

## Chapter 5

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### **An Internet Natural Science Remote e-Laboratory (INRe-L) for Remote Experiments**

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*Presented in this chapter is an Internet Natural Science Remote e-Laboratory (INRe-L), which offers remote interactive experiments and contributes to a remote laboratories cluster within the EU. The cluster was established as a common undertaking of three universities - Charles University and Tomas Bata University in the Czech Republic, and Trnava University in Slovakia. At the present stage of development, the e-Laboratory includes experiments from physics, chemistry and environment monitoring, with 13 free access experiments available constantly. The laboratory uses the unified approach, as the hardware is the ISES (Internet School Experimental System) and its modules (see [www.ises.info](http://www.ises.info)), and the software for the server-client connection is based on Internet web services with a common browser and Java applets. The unique quality of the system is its simplicity both in use and in compilation (using the copy and paste approach of the pre-built building blocks), enabling the easy use of experiments by any interested party and, on top of this, easy construction of new experiments by using ISES hardware and ISES CONTROL KIT software. The experiments may be found both on <http://www.ises.info> and <http://kf.truni.sk/remotelab>. The laboratory has been extensively used for teaching purposes using Integrated e-Learning (INTe-L) - a new strategy of education based on e-experimentation.*

## INTRODUCTION

The present state of information communication technology is making it possible to devise and run computer based e-laboratories with remote experiments (RE) accessible to any user with a connection to the Internet, equipped with very simple technical means and making full use of web services [1]. Thus, the way is opened to a new strategy of education of natural science with strong global features, based on experiment and experimentation. We have named this strategy Integrated e-Learning (INTe-L) [2], with remote experiments across the Internet as the basis for this strategy. Recently, we presented both pedagogical and technical reasoning for RE, as well as the outlines of a simple system based on the server-client approach and on the web services and Java applets [1]. We established the outlines of the prospective remote laboratory system with data transfer using the Internet School Experimental System (ISES) as hardware and the ISES Web Control (IWC) kit as software [2]. In this paper we report on the progress in building the first Czech-Slovak Internet natural sciences remote e-Laboratory (INRe-L) based on these principles.

The main goal of building INRe-L is to fill in the gap in e-learning courses where the experiment and experimentation aspects have been missing. The ultimate goal of both projects has been the construction within a cluster of European universities of real interactive natural science experiments that are currently not offered, preferentially within the EU project. The project envisages a new approach in the technical solution of RE and the currently unsolved didactics problems of e-Laboratory. The database of the experiments together with bilingual instructions creates a new form and technical realization of interactive experiments for implementation in both lectures and laboratories in locations otherwise not accessible for the laboratories. The output of the projects provides a possibility for a community to participate in e-experiments. In such a way, e-Laboratory creates a real possibility not only for a broad community to join scientific experimentation, obtaining e-literacy and e-skills in the process, but for the implementation of a new form of natural sciences education. The experiments may be found both on <http://www.ises.info> (Prague e-Laboratory) and <http://kf.truni.sk/remotelab> (Trnava e-Laboratory) (Figure 1).



FIGURE 1

THE HOME PAGE OF BOTH PROJECTS: E-LABORATORY IN PRAGUE (LEFT, [HTTP://WWW.ISES.INFO](http://www.ises.info)) AND E-LABORATORY IN TRNAVA (RIGHT, [HTTP://KF.TRUNI.SK/REMOTELAB](http://kf.truni.sk/remotelab))

Both projects envisage forwarding the innovative simple solutions for RE, which also includes solving the concomitant and substantial pedagogical and psychological problems connected with this new form of e-Laboratory for the lectures, seminars and e-Laboratory within the new strategy of education – the Integrated e-Learning [3].

The layout of the present paper is as follows: First, we present the motivation and technical implementation of INRe-L in comparison with the existing e-laboratories in Europe, and then we present the Prague e-Laboratory, followed by the Trnava e-Laboratory, with a brief description of experiments. The reasoning for the INRe-L and RE is described in some detail with both their technological and pedagogical assets. The closing part deals with the outlook in building INRe-L and then offers some conclusions.

## MOTIVATION AND TECHNICAL IMPLEMENTATION

The present state of information communication technologies (ICT) in the area of measurements, data collection and transfer using web services is rather complicated and not clearly enough arranged for a physics or natural science teacher to build a remote experiment. Missing standards lead to many individual solutions, and therefore to unnecessary hurdles for hosts and users [4].

Many real remote e-laboratories across the Internet have begun providing experiments on real world objects, supplying the client with the view of the experiment, an interactive environment for the experiment control and resulting data for evaluation. Three European activities have increased interest in remote physics laboratories, the project PEARL, “Practical Experimentation by Accessible Remote Learning” [5], the project Remote Farm by Thomsen et al. [6] and the inspirational pioneering undertaking - Remotely controlled laboratories (RCL) in Kaiserslautern, Germany by Jodl et al. [7]. The cumulative experience, the inventory of the state of the art and corresponding references in Europe and United States are to be found in [7]. The normative goals in remote experiments are documented by the project LiLa–Library of Laboratories (<http://www.lila-project.org/>).

To build a remote real physics experiment requires as the first step to set up the computer controlled experiment. For this purpose we use user friendly hardware and software for the easy creation of physics experiments, that is ISES (Figure 2) and IWC kit. This forms the basis of our approach to the simple and prospective building of RE. In this chapter we will mention only a few pieces of information characterizing the system; more details are to be found elsewhere [3] ([www.ises.info](http://www.ises.info)). The ISES system is a user friendly hardware and software for the easy building of physics experiments. The system is composed of an interface card, a set of variable modules and sensing elements, and a service graphical and evaluation software. The service program enables the simultaneous measurement of 10 different channels (8 analog and 2 binary) and the use of 4 output channels. All these modules are fully programmable, using the programming panel. The data are depicted both in analog or digital form on a variable number of panels, with depicted quantities either measured by modules or their combinations (addition, subtraction, product, quotient etc.). The software provides data processing (integration, differentiation, fitting, approximation etc.). The data export for another graphical processor is straightforward.

The IWC kit then allows for compilation of the control program by the user on the copy-paste principle deploying ready-made packages for automatic creation of the sub servers, prefabricated program segments for client web page creation (view of the



FIGURE 2  
INTERNET SCHOOL EXPERIMENTAL SYSTEM (ISES)

experiment, experiment controls, graphs, data digital displays and others) and prefabricated Java applets for the transfer of the data.

Next, we present the individual experiments in both e-laboratories with a brief description of the experiments and their web pages, live web camera views and examples of the measured quantities. The remote experiments presented here were devised within the activities of both universities intended to help the teachers in the practical classes – lectures, seminars and laboratory exercises. The individual experiments have not followed any predefined scheme, but served for covering those that were the most demanded in the teaching at both universities. We are now in the process of redefining and widening the role of remote experiments and performing the extensive work in covering all the taught subjects, the associated instruction manuals and assignments both for the seminars and laboratory exercises in the framework of Integrated e-Learning [3]. The still greater ambition is to build a grid of European remote laboratories within the EU project, covering the typical curricula of university physics.

We have in mind to facilitate a wide usage of remote experiments by interested teachers in the teaching process and spurring their own interest in building RE. We are really quite near to fulfilling the goal (see for example the Czech web page of Masaryk University in Brno, <http://ises.tym.cz/index.php?page=experiment&experiment=nucenkmit>) of actively performing remote experiments, as the contemporary physical hardware and software available enables the straightforward and easy construction of proprietary experiments available for the school in question or for the needs of the students.

### EXPERIMENTS IN THE PRAGUE E-LABORATORY

The first RE started in the Prague laboratory in 2002. The present state (VIII/2010) of the RE in the Prague e-Laboratory is accessible via the web page ([www.ises.info](http://www.ises.info)). The detailed instructions (Motivation, Introduction, Physical Background, Experimental Setup, Experiment and Assignments) are given for each experiment on the web site.

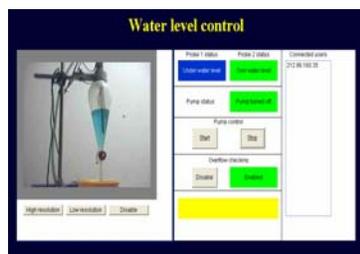
It should be stressed that the leading idea behind the choice of the experiments was the desire to have one introductory experiment, one experiment with the features of manual control, one experiment with the features of the data logger and then the experiments, covering step by step the basic course of university level physics. We focused from the very beginning of our activities in remote experiments on mastering the data transfer to the remote experimenter in order to enable the further processing of the data. We realized at the early stages of the building of the e-Laboratory that the suitability of any classical experiment for RE differs in wide range due to their steady or dynamic character, the level of the observed signals and the number of parameters to study the phenomenon in question. We avoided on purpose the complicated and sophisticated instrumentation for RE building, because we tried to persuade the instructors to build similar experiments by themselves for their teaching.

*“Water Level Control” (Figure 3)*

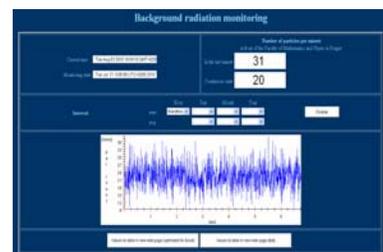
The introductory remote experiment “Water Level Control” is a remote experiment with the manual control of the type “On/Off”. It controls the water level interactively and manually from the webpage without data transfer to the user. The controls are “Run Experiment”, “Pump Control”, “Start-Stop”, “Overflow Checking” and “Enable-Disable”. Further, the messages “Probe 1 Status” and “Probe 2 Status” signal the height of the water level. The assignment and questions are oriented toward the water pumping dynamics and its monitoring.

*“Environment in Prague” (Figure 4, <http://kdt-16.karlov.mff.cuni.cz/en/mereni.html>)*

The experiment “Environment in Prague” is a remote laboratory experiment monitoring the temperature, pressure, intensity of sunshine and, as a novelty, the background radiation at the Faculty of Mathematics and Physics, Charles University in Prague. The experiment demonstrates the possibility of a typical data logger to monitor different physical variables with simple technical hardware and software across the Internet. It is a typical task of remote sensing, where the selected variables are only sampled at certain time intervals, and measured and stored without any remote control. The experiment has been running since 2002 with more than 5,000 connections to date. More users may be



**FIGURE 3**  
THE HOME PAGE OF THE E-LABORATORY  
IN PRAGUE FOR “WATER LEVEL  
CONTROL”: THE LIVE VIEW OF THE  
EXPERIMENTAL VESSEL (LEFT) AND THE  
CONTROLS (RIGHT)



**FIGURE 4**  
THE HOME PAGE OF THE E-LABORATORY IN  
PRAGUE FOR “ENVIRONMENT IN PRAGUE”  
(TEMPERATURE, AIR PRESSURE, SUNSHINE  
AND RADIATION), SHOWING  
BACKGROUND RADIATION

connected to this experiment at one time, and it is accessible round-the-clock. The tasks and questions are oriented towards the evaluation of measurements related to the weather and environment, and their relation to human mood and body fitness.

*“Electromagnetic Induction” (Figure 5)*

The experiment “Electromagnetic Induction” is useful for the demonstration and quantitative elucidation of electromagnetic induction phenomena. The experiment uses a rotating coil in a homogeneous magnetic field and monitors the corresponding signal. The goal of the experiment is to show the phenomenon and how it complies with Faraday’s law of electromagnetic induction. The only parameter is the voltage for the driving motor influencing the frequency of the rotation of the coil, and data is the time representation of the electromotive voltage from the rotating coil.

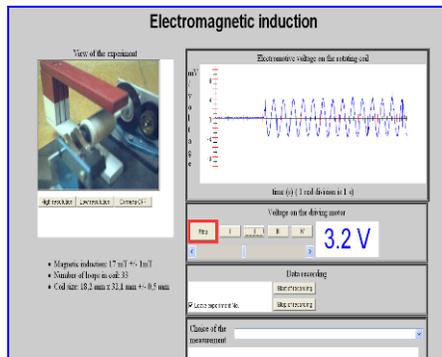


FIGURE 5

THE WEB PAGE ON THE CLIENT COMPUTER OF THE REMOTE EXPERIMENT “ELECTROMAGNETIC INDUCTION”: LIVE WEB CAMERA VIEW, FREQUENCY CONTROLS AND THE GRAPH WITH THE TIME REPRESENTATION OF THE ELECTROMOTIVE VOLTAGE

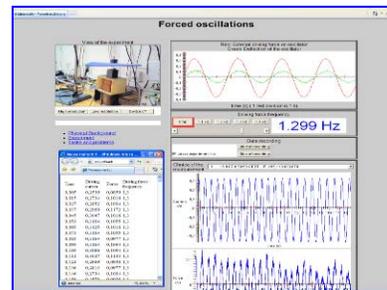


FIGURE 6

THE WEB PAGE OF THE REMOTE EXPERIMENT “NATURAL AND DRIVEN OSCILLATIONS”: LIVE WEB CAMERA VIEW, FREQUENCY CONTROLS, GRAPH OF THE MEASURED DATA AND THE TRANSFERRED DATA

*“Natural and Driven Oscillations”*

(Figure 6, [http://kdt-17.karlov.mff.cuni.cz/pruzina\\_en.html](http://kdt-17.karlov.mff.cuni.cz/pruzina_en.html))

An experiment from mechanics of oscillations is an important part of a physics course, forming the basis of many phenomena and technical applications, ranging from UV absorption in atmosphere, in telecommunications or in molecular, atomic or nuclear physics. The remote experiment “Natural and Driven Oscillations” is built as a simple mechanical oscillator with a mass and spring externally driven by an electromagnetic generator of variable frequency. The parameter is the driving force frequency, and the data transferred are the instantaneous driving force and the deflection. The wide range of tasks and questions are oriented on the study of the natural oscillations and their damping, the amplitude and phase characteristics, the resonance phenomena and the energy transfer.

“Photovoltaic Cell”

(Figure 7, [http://kdt-4.karlov.mff.cuni.cz/vacharakteristika\\_2\\_en.html](http://kdt-4.karlov.mff.cuni.cz/vacharakteristika_2_en.html))

This remote experiment may be used in courses dealing with circuits, solid state physics and the environment, by stressing the respective teaching goals. It consists of a solar cell illuminated with a light source of variable light intensity and voltage applied on the cell. The  $I-U$  characteristics in dark and under illumination give a great deal of information, ranging from the equivalent circuit, solar to electric energy transformation efficiency and fill factor, optimum load for maximum power transfer, etc. The transferred data are the averaged  $I-U$  characteristics, the number of the measurements and the corresponding mean square deviations.

“Diffraction on Micro-Objects”

(Figure 8, [http://kdt-13.karlov.mff.cuni.cz/sterbina\\_en.html](http://kdt-13.karlov.mff.cuni.cz/sterbina_en.html))

This physical optics experiment shows diffraction phenomena on micro-objects and their change with the dimensions of the micro-objects and the wavelengths of the laser as the coherent source of light. The transferred data is the spatial distribution of the diffraction intensity. The goal and assignment are to determine the geometrical dimensions of micro-objects.

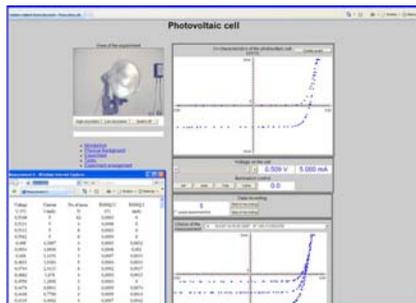


FIGURE 7  
WEB PAGE OF THE EXPERIMENT  
“PHOTOVOLTAIC CELL”: LIVE WEB CAMERA  
VIEW, CONTROLS, GRAPH OF MEASURED  
DATA AND TRANSFERRED DATA

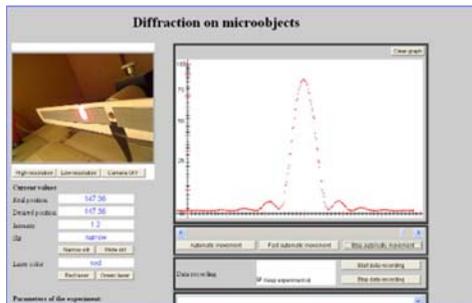


FIGURE 8  
WEB PAGE OF EXPERIMENT “DIFFRACTION ON  
MICROOBJECTS” AND/OR HEISENEBER  
UNCERTAINTY PRINCIPLE: LIVE WEB CAMERA  
VIEW AND CONTROLS (LEFT) AND GRAPH OF  
DIFFRACTED INTENSITY DISTRIBUTION OF RED  
LASER

A second experiment ([http://kdt-13.karlov.mff.cuni.cz/heisenbergcontrol\\_en.html](http://kdt-13.karlov.mff.cuni.cz/heisenbergcontrol_en.html)) from Quantum Theory uses the hardware of the previous experiment and differs only in instructions and assignments. The goal is to verify the validity of the Heisenberg principle of uncertainty as the crucial law for the micro world using the diffraction probability distribution of photons on a screen after the passage of a slit and/or to find the approximate value of the Planck’s constant.

“Magnetic Field Mapping” (Figure 9, <http://kdt-27.karlov.mff.cuni.cz>)

This is an important experiment for electromagnetic theory. It uses Helmholtz coils connected to the current source independently, and a 2D magnetic sensor positioned on a plane. The magnetic field distribution is presented by arrows, the direction and color of which represent the field direction and magnetic field strength value, respectively. The magnetic field distribution may be influenced by inserting materials with different magnetic properties.

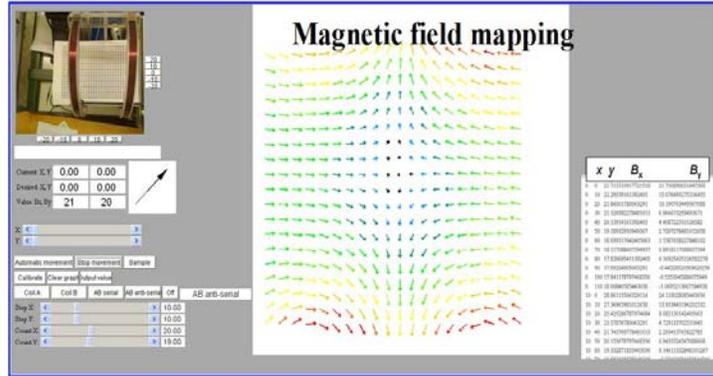


FIGURE 9

WEB PAGE OF EXPERIMENT “MAGNETIC FIELD MAPPING”: LIVE WEB CAMERA VIEW OF HELMHOLTZ COILS, CONTROLS (LEFT), MAP OF FIELD DISTRIBUTION OF NON-PARALLEL CONNECTED COILS AND CORRESPONDING TRANSFERRED DATA (RIGHT)

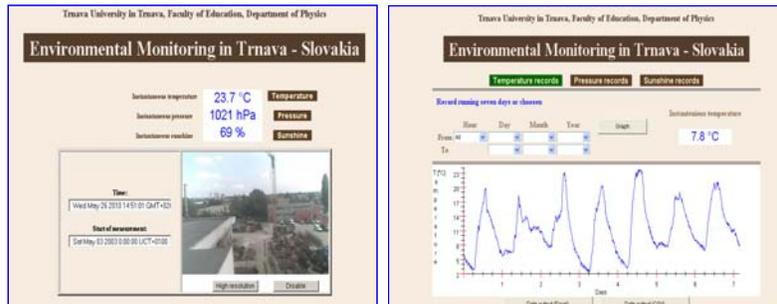


FIGURE 10

REMOTE EXPERIMENT “ENVIRONMENTAL MONITORING IN TRNAVA”: LIVE VIEW (LEFT) AND TEMPERATURE, PRESSURE AND SUNSHINE INTENSITY (IN THIS CASE TEMPERATURE MONITORING (RIGHT))

## EXPERIMENTS AT THE TRNAVA E-LABORATORY

The Slovak e-Laboratory of RE was built in the Department of Physics, Trnava University in Trnava using identical technological approaches, based on the ISES and

IWC kit ( see [www.ises.info](http://www.ises.info) ) . Here we want to present experiments by their web pages, their live web camera views and examples of the corresponding measured quantities.

“Environmental Monitoring in Trnava” (Figure 10, <http://remotelab1.truni.sk>)

The RE monitors, displays and stores the data of temperature, air pressure and the intensity of sunshine in Trnava.

“Electrochemical Cell” (Figure 11, <http://remotelab2.truni.sk>)

The remote experiment Electrochemical Cell represents one of the few attempts to introduce RE into chemistry worldwide. The electrochemical properties of the galvanic cell are expressed by the measurements of electromotive force and conductivity of the electrolyte. It is possible to check the validity of the Nernst equation by changing in a controlled manner the concentration (conductivity) of the electrolyte. The computer controls the electromagnetic valves for letting in and out the electrolytes, titration pump and stirring device. The schematic representation of the experiment is in Figure 11. It consists of two reaction chambers with metal electrodes and electrolytes, one with a variable concentration, connected by a membrane.

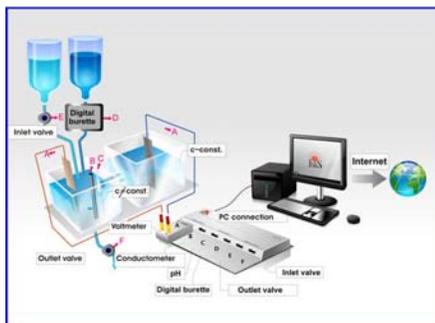


FIGURE 11  
SCHEMATIC DIAGRAM OF REMOTE INTERACTIVE EXPERIMENT “ELECTROCHEMICAL CELL”

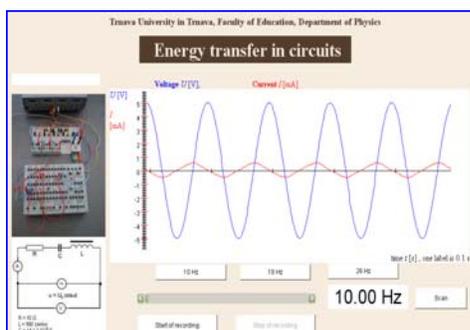


FIGURE 12  
REMOTE EXPERIMENT “ENERGY TRANSFER IN OSCILLATORS”: VIEW OF EXPERIMENT (LEFT) AND CONTROLS FOR FREQUENCY DRIVING VOLTAGE AND CURRENT (RIGHT)

“Energy Transfer in Oscillators” (Figure 12, <http://remotelab3.truni.sk>)

This remote experiment provides an electronic analogue to the experiment “driven oscillator on a spring” in Figure 5, providing the current (voltage signals and their respective phase shift) and allowing the possibility to study the resonance phenomena and the energy transfers in the system.

“Free Fall” (Figure 13, <http://remotelab4.truni.sk>)

This remote experiment deals with the understanding of free fall acceleration, where the time domain data are logged and subsequently evaluated. The experiment may be also used for free fall in viscous media and also in the second version of the RE used to demonstrate electromagnetic fields and to prove Faraday’s law.

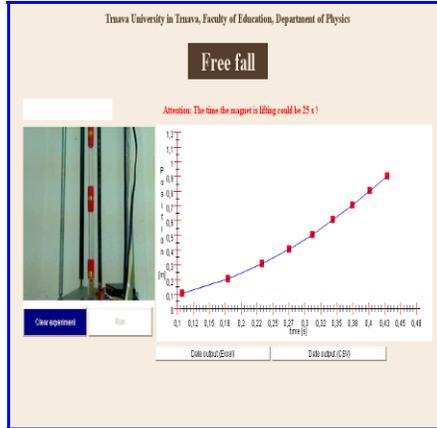


FIGURE 13  
REMOTE EXPERIMENT “FREE FALL”: LIVE VIEW OF EXPERIMENT (LEFT) AND RESULTING TIME REPRESENTATION OF THE COORDINATE OF FALLING BODY (RIGHT)

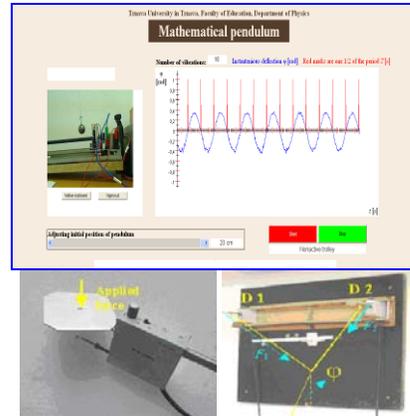


FIGURE 14  
WEB PAGE OF RE “MATHEMATICAL PENDULUM” (UPPER PANEL) AND DETAILS (BOTTOM PANEL) SHOWING DYNAMOMETER (LEFT) AND PENDULUM ARRANGEMENT WITH DYNAMOMETERS, D1 AND D2

“Mathematical Pendulum” (Figure 14)

This experiment takes a unique recording of the instantaneous angular deflection by two dynamometric sensors ISES. Its exploitation is in kinematics, dynamics and the energy of curvilinear motion and oscillations.

## DISCUSSION OF REMOTE LABORATORIES

### Technical Issues

Figure 15 depicts all RE of the e-Laboratory INRe-L both in Prague and Trnava with their web addresses for open use (detailed information by F. Schauer at [fschauer@fai.utb.cz](mailto:fschauer@fai.utb.cz)). The number of remote access or connections to individual RE of the Prague e-Laboratory is shown in Table 1. The inset depicts the total number of connections in the period 2006-2010.

# Internet Natural ScienceRemote e-Laboratory (INRe-L) of Remote experiments

F. Lustig , J. Dvořák, P. Brom , P. Jusko, A. Řehák  
and  
F. Schauer, M. Ožvoldová, P. Čerňanský, Ž. Gerhátová, L. Tkáč, M. Beňo

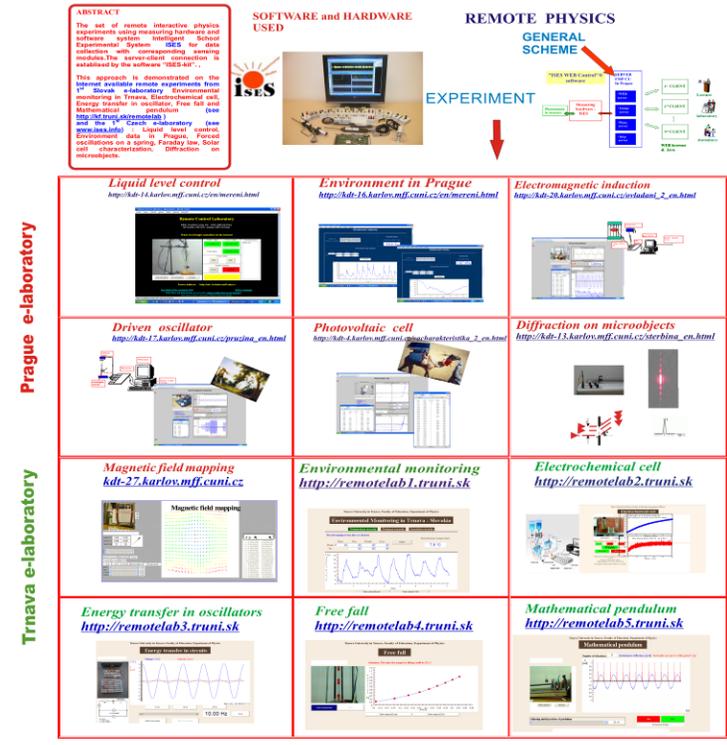
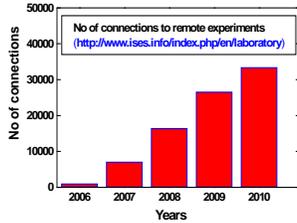


FIGURE 15  
OVERVIEW OF ALL REMOTE EXPERIMENTS IN E-LABORTORY INRE-L  
AND THE TEAMS IN PRAGUE AND TRNAVA  
VIII/2010



Number conn. Experiment	Starting date	07/2007	04/2008	05/2009	06/2010
(1) Water level	04/2004	2 896	3 357	4 733	5 462
(2) Environment in Prague	12/2005	1824	4 827	7 327	8 532
(3) Electromag. induction	10/2006	998	3 241	5 713	7 579
(4) Oscillations	10/2006	570	1 498	3 054	3 480
(5) Solar energy conversion	10/2006	675	1 843	3 127	4 185
(6) Diffraction on microobjects	07/2007	72	1 128	2 620	4 140
$\Sigma$	~1500	7 035	16 385	26 574	33 378

TABLE 1  
NUMBER OF CONNECTIONS TO REMOTE EXPERIMENTS IN PRAGUE  
IN YEARS 2006-2010

A general consensus among the academic staff and the authorities of the universities exists about the weight and importance of laboratory work in science and engineering in general, and in physics in particular. On the other hand, in real university life, due to manifold reasons, including the need for new instruments, new techniques and methods, and resulting costs requirements, the quality and the role (expressed in teaching hours) of the laboratories have begun to diminish. Besides, laboratory work is usually only loosely bound to the time schedule of the lectures and seminars and, at a majority of universities, consists of the lists of experiments with more or less given recipes, the strict objectives and goals to be achieved by the student within the planned teaching hours. It is then a common habit to have fixed, prepared laboratories with experiments for the whole term with students “circulating” individual experiments in an arbitrary way. In this way, the access of the students to the laboratories for independent study is not accounted for in the planning. The same goes for the students of distance education and students, who, for a variety of reasons, are excluded from laboratory work.

The general and the most decisive criterion for the introduction of the remote laboratories in our case was the trend to draw students more into practical experimental work and to remove the barriers for independent laboratory work.

The provision of remotely controlled real experiments accessible over the Internet can potentially positively address all of the following issues [8]:

- Remote real experiments in most cases work around-the-clock. Students and those interested may choose optimal times and work at their most suitable speed. If an instructor’s presence is required, a reservation system for the experiment may be utilized.
- Access to costly and potentially hazardous experiments is feasible.
- The possibility of introducing students in a natural way to the real contemporary world of science and technology, with teamwork mediated by computers and the web and organized through distance learning so as to build communication skills.

- The university premises do not limit access to the RE, with a computer and the Internet mediating them. Groups of distance students can profit from RE. In the present scheme of organization, they work in laboratories in blocks covering more than one laboratory experiment, completely independent of lectures. RE positively influence the very population of people who, for different reasons, are excluded from laboratory work.
- Remote experiments support globalization and the delivery of experiments to underdeveloped countries.

When RE is introduced, the provisions for high quality educationally effective interface design, instructions for the experiment, questions and problems connected to the experiment, additional reading and the possibility of communication with the help of an instructor are all of paramount importance. Students should concentrate during the measurements and subsequent data processing on the examined phenomena and not on the instrumentation and its function. Also, they should from the very beginning of the work with the RE know what to measure and what to observe, and thus the communication web page on their computer should be as simple and self explanatory as possible, without unnecessary details and formulas. After their transfer to the client (experimenter) computer, the centre of gravity in the RE should be in data processing and evaluation [9].

### **Pedagogical Issues**

Empirical research concerning the outcome of remote laboratories is under way on several levels. Each experiment has the ability to record the individual steps of the experimenter and the time spent on each step, and the evaluation gives the possibility to follow the execution of the experiment. On another level, we compare hands-on, remote and virtual experiments, e.g., photoelectric effect; see:

<http://www.ises.info/index.php/en/laboratory/experiment/photoelectric-effect-VA>.

The third level is project-based education, where the students take measurements on remote experiments and produce their own project with data, evaluation and discussion. In searching for the pedagogical reasons to introduce remote laboratories, it is valuable to summarize the skills and benefits of the laboratory work that may be acquired [10, 11]. All of these skills and benefits should be taken into account when building a remote experiment. On top of this, without the claim of being exhaustive, current students should learn and make full use of the advantages the ICT and Internet bring to laboratory work. In the majority of progressive university laboratories, the computer has found its way into experiments in various ways, from data collecting (functioning and replacing e.g. analogue and digital oscilloscopes), through filtering noise to simple processing and exporting and graphical presentation. Our own experience and the golden rule in introducing computers into student laboratories are the ability of the computer to reduce routine work, while not encroaching upon the borders of the physics principles and laws of the examined phenomenon. The Internet opens the possibility for the search for information and supporting material and for result comparison.

These assets support the introduction of RE; let us enumerate the most important.

*Substitute “Recipe Labs” [12] by Research Laboratories*

Laboratory classes in traditional laboratories typically involve students performing teacher-structured laboratory exercises or experiments. Each step of a procedure is carefully prescribed and students are expected to follow the procedures exactly. Usually, little is left to the student's own thought or ingenuity. This requires little student engagement with the content, and as it is commented in [13], “students can be successful in their laboratory class even with little understanding of what they are actually doing”. In [14] the authors suggested that the recipe lab “omits the stages of planning and design”, and it encourages ‘data processing’ rather than ‘data interpretation’. In [15] the authors developed this further by commenting on the various steps a research scientist would take before actually getting to the practical aspect of the experiment by asking: What questions are we trying to answer? What observations would provide an answer to the questions? How can we best create conditions for making the desired observations? How will we process and evaluate the observations? What will we do next?

RE provide more scope for skill development, concept comprehension and the experiment process. The students gain experience of the whole scientific process in a relevant and stimulating format. Furthermore, they seem to enjoy the experience of working by the method of trial and error and the method of hypothesis formulation and proving or disproving as the most idea-generating method in the scientific method at the same time, this is the main objection against the introduction of virtual e- laboratories.

*Project Work by RE*

Once we have introduced the research laboratories using RE, we can also start to think about project education [16]. The problem solving students encounter in their projects with RE helps them learn a set of important concepts, ideas, skills and techniques that will be required in subsequent subjects and their future careers. This form of education constitutes an enormous change; students must be willing to take charge of their own learning and to cope positively with the attitudinal shifts that occur when they experience change. The enormous advantage of this approach is the possibility to work at any time, from any destination and at any speed.

*Skills Students Acquire*

The subject of additional acquired skills is very obvious in RE work. On the one hand, students are forced to measure independently but, on the other hand, they can easily share experience with RE. Moreover, the tutors, or other sources of information on the RE, are readily available. This forces students to exchange information, knowledge and know how in a teamwork fashion. This supports self awareness as the planning of work, necessity of selecting appropriate techniques and procedures and understanding of errors is necessary. Further, the main feature of project work forces students to analyze and evaluate the obtained data. The project work using RE strengthens the possibility to measure and observe events of the real world and its peculiarities and thus serves as an introduction and interest generator in general science issues and presentation skills.

The additional gained skills in ICT and in Internet operation are quite important and obvious, but above all it helps university teachers in their struggle against the deeply

seated and broadly exercised notion about the Internet as the ICT environment suitable for chatting, playing and surfing, but not appropriate for serious, especially scientific work.

To optimize pedagogical and educational goals of RE, a constant feedback of its effectiveness and operation should be provided. The statistics of the visits to individual experiments with a detailed recording of the activities split into individual steps and corresponding times spent are imperative for the pedagogical research and constant improvement of both the hardware and software of RE, similar to the pedagogical research on the efficiency of applets [17].

The next important steps in the development of remote experiments and studying their impact on the psychology of the experimenter were the pedagogical and psychological aspects of RE. We started the systematic recording on the server side of detailed steps, the experimenter on the client side takes during measurements, with the time intervals spent in each step. To give more specific insight on which activities are collected, in Table 2 there are summarized the types of activities recorded in the experiment “Diffraction on microobjects” in time scale. The scope of the data is

Activity No	Activity
1	User connection
2	Auto measurement start
3	Manual measurement
4	Wider slit on
5	Narrow slit on
6	Green laser on
7	Red laser on
8	Start recording data
9	Stop recording data
10	Data transfer
11	User disconnected

TABLE 2  
ACTIVITIES RECORDED IN THE  
EXPERIMENT “DIFFRACTION ON MICRO-  
OBJECTS”

enormous and this material is currently evaluated for the assessment of the pedagogical impact of the experiment and its psychological improvements.

A last and recent step was the remote scientific experiment “in solid state”, which enables students to characterize a photovoltaic solid state cell [18].

To add to the general characteristics of the e-Laboratory of remote experiments in Prague, access to any experiment is at present granted to any interested party without any checking or registration. The laboratory is operated around-the-clock, constantly monitored as to the state of the experiments and improved upon. All the experiments give a view of the experiment using live camera and enable the choice of the measured and transferred data to the client – experimenter for their processing (with the exception of “Water level control”).

In the near future, our activities in the direction of ISES and ISES web control will be focused on the building of remote laboratories distributed among Charles University in

Prague, Tomas Bata University in Zlin and several universities in Slovakia, with the centre at Trnava University in Trnava. The main goal of the emerging e-Laboratory network is to cover the university syllabus of a basic physics course by experiments in the direction of Integrated e-Learning [19].

We have envisaged and started building the following new RE:

- “Photoelectric Effect”
- “Standing Waves in a Resonator”
- “Sources of Energy”
- A set of “Mechanics RE”

## CONCLUSIONS

A concerted project of an e-Laboratory of remote interactive experiments in the Czech and Slovak Republics has been successfully launched and brought to fruition, with 13 functioning remote experiments already designed and implemented, covering physics and partially chemistry courses. The experiments have already found application in secondary schools and universities both at home and abroad (as evidenced from the records delivered by the system and Table 1 with connected graphical representation). The main conclusions from long lasting activities during the construction of e-Laboratories in Prague and Trnava may be summarized as follows:

- RE play and will continue to play a decisive role in increasing interest, motivation and individual involvement in pedagogical processes covering various areas of the natural sciences, including lectures, seminars, laboratory exercises, project work, examinations and self study, and in general integrated e-Learning [2]. The pedagogical research on the usage of RE proved the hypothesis of increased involvement of both students and teachers in the pedagogical process (M. Ožvoldová, to be published).
- The e-Laboratory will serve as a centre of the university network of natural sciences experimentation [20].
- The wide participation of students of both undergraduate and graduate studies in building the laboratory proved the feasibility and interest and ability of students to build such new and pioneering applications of ICT. This experience is very promising for the spread of this technique among teachers for building remote experiments for their own use.

## ACKNOWLEDGMENTS

The authors acknowledge the participation and contributions of all members of the working teams both in the Prague and Trnava laboratories in building the e-Laboratories; without them such an enormous undertaking would not be conceivable. This work was supported by the following projects: Grant of the Ministry of Education of the Slovak Republic VEGA, Slovak Republic, Project No 1/0332/08: “Globally Available Natural Science Experiments as a Constituent Part of Integrated e-Learning”; KEGA, Slovak Republic, Project No 3/72277/09: “Completion of the Remote e-Laboratory as a Tool for Development of Student's and Teacher's Key Competencies for Third Millennium”; and the Project of the Ministry of Education of the Czech Republic 2009, 14/2, “Development of Hardware and Software for ICT on MFF, Charles University in Prague”, Subproject “E-Laboratory of Distant Interactive Physical Experiments”.

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