INTEGRATION OF VIRTUAL AND REMOTE EXPERIMENTS INTO UNDERGRADUATE ENGINEERING COURSES

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Abstract: Experiments play an important role in the education of undergraduate engineering students as they provide hands-on experience with the foundations of the discipline. Unfortunately, the change of the university program in Germany from the Diploma model to the Bachelor/Master model had a direct negative impact on the curricula and the course schedules. The result of which is that the first-year curriculum is overloaded; exercises or practical courses have been dropped altogether from the first term, have been rescheduled to later terms and have been reduced in length. For this reason, other forms of experimenting have to be developed and integrated into the existing courses or lectures; virtual laboratories and remote experiments offer such an option: they enable students to access equipment 24h/7 days a week, they are independent from opening hours and the work schedule of the staff. Furthermore, simulations do have some other advantages: they provide a better control on the simulated phenomenon, allow observing effects and running experiments that are only very hard to measure or perform in practical applications. Another advantage besides their cost-efficiency is that simulations allow observations of effects in a simplified environment without any measurement errors.
Therefore, remote and virtual experiments have already or will soon be set up by various universities across Europe. However, building a pool of experiments sufficient to cover all of undergraduate physics is an overwhelmingly complex and costly task for a single university to handle on its own. Therefore, the EU-funded LiLa project – short for “Library of Labs” – is building a network of virtual laboratories and remote experiments. The LiLa Portal provides access to manifold experiments, free to use in courses and lectures. Additionally, LiLa partners will profit from the experience gained from using remote experiments, and the LiLa network will provide best-practices in applications of remote experiments.
This article starts with an introduction of LiLa and its aims; it then presents the integration of virtual labs and remote experiments into an existing course, “Physics for Engineers”, at the University of Stuttgart. We introduce our concept for exercises with online-experiments and present some results of the pilot phase which took place in the winter term 2009/2010.

Keywords: Remote Experiment; Virtual Laboratory, Online Course, Physics in Engineering Education

1. Introduction

Learning by experimentation is a fundamental element in natural and engineering sciences. Experiments allow students to learn foundations of engineering in practical hands-on courses. Here, students learn how to solve practical problems and delve into experimenting by using real equipment [1]. But a worrying trend has emerged at universities in Germany: students' schedules are overloaded, and time available for additional work besides the bare minimum is decreasing. This trend has been triggered by the recent change of the university program from the diploma model to the two-tier Bachelor/Master model. Doing their homework, preparing their courses, and reconsidering the content of the lecture costs too much time, leaving students with only very limited time for practical hands-on lab sessions. Remote experiments and virtual laboratories as provided by the LiLa Portal have an important advantage: they allow students to experiment whenever and wherever they want. Thus, remote or virtual lab sessions are an ideal supplement to entry courses that would otherwise not include any type of practical lab training. However, as we will argue, just providing the labs is not sufficient – learning material around them must be provided as well. In this paper, we report our experience on deploying experiments from the LiLa pool in a freshmen physics course at the University of Stuttgart.

2. LiLa – The Library of Labs

2.1 The project and its goals

The LiLa project – short for "Library of Labs" – is a European Community funded [3] project to network remote experiments and virtual laboratories [2]. The goal of this project is the composition and dissemination of a European infrastructure for mutual exchange of experimental setups and simulations, specifically targeted at undergraduate studies in engineering and science [1]. Various universities around Europe have already or are planning to set up virtual or remote experiments or laboratories. Remote experiments refer to real, physically existing experiments that are controlled remotely over the internet. Virtual laboratories are highly flexible environments to run simulations. The participating universities started to cooperate and to share their resources within the framework of the LiLa project. A LiLa partner can now use a range of experiments provided by other universities for their own lectures. Hence, the range of experiments for the students increases and teachers can access additional teaching material. This also has a didactical effect: on the one side teachers can use idealized simulations running solely in a computer system and on the other side they have the freedom to offer complementary real experiments, controlled remotely. Comparing these two different experimental setups will have a good learning effect for the students. Another positive effect of LiLa is that costly equipment can be shared between the several universities. Last, but not least, LiLa partners will profit from the experience gained by using remote experiments: the LiLa network will provide best-practices in the applications of remote experiments.

2.2 Examples for experiments and laboratories in LiLa

2.2.1 Virtual laboratories in LiLa

Virtual laboratories are purely computer-based frameworks that do not interact with physical equipment. An example for a virtual laboratory is "VideoEasel", the virtual lab at the University of Stuttgart, a simulation framework for experiments in physics

(Figure 1). Further virtual laboratories are provided by partners in Basel, Cambridge and Linköping.

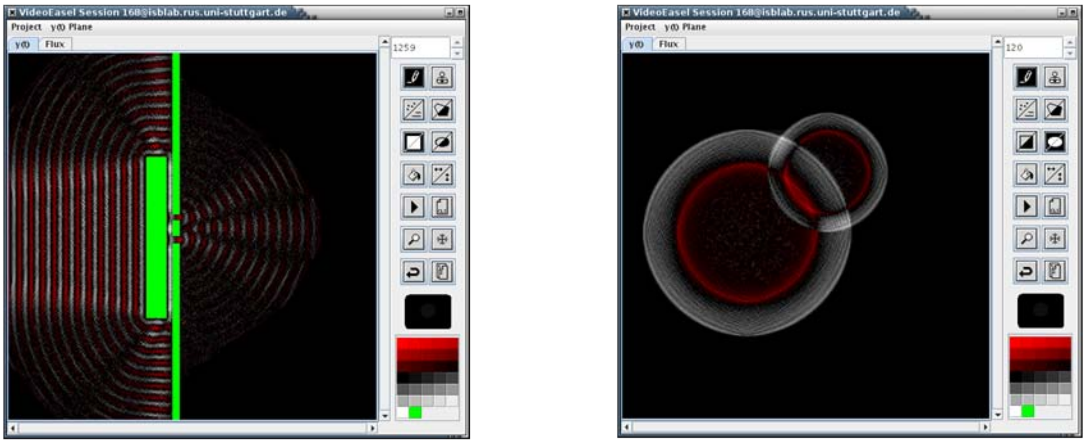


Figure 1: Experiments in VideoEasel – Wave Equation – left: doubleslit, right: linear superposition

2.2.2 Remote experiments in LiLa

Remote experiments are experimental setups controlled remotely; sensor data and control parameters of the experiment are made accessible over the internet using appropriate software – typically LabView [4] by National Instruments. Remote experiments are already deployed by partners in Berlin, Cambridge and Basel. For example, our partners in Berlin developed the Remote-Farm [5] where several remote experiments are accessible via the web-browser (Figure 2). All experiments are real-life setups hosted at the TU Berlin [6].

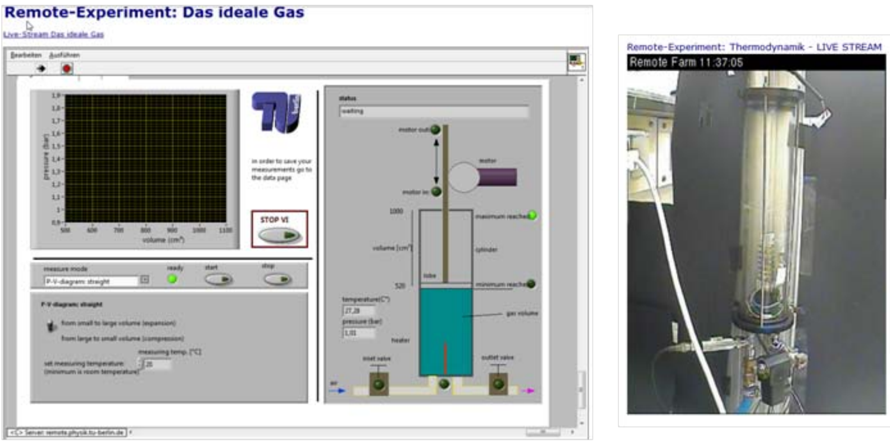


Figure 2 - LabView Control of the remote experiment - The ideal gas and the live stream of the lab.

3. Integration of virtual and remote experiments into an undergraduate engineering course

3.1 Initial Situation in "Physics for Engineers"

"Physics for Engineers" is a first year freshmen course taught to all engineering students, including mechanical engineering, aerospace engineering and many others. Currently about 1300 students are attending the course. Due to the high number of participants and limited room capacity, the same lecture is given twice a

day, giving all students a chance to attend. The curriculum does not include any mandatory exercises for this specific lecture, nor does the tight schedule allow for a mandatory lab course. However, our experience is that students participating in the optional homework exercise have a considerably higher chance of passing the final written exam. To motivate students and to make them aware of the importance of exercises, such experience is announced in lectures, and optional pen-and-paper exercises are available in the Learning Management System (LMS) ILIAS. However, until recently, hands-on lab courses have not been part of these optional homework exercises. The aim of this first pilot study is to offer students LiLa content as learning alternatives to the equally optional pen-and-paper exercises [7].
An initial questionnaire established a first ground on the motivation and interests of the students in remote and virtual experiments and helped to determine their available time. We found that more than 80% of the students are interested in participating in optional exercises; more than one third claimed to be willing to spend one to one and a half hour on these exercises.

3.2 Concept for exercises with online-experiments

The ILIAS Learning Management System is already used by the lecturer offering the optional pen-and-paper exercises, including additional materials like the script etc. For this reason, our goal was to use ILIAS for the optional online-experiments, too. Thus, we required a concept how to fit online-experiments into the LMS.

We developed a structure which separates the exercise into three different phases:

1. *The orientation phase:* This first phase allows students to familiarize themselves with the online-experiment. To this end, an abstract on the experiment is presented including a short description of the experiment and the task to perform. Learning goals are described in this phase and a small pre-test evaluates the knowledge of the students before they run the exercises with online-experiments.
2. *The execution phase:* This is the main phase of the exercise. Here, the given task should be mastered by the students using the online-experiment.
3. *The review phase:* In this phase the progress of the students will be checked. This phase is also implemented as a small test.

At the end of the term, we offered an open-ended question for the students to solve. The procedure here was as follows:

1. The task to solve was to answer an open-ended question. In this first test, we asked "What kind of waves develop if you throw a square brick into water?" and expected students to setup experiments to demonstrate Huygen's Principle.
2. We also offered a virtual laboratory running a simulation of the wave equation.
3. Students were asked to write a short report about their results. Explaining the theoretical background, describing their own experiment and how this experiment gives an answer to the open-ended question.
4. Each participant had to correct and evaluate the documents of their peer students. For this step, we provided criteria (like correctness, completeness etc.) for evaluating the reports. They could give up to ten points for each criterion.

5. Based on the final scores of the reports, we selected a winner.

We offered this exercise at the end of the term, but unfortunately the result was that the students ran out of time due to the upcoming finals and only one out of 1300 students participated in this exercise.

3.3 The first test phase and its results

We offered four exercises with online-experiments to the first-year students of the winter term 2009/2010. We developed an online questionnaire which was to be filled out by the students after experimenting. In this section, we present some results of these questionnaires and focus on some selected, interesting results.

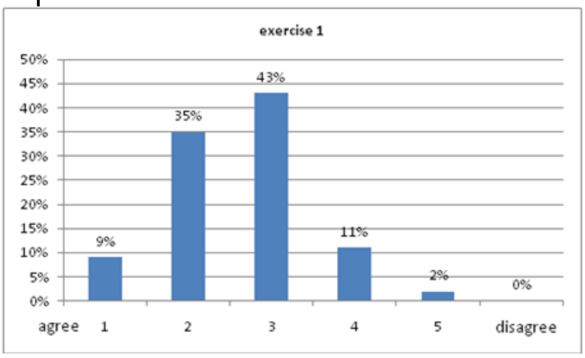
Number of participants in the exercises with online-experiments:

Exercise	Pre-Test	Execution	Post-Test
1	325	245	153
2	203	173	115
3	133	Simulation: 50 Remote Experiment: 23	15
4	21	1	No Post-Test in this exercise

Table 1: Number of participants in the exercises in the winter term 2009/2010

3.3.1 Results of the online-questionnaires

a) Do you think your learning success increases by doing the exercise with online-experiments?



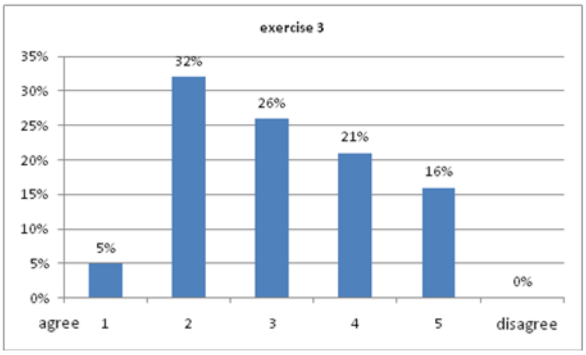
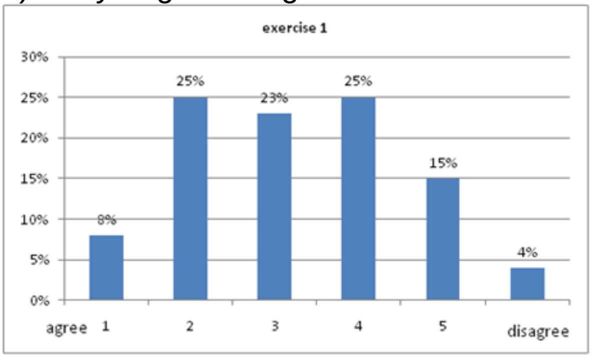


Figure 3: Increasing learning success by doing the exercise (results of exercise 1 and exercise 3)

Here we can see that the answers are widely spread and not all students are sure that online experiments help to improve their learning success. This should be taken care of in future investigations. One idea is to present the correlation between grade and participation in online experiments to the students (here depicted in section 3.3.2). We have to say that this has already been done by the lecturer, with little success though. A better idea could be that we give them a feeling of "one experiment says more than 1000 words" or "you must try it yourself to believe it". We should try to arouse the student's curiosity. We tried this by offering an open-ended question at the end of the term, but believe that such a research-type question should take place near the beginning of the course. We also need to improve the task itself, of course. Nice examples for such experiments and tasks would be phenomena that “contradict” common understanding; e.g. “Does lead fall faster than feathers?” or “If I blow over a piece of paper, do I push it downwards?”. We also could provide questions which let them describe or analyze all-day processes like “if ice melts in my glass of water, does the water level rise or fall?” motivating them to research the underlying physics.

b) Did you get enough information for handling the exercises and the experiment?



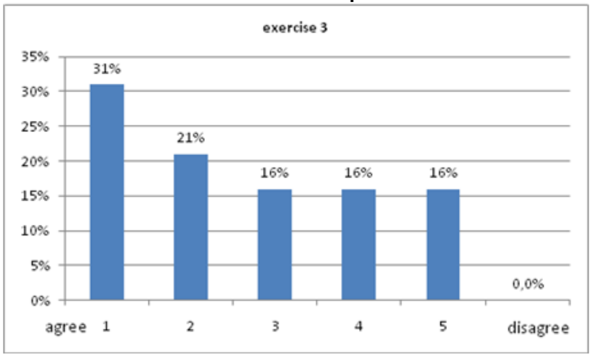


Figure 4: Enough information for handling the exercise (results of exercise 1 and 3)

We also noticed that our description and informations on the exercises and experiments are not yet sufficient, another factor to improve. Therefore, we decided to perform prelimininary tests of all future exercises, including instructions from selected students. Clearness of the exercise description is an important factor that should not be forgotten during preparation.

3.3.2 Correlation of passing the exam and participating in the exercises with online-experiments

We compared the results of the exam of those students who participated in the exercises with online-experiments and those who did not. The overall result is as follows: 1065 students took the exam at the end of the winter term. 31% failed and 69% passed the exam. 284 students participated in at least one exercise with online-experiments in this term. 14 % of these failed and 86 % passed the exam. Of the 33 students who participated in exercise 1, 2 and 3, 3 % failed and 97 % passed the exam. Figure 5 shows the differences between these three cases. First, students who participated in at least one exercise were considerably less likely to fail than students who did not participate at all. Second, we see that nearly all students who did three exercises passed the exam. However, further research is required because at this point we cannot be certain that this effect is caused by the partcipition in online-experiments. It is possible that the students who participate in such exercises are already the more motivated, more interested and perhaps already the harder-working students. At this moment we are not able to give an clear answer, and are uncertain how to distinguish the two effects – if it matters at all. More important is that we should be able motivate students to do exericises, to do experiments, to be curious and thirsty for knowledge. Unfortunately, our exercises with online-experiments are not yet „cool“ enough to enforce this.

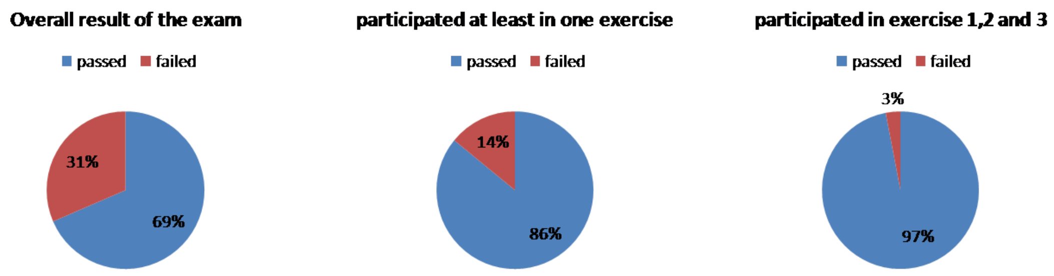


Figure 5: Comparision of the results in passing the exam

3.3.3. Some comments from students

- I have had no time for doing additional exercises
- I missed the time period for doing the exercise
- Great Idea- Was fun to do
- The exercises improved my understanding
- Very interesting and nice experiments – do more of them!
- The last (open ended) task was a good idea
- Sometimes I was missing additional information for solving the tasks (1)
- The second simulation (VideoEasel) did not work / did work very slow (2)
- The VideoEasel experiment is difficult to handle (3)
- Very high demands (4)
- Template answer would be helpful, please put them on the LMS (5)

(1) was caused by problems in the beginning, we first needed some experience in providing tasks on online-experiments. A good solution is to test each exercise before starting it. These tests are now done by some selected students. (2) was caused by technical problems with our virtual lab. This problem has been fixed and the first exercise in summer term showed that VideoEasel is now fast enough. We also worked already at problem (3) and improved the handling of VideoEasel. We think (4) was caused by a bad synchronization between the lecture and the exercise. We are working on that and in the future, we take care of a better synchronization. For solving problem (5) we adapted the exercises and supplemented them with template answers.

3.4 Lessons Learned

At present, the colleagues from the department of Physics have not yet acquired a good feeling for “good” online-experiments and “good” exercises on them. We need to build a pool of useful experiments and guidelines for teachers on how to deploy them in lectures. Examples drawn from courses which already use experiments will definitely be very helpful.

We noticed that the participation of the students decreased with the exams coming closer: As a consequence, we changed the layout of the lecture and the experiments in the summer term 2010 a bit and offer the advanced experiments earlier.

The content of an exercise should always be discussed in the lecture before the experiment becomes available online. Students sometimes found a “very high demand” if that was not the case.

Around 29% of the students mentioned technical problems in the winter term 2009/2010 and, as said, these problems drove them off. Also, the usability of some experiments requires improvement. We already worked on these problems and hope to have removed at least some of the technical and usability obstacles.

The fact that the work load in the first semester is quite high is unfortunately beyond our influence, and we cannot reasonably address this problem in short term.

4. Discussion and conclusion

After the first test period we can say that exercises with online-experiments are a good and motivating addition to lectures. Most of the students are interested in doing such exercises and they commented positively on the available experiments. The biggest problem is still lack of time due to the tight schedule. As long as these exercises remain optional and voluntary this problem will persist. We should try to make the experiments and exercises "cool" to catch the curiosity of our students.

Other problems which arose in the pilot phase are issues which can be corrected by improvements of the exercises and experiments themselves, such as improving technical or usability issues, adding further information to the exercise tasks, adding solutions and the way how to solve a problem to the exercises.

During the summer term 2010 the exercises with online-experiments are being held again. In this term only around 60-70 students are participating in the lecture "physics for process engineers". Also here the exercises are continuously improved.

At this point we want to thank the European Community for funding the LiLa project. We also thank Dr. Michael Jetter and his team from the physics department for their cooperation in using and testing the online-experiments and for developing the exercises with online-experiments with us, and Pieter de Vries for the assistance developing the evaluation. Last, but not least we thank the TU Berlin for providing their remote experiments.

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