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Transforming Experimental and Laboratory Work in Physics

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Abstract. In every natural science, experimental and laboratory work should always be a part of the education process. It is the aim of this article to show a way of improving the natural sciences education using the Integrated Remote and Virtual Laboratory Environment, which is not an alternative but an enhancement!

This article will include a preview of Remote Control Laboratory (RCL) (e. g. our <http://www.ises.info>), Remote Sensing Laboratory (RSL) or news from our Remote Network Laboratory (RNL) (to be specific: remote radiation monitoring, for now on <http://kdt-26.karlov.mff.cuni.cz>). It will also show a way to contribute to the transformation of natural sciences laboratories using virtual simulation with data export and import (once again a preview of the new visualization simulation environment ISES SimLab). In It's conclusion the article will also suggest a way to transform the entire process of natural science education.

Keywords: alternative teaching methods, real experiments, remote experiments, virtual experiments, computer-aided measuring systems, e-learning.

Introduction

Teaching of natural sciences should be based on experiments. Recent research tells us, that teachers spend over 60% of their time by lecturing.

Assignments are typically homework problem with short quantitative answers, seminars and especially laboratory work are more or less “ recipes “ style usually only loosely bound to the time schedule of the lectures and examinations largely based on written exams containing theory and a little of problem solving. In all new emerging teaching technologies the nearly unanimous opinion prevails about their most decisive feature - to remove the barriers for the possibility for student's independent and exploratory work in all sorts of laboratories in elucidation of the real world [1]. The main possibility, without any dissenting voices for this trend, was to bring about the change in the physics laboratories in the direction of substituting the “recipe labs” [2] by research laboratories. It is very instructive in this respect to consult the very instructive and still valid document, American Association of Physics Teachers (1977) [3].

It is the aim of this article to suggest a way to change this trend. The teaching methods for Physics have reached an admittedly advanced status. The new pillars of education are: 1. Computers (as a computation tool, as a teaching tool (LMS), for multimedia, etc.), 2. the internet (browsers, databases, e-learning, etc.), 3. simple hand-made experiments, 4. integration of other natural sciences, 5. project-based teaching, etc. Computers have now become a regular part of experiments, be it traditional, remote or virtual. Computers have automated the experiments as well as made them much more effective. They also made long-term data gathering and rapid event recording possible. It is now also possible to receive immediate graphical and statistical output. Computers are also able to deal with exceptionally complex systems, etc. (no need to elaborate). The internet and nowadays mobile technology as well are another element, which massively transformed class work. However, it is not our aim to further describe what an asset all the e-technologies are. Simple “home-made” experiments are very attractive and useful, by now they are a separate category from classical teaching tools and have earned a rightful place for themselves. Another trend in teaching the natural sciences are the increased efforts to integrate Physics, Chemistry and Biology. Each subject is kept in their traditional boundaries, but projects financed by the EU clearly dictate integration. And lastly we should mention new teaching methods such as project-based teaching, group-based teaching and individual teaching etc.

This article aims to mobilize teachers to use new technologies in school experiments. We should be aware of the marked difference in the technologies students use in school and out of school. Our students are of the “e-generation”, the network and internet one. How is it possible that our students normally communicate over the internet, constantly multitask and without their trusty teacher “Google” cannot even begin to solve any problems? They use the internet as an external brain, they constantly use ICQ and Facebook and play on-line games. And then in school they are bored by an “x-generation” teacher standing in front of the blackboard, holding a piece of chalk and swamping the students with facts instead of providing them with competences. Let us try to teach the students to educate themselves further by not asking them to provide the right answers, instead motivate them to ask the right questions. Only then will they be able to survive in the new age of the exponential increase of knowledge.

I apologize to the active teachers who make use of interactive or hand-made teaching tools and supplement their teaching with projects, computers, the internet etc. But there are still only very few such teachers who can rouse the students’ interest in active learning. This is supported by the latest results of international tests like TIMMS or PISA.

In the introduction we named the new pillars supporting the basics of teaching natural sciences, but what should be done with them further? This article will endeavor to provide an answer. We will shortly summarize the traditional, remote and virtual laboratories and try to begin the integration of all the pillars of high quality natural sciences education.

1 Traditional Laboratories

Let us begin already on the level of laboratories supported by computers. Of course, laboratories devoid of any computers have their charm. But our aim will be to make the classical laboratory tools more attractive with the help of computers. Schools are often equipped with measuring systems like ISES, Vernier, Pasco, IP Coach and others. For classroom laboratories the ISES systems [4], [5] are suitable, they are compact, the measuring modules are permanently connected to the measuring console. The ISES system has arguably the most advanced technical parameters of the aforementioned systems both concerning the number of inputs and outputs as well as its versatility and compatibility with other measuring systems and others. It is very easy and intuitive to connect it with classical school experiments. A big leap from one demonstration set to full frontal equipment are fully equipped classrooms.

The traditional laboratories are now combined with mobile laboratories. Although those can be allocated in school, they find most use outside the classroom. They can also function as a datalogger, where data can be gathered and analyzed online or offline. They can function in situations well known to the students from their own daily lives, but who cannot translate these daily situations into Physics, Chemistry or Biology. (Mobile systems are represented by Vernier, Pasco and others.)

2 Remote Laboratories

Remote laboratories are still very new (foreign remote labs [6], [7], [8], czech remote labs [9], [10], etc.). They are real laboratories with real experiments, however, anyone can access these laboratories, whenever and from wherever they wish via an internet connection using freely available browsers like Internet Explorer, Mozilla Firefox, Opera, etc. Remote laboratories can be used as a set of experiments and tasks for students but they may also serve as an experiment database for teachers or lecturers, who may just include the desired experiment at any time in their lecture or seminar. Remote experiments also have a reservation function, it is possible to reserve them for a certain time on a name and password. Using the remote laboratories, students can on their own explore the development and behavior of each experiment and deduce what can be measured and verified. A remote experiment can, however, be set up as a standard laboratory task, where students measure and record data, transfer them to their computer via the internet and finally assess the data, draw them into graphs and create appropriate tables, verify various curves etc. It has been practically proven that it is possible to submit written reports from a completely different station via the internet. Try for yourselves for example our experiments in our laboratory at <http://www.ises.info> (tasks involving springs, damped, with an excitation force etc., diffraction on a slit, the photoelectric effect, solar energy, controlled water level, etc.).



Fig 1. Remote experiments portals
<http://www.ises.info> and <http://kf.truni.sk/remotelab>

The still growing remote laboratories can be found in Prague at the Charles University Faculty of Mathematics and Physics (<http://www.ises.info>) and in Slovakia at the Faculty of Education in Trnava (<http://kf.truni.sk/remotelab>) and in Brno at the Faculty of Education (<http://ises.tym.cz>) etc. Challenge – Let us try to create a network of remote laboratories at various schools and connect various remote experiments into a single Czech/European portal etc.!

A typical and in fact the only system allowing the creation of free (and immediately freely accessible) remote experiments is the ISES system and its software modular ISES Web Control module [11], [12] which allows even non-programmers to simply build any remote experiment using its modular structure. It is only about as difficult as creating any other website. Remote experiments using the ISES and ISES Web Control systems can be simply “assembled” from ready-made and very flexible components. Remote laboratory tasks provide experimental data, which any user can download to his computer simply by using the clipboard and then further work with them for example in Excel or in virtual simulations, as shown below. More about remote experiments can be found at www.ises.info.

Remote experiments can also be built using the LabVIEW system, but it has a disadvantage, you need specialized software to run any experiments (You need to install the Run-Time Engine, which may be freely available, but you have to install it with administrator access rights, which makes using the LabView somewhat complicated, not to mention you have to program it as well.) Neither the Pasco, Vernier nor Phywe systems support remote experiments.

We shall add a recent remote experiment and that is monitoring the natural background radiation. It uses the newest remote laboratories RemLabNet and we shall run the same experiment in many various locations (all connected via network).

Our actual RemLabNet type remote experiment example is the monitoring of natural background radiation in various locations in the Czech Republic (our provisional variant can be found at <http://kdt-26.karlov.mff.cuni.cz>).

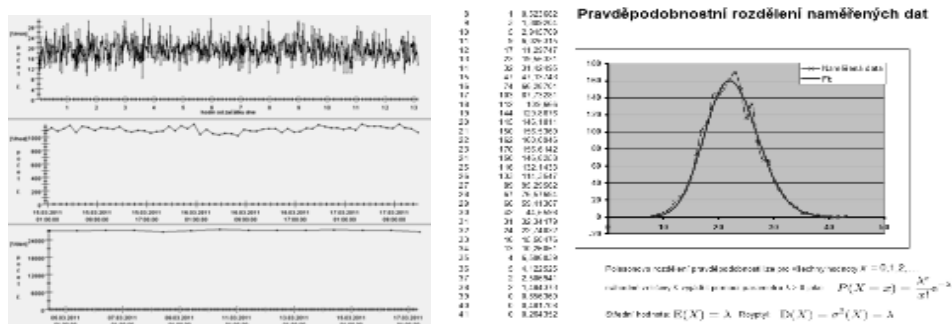


Fig 2. Minute, hourly and day-long records, a Poisson Distribution of natural radioactivity, output from <http://kdt-26.karlov.mff.cuni.cz>, a RemLabNet type task.

We are monitoring the natural radioactivity in minute, hourly and all-day-long intervals. Every ten seconds non-stop we use the Geiger-Müller counter to measure and record the number of beta and gamma particles, which fly through the Geiger-Müller counter. You can find information online on the above-mentioned website. It is possible to select data from a chosen interval and download it to your computer for use in your applications. It is a set of random hardware data describing the values of background radiation, which is now frequently watched, especially after the disastrous tsunami in Japan, where they suffered damage to their Fukushima nuclear plant. However, this data can be effectively used to verify the Poisson Distribution of natural radioactivity.

In a short summary of remote laboratories we should emphasize the fact that these laboratories provide sets of real experimental data which can be obtained by using interactive active control (Remote Control Laboratory) or observation (Remote Sensing Laboratory) or in network variants of RemLabNet type laboratories.

3 Virtual laboratories

The last type of laboratory to be introduced in our article are Virtual Laboratories. In those you can find virtual experiments, virtual models, applets, flash animations, etc. They are programs available from a local computer or which can be ran via the internet. There are countless applets and flash animations to be found on the internet. But some points of interest are for example: <http://www.walter-fendt.de/> (relatively simple applets), or <http://phet.colorado.edu/> (excellently made, although somewhat complex applets, truly unique simulations). It is possible to use these simulations in virtual experiments which simply cannot be done in a real laboratory (for example changing gravity, research of micro- and macrospace, work with dangerous sub-

stances, etc.) You can perform truly fascinating experiments, tests and measurements using these virtual laboratories.

Available simulations do not enable us to work with the data, but it is possible to observe graphical outputs react to changes in input data, etc. The latest advance in simulations makes it possible to export and import data into the simulations. Those were created by F. Lustig and B. Bardiovský using the ISES Sim Lab [13] software kit. (note: The idea of simulations with data import and export has already been published in 2008 by F. Lustig and M. Dekar [14], but this pilot project has been cancelled.) That is why a new project with the same idea behind it has been launched. One has to wonder why nobody else has published similar applet and simulation variants. Perhaps there was no need to compare and fit data, be it real or simulated.

We shall introduce working with such an applet on “Oscillations in a Spring” (free oscillations, damped oscillations, forced oscillations) virtual experiment. A very well done animation of the oscillations in a spring makes it possible to interactively change many parameters in this experiment – it is possible to set weight, spring stiffness, spring length, then it is possible to set outside parameters like damping or excitation force. Furthermore it is possible to set the gravitational constant (the oscillation happens on Earth, on the Moon, on Saturn, etc.).

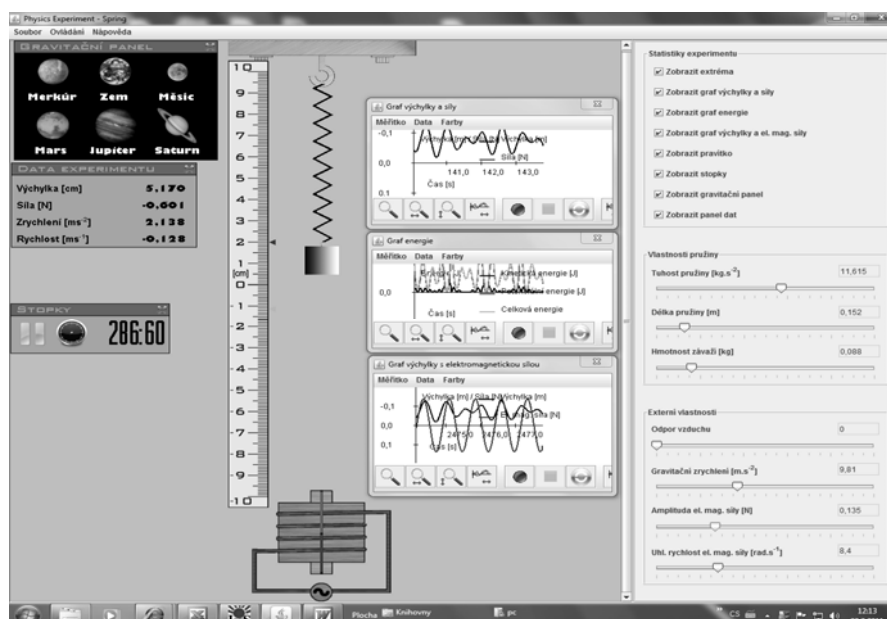


Fig 3. Virtual Laboratory interface with the “Oscillations in a Spring” experiment. This simulation runs on imported data for example from a remote experiment and enables users to try and fit real data from a remote experiment with theoretical data from a simulation.

It should be obvious that we cannot simulate changing the gravitational constant in a real laboratory. On the other hand, it is quite easy using a virtual laboratory. And a student may find out the “surprising” fact that the time it takes for the spring to oscillate remains the same no matter the planet.

And now to the newest and most interesting part, the simulation interface provides users with the ability to import and export data. The graphical output data can be exported using the clipboard and saved into a file on your computer. You can then process the data as needed. However, much more important is the ability to import data from a remote or real local experiment. Such data is then put into the background of the simulation and by changing the settings of various parameters it is then possible to seek a match between remote or local experiment and carefully modeled simulated virtual experiment.

The authors’ simulation interface has a simple toolset like a ruler or a stopwatch, which makes it possible to conduct the same experiments as with a real spring – measuring displacement and the duration of oscillation. It is additionally possible to measure the amplitude and the frequency of excitation force. This way it is possible to study the issues of resonance, phase shift or energy conversion. There are graphical outputs of the experiments’ basic values available in the simulation interface, including for example the more complex graphical output of various energies. Such an applet uses the graphs to visualize situations, which are difficult to imagine based only on their descriptions and basic Physics equations. And here it is almost in the form of a game. Through this approach of research and discovery we are getting closer to the way scientists study various events, state their hypothesis, try to empirically confirm it, process the data and finally reach new conclusions, describe new patterns and announce new discoveries. It indeed goes almost always from an experiment to a theory, instead of going from a theory to an experiment, as it often happens in schools nowadays.

4 Integrating Traditional, Remote and Virtual Laboratories

In this part I would like to deal with using the traditional, remote and virtual computer experiments, hand-made experiments, project-based teaching, integrated teaching, e-learning, multimedia environment, etc. to transform teaching in laboratories and start to think about changing the whole way of teaching natural sciences...

Let us think that you are teaching about oscillations in a spring – free, damped, driven and others, just about everything you can teach about oscillations in a spring. So far we have introduced three types of laboratories, traditional, remote and virtual, but we have not forgotten about hand-made laboratories. Each of the afore-mentioned types of laboratories has its undeniable advantage. However, we would like to go even further. Let us try to research one problem, one issue using each of the three types of laboratories. Each student should choose for him- or herself which type of laboratory to use. The class should split into groups which deal with the problem traditionally, remotely or virtually.

Traditional experiments with a spring do not actually require a computer, only a stopwatch and a ruler. It should be no trouble to find out the oscillatory period, amplitude, spring stiffness, damping, etc. However, if we use a computer in the experiment, we will additionally get records of harmonic oscillations, damped oscillations and maybe even driven oscillations in time (The measuring system can excite the weight on the spring for example by harmonic electric/electromagnetic force.). The computer will record everything and the student then only has to process the data. In the end the student will work his way to the harmonic, driven and damped oscillation in a spring equations. That is about as far as the real local experiment can go.

If there is no real experiment at hand, it is possible to choose a real but remote experiment. Students can “conduct” an experiment via the internet. Online camera shots are available along with the option to control the various parameters of the experiment. After the measurements students can easily transfer the collected data to their computers and process it there. Or it is possible to try those experiments with the students during the lesson or make it their homework to review their knowledge of oscillations in a spring. Let the students measure the stiffness of a spring via the internet (Of course the address has been announced during the lesson.), let them find out the oscillatory period, the resonance frequency and study the phase characteristics of displacement and excitation force. There are more than enough tasks which the students will be glad to solve, simply because it is “on the net.” This has been empirically verified.

And the third group shall conduct virtual experiments. And those are far from boring. They will try to work with a virtual spring as they would with a real one. Only this time they will have the option to change gravity and air resistance and have several different springs at hand with various lengths and stiffness values, various weights etc. Therefore if a student should decide to use this virtual reality, he would have a much more flexible experiment available to him. Students of this group are quite likely to bring more valuable data and conclusions. YES, they would miss the real experience with the spring, but we do not wish to deny them this. They will confront their results with the group which worked with the real spring. A virtual simulation, for example our “Oscillations in a Spring,” allows not only for virtual experiments, but the new version also makes it possible to import data and compare them, fit the data from a traditional or remote experiment and from the virtual one.

All three groups of students judge the experiment based on not only quality but also quantity. The final output should be their data. Then they should consult with each other about their results, confront and compare the data from each group with the others. Data, be it from traditional, remote or virtual experiments, can be processed using for example EXCEL or, optimally, in the simulation interface, viz. the above-described “Oscillations in a Spring” simulation.

Study materials can be in the form of books – the course books, or in electronic form, students themselves can browse the internet looking for information, where they should keep in mind the validity of anything they might find, or maybe they can follow interactive walkthroughs etc. Students should work separately or even individu-

ally, but later during the group discussion they learn to work together in a collective, which is also one of the stated, albeit often overlooked, goal laboratory schoolwork.

We have tried to suggest a way to transform natural science laboratories that should be feasible. Maybe it will even contribute to the transformation of the way natural sciences are being taught. We think that it is enough to integrate the above-mentioned “pillars” of teaching, connect them and merge them into one single pillar.

Conclusion

And now a question begs to be asked. Where is the teacher? A teacher is part of every group, he does not lecture from the blackboard, he is not some expert or a walking encyclopedia, he is a provider of the learning process. A teacher should “pull” the students, not “push” them, he teaches them to ask the right questions and to work together. A teacher works individually both with the talented students as well as with those who need a little help, etc. And those are among the reasons why a teacher is indispensable.

We have “integrated” the various types of laboratories in this article. A wider meaning of integration would be one, where e-texts, e-simulations and e-experiments are brought together into one learning environment, which might be part of an LMS system (for example Moodle). We call such a process “Integrated E-learning” and is further described in [15].

At last, we would like to summarize that connecting “hand-made” traditional computer experiments, remote and virtual experiments to each other, supported by project-based teaching, group teaching, including the integration of natural sciences etc. is the new additional value of student laboratory work.

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References

1. Wieman, C. and Perkin, K. “Transforming Physics Education,” *Physics Today*, Vol. 58 Nov. 2005, pp. 26-41.
2. Domin, D. S. “A review of laboratory instruction styles,” *Journal of Chemical Education*, Vol. 76, 1999, pp. 543-547.
3. American Association of Physics Teachers 1977, in A. B. Arons, “A Guide to Introductory Physics Teaching”, Wiley, New York, 1990. (also available at <http://www.ncsu.edu/sciencejunction/route/professional/labgoals.html>), (30. 5. 2011).
4. Lustig, F. Computer based system ISES. Available at <http://www.ises.info>, 1990-2011.
5. Schauer, F. Lustig, F. Ozvoldova, M. ISES - Internet School Experimental System for Computer-Based Laboratories in Physics, in *Innovations 2009 (USA)*. World Innovations in En-

- gineering Education and Research. iNEER Special Volume 2009. chapter 10. pages 109-118. ISBN 978-0-9741252-9-9.
6. Remote experiments portal: <http://rcl.physik.uni-kl.de> (30. 5. 2011).
 7. Remote experiments portal: <http://kf.truni.sk/remotelab> , (30. 5. 2011).
 8. Gruber, S. Vetter, M. Eckert, B. and H. J. Jodl, "Experimenting from a Distance – Remotely Controlled Laboratory (RCL)," Eur. J. Phys. Vol. 28, No. 5, 2007, p. 127.
 9. Remote experiments portal: <http://www.ises.info> , (30. 5. 2011).
 10. Remote experiments portal : <http://ises.tym.cz> , (30. 5. 2011).
 11. Schauer, F. Lustig, F. Dvořák, J. Ožvoldová, M. Easy to build remote laboratory with data transfer using ISES – Internet School Experimental System ISES. Eur. J. Phys. 29. 753-765. 2008.
 12. Lustig, F. Dvořák, J. ISES WEB Control, software kit for simple creation of remote experiments for ISES. ISES Rem Lab. Teaching tools co. PC-IN/OUT. addr. U Druhé Baterie 29. 162 00. Prague 6. Czech Rep. 2003.
 13. Lustig, F. Bardiovský, V. Kmity na pružině. Simulační prostředí „ISES Sim Lab“, Teaching tools co. PC-IN/OUT. addr. U Druhé Baterie 29. 162 00. Prague 6. Czech Rep. 2011.
 14. Lustig, F., Dekar, M. E-technology park with remote and virtual laboratories, in sborník konference ICTE 2008, Rožnov pod Radhoštěm. 8.9.-11.9. 2008. elektronický sborník na CD. editor Erika Mechlová. ISBN 978-80-7368-577-5. s. 33-37. 2008.
 15. Schauer, F. Ožvoldová, M. Lustig, F. Integrated e-Learning - New Strategy of Cognition of Real World in Teaching Physics, in Innovations 2009 (USA). World Innovations in Engineering Education and Research. iNEER Special Volume 2009. chapter 11. pages 119-135. ISBN 978-0-9741252-9-9.