difficult to access. We have also discussed the advantages of employing interactive new media or remote experiments in examination situations. The perception of students to this form of examination was generally positive. We find that the interactive elements in general may be used in lecture room classes, exercises, seminars or tutorials. Different types of interactive elements are suited better for different learning situations.

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APPENDIX A: LIST OF ITEMS

List of items used in the remote experiments describe here.

Remote experiment: *Solar Cell*
Current Source (ADVANTEST R 6243)
Solar Cell
PC + GPIB Interface + Parallel Port Interface
Power Supply for light

Remote experiment: *Magnetic hysteresis*
Coil
Current Source (ADVANTEST R 6243)
Sample (Soft Iron)
Hall-Probe
Digital Multimeter with PC-Interface (Keithley Model 2000)
Current Source for Hall-Probe
PC + GPIB Interface