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RESEARCH ARTICLE

A practical approach for managing online remote experiments: (OnPReX)

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The development of Internet technologies leads to recent trends in online based education in universities. Online learning based on remote experiments is capable of diminishing the scantiness in practical courses. In this paper we present an online practical course based on remote experiments (OnPReX), interactive graphics and an online tutoring-system organized at the Berlin Institute of Technology(TUB). We developed two online practical courses, focusing on classical and modern physics, for bachelor and intermediate diploma engineering students. We ran the online practical course based on remote experiments in two test phases over two semesters and conducted an evaluation from which we improved the course. The online practical course based on remote experiments is successfully integrated as an elective courses at the TU Berlin.

Keywords: Remote experiments, online tutoring, online course, Physics in engineering education, authentic learning environment.

1. Introduction

An integral part of every engineers toolbox are computers, used for computations, data collection and reduction, simulations, controlling devices and to share information via the Internet. No engineer today could imagine doing his or her job without one. Using computers routinely is fairly normal, particularly in the laboratory. Learning by experimentation is a fundamental element in natural and engineering sciences. The involvement of science and engineering students in practical work is a fundamental precondition of understanding the concepts and processes of science. A practical course in undergraduate engineering and science studies require large amounts of resources, equipment and manpower. Unfortunately in engineering education many universities are not able to provide the laboratory capacity for numerous undergraduate students, due to the high costs involved. At the Berlin Institute of Technology more than 500 students participate in a undergraduate physics course. In addition physics models and practical experiments must be involved in the learning process of physical phenomena elements of physics theory, physics models and practical experiments must be involved. Often the parts of theory, models and experiments are offered separately, with time shifts in the curriculum, leading to discontinuities in the learning process. Thirdly, there is a set

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of physical experiments not included in physics curricula, because they have an unique or expensive setup (e.g. Raman spectroscopy). Some other experiments are too dangerous to be conducted by beginners (e.g. the experiments with radioactive sources). Due to the lack of possibilities to provide a practical course for these students we organized an online practical course based on remote experiments. We combine the remote experiments with an e-learning software platform called Moodle (Moodle (2009)) and created an online practical course with remote experiments. Remote experiments are real-life settings, built up at the TU Berlin and connected to a PC. We named this Remote Farm (Remote-Farm (2009)). The computers are used as web servers at the same time, so everybody get access to the experiments through a free browser plug-in and gain control over all devices. All data recorded during the experiment is stored online and accessible for users. An online practical course with remote experiments (OnPReX) means that the participants after studying the fundamentals of physical phenomena perform the experiments in small groups with the help of available literature and the online tutoring system. The acquired data can be evaluated and analyzed with suitable data processing programs. The reports, are sent for correction via email to the lecturing tutor. In this course we offer the engineering students the opportunity to understand the physical phenomena through the self managed learning and by means of theory, physical model (simulation) and experiment (remote experiments) contemporaneously, whereby similarities and differences between the theory, the simulated model and the experiment can be studied. These lead to the better understanding by means of analyzing of a given physical phenomenon from various perspectives. The OnPReX participants, due to the online character of OnPReX, have the possibility to take part in the practical course any time and from anywhere.

By completing the OnPReX-course, the participants gain and improve the following skills and abilities (text editing, data processing, online group communication, IT communication, scientific reporting). We thus formulate the following objectives(general goals):

- Learning of the fundamental physical phenomena by experiment, simulation and theory in an authentic learning environment.
- Learn to deal with remote-controlled experiments and with practice-related problems during the experiment.
- Integration of IT communication and online competence into the group collaboration process.
- Learn to prepare a scientific report including calculation of errors, reporting information objectivity, citation and copyright guidelines.

In Section 4.2 we show by means of an evaluation whether the general goals of OnPReX are achieved. As most of OnPReX participants are students in the first semester, they are not advanced in the skills listed above. These skills are long life learning experiences de Vries and Bograad (2009).

2. The course

Theory and experiments are the bases of physics. The theory formulates the relation of physical quantities and simplifies the physical phenomena with the objective of making the physical prediction by means of mathematics possible. The experiments allow the verification of these predictions. Any learning process in science should be based on these two elements. In general these two elements are offered in separate courses, consequently the learning process of theory and experiment does not take place in parallel. The online practical course based on remote experiments (OnPReX) offers the possibility to deal with theory and experiment at the same time producing a deeper understanding of physics. The elective OnPReX is an optional course for bachelor and intermediate diploma students. The OnPReX course is separated with regard to contents in classical physics and modern physics parts. The duration for each of these courses is one semester and is offered by the department of Solid-State Physics at Berlin Institute of Technology. The OnPReX-course was tested over two semesters, and is integrated in the existing program and course offerings for a year. The participants of this course, which are mostly engineering undergraduate students, work in groups by three. Each group conducts six remote experiments, analyze the data obtained from experiments and writes six reports. Additionally every participant must take an oral exam to get the three ECTS (European Credit Transfer System) points.

2.1 *Theoretical substantiation of an authentic learning environment*

For the development of the remote experiments we used the didactical model as described by (Herrington *et al.* (2003)) in his work on the authentic learning environment. According to (Herrington *et al.* (2003)) an authentic learning environment fits a authentic learning environment the reality of companies using e-learning and allows students to gain practical knowledge and experiences. The concept of authentic learning environment is based on the theories of constructivism and connectivism.

Constructivism indicates that everyone has his own mental model and is unique in terms of knowledge and experience. According to constructivism, learning is the result of individual mental construction, whereby the learner learns by means of matching new against given information and establishing meaningful connections. In constructivism the knowledge has personal meaning. It is created by individual students and learning is successful when students can demonstrate conceptual understanding.

Connectivism clarifies the role of technology in the field of knowledge and learning. The new information media such as forum, wiki, You tube, and blogs, have changed the information resources. Pursuant to Siemens (2005) learning is the ability to connect different " nodes of knowledge" from a network of data and information and store these connected "nodes". This is called "connected knowledge". In summary connectivism assigns that learning and knowledge generates from the diversity of options and is a process of connecting specialized nodes or information sources. In connectivism the ability to see connections between fields, ideas, and concepts is a core skill (Siemens (2006)). The accurate and up-to-date knowledge is the intent of all connectivist learning activities. The making of decision is itself a learning process. The authentic learning environment concept is our dominant pedagogical approach and is further discussed in Section 3. In Table 1 we listed the ten characteristics of an authentic learning environment and discuss their analogies in OnPReX.

2.2 *The course cycle*

We show the course cycle of OnPReX in Figure 1. In Figure 1 the four sections that the participants must pass are shown in four quadrants. The environment in which every process takes place is shown in Figure 1 (gray squares). These processes are learning the theoretical background of the experiments in Moodle learning environment, conducting experiments in Remote Farm via Internet, analyzing the

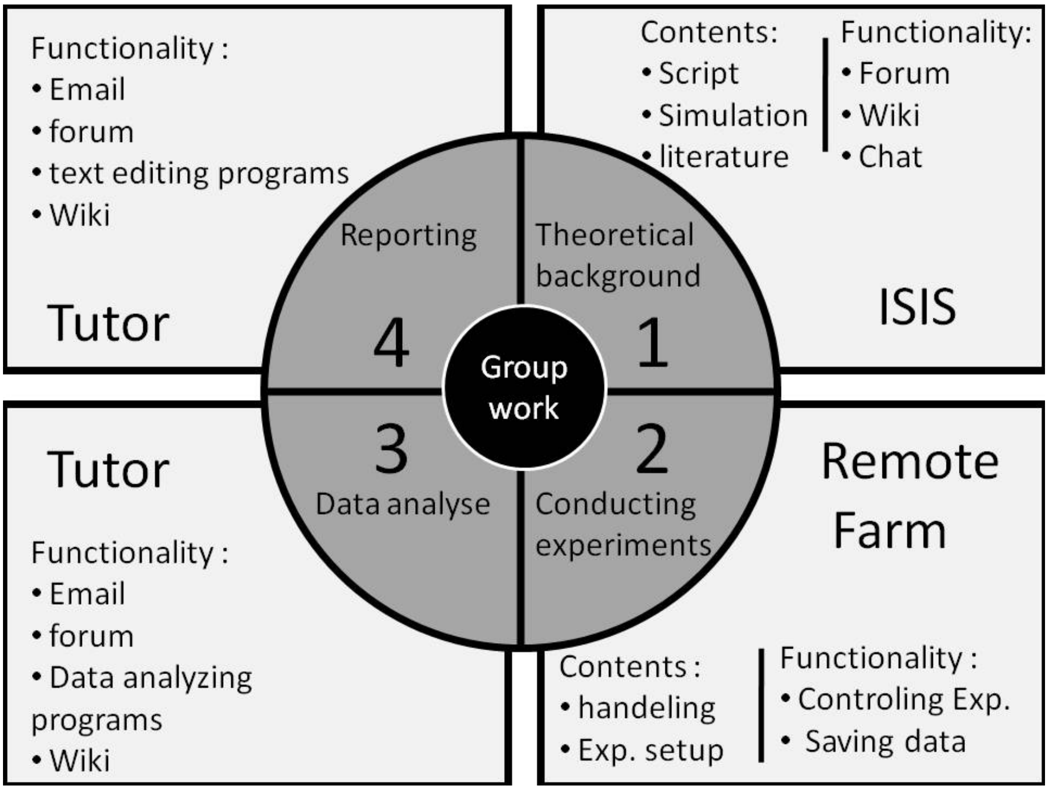

Figure 1. The four steps in OnPReX-course cycle.

obtained data in cooperation with the other group members and tutors and finally writing scientific reports with help from the tutors.

2.2.1 Learning the theoretical background: Step 1 in course cycle

A well organized online course requires an efficient course management system (CMS). We chose the Moodle for our Virtual Learning Environment. The use of Moodle as the course management system is supported by "social constructionist pedagogy". Moodle is designed to help teachers create online courses with opportunities for improved interaction between students and tutors. The advantage of Moodle is that it can be easily deployed to thousands of students. Many institutions use it as their platform to conduct full online courses. Moodle offers series of activity modules such as announcements, course contents, documents, groups, project calender, forums, wikis, databases to build richly collaborative communities of learning around their subject matter (in the social constructionist tradition). The Multimedia Center for teaching and research "MuLF" of Berlin Institute of Technology offers all TU students via ISIS (Information System for Instructors and Students) the access to the e-learning platform Moodle. ISIS platform offers for each course environment, where the whole course organized. We use two separate Moodle (ISIS) course environments, one for OnPReX classical and one for OnPReX modern. The ISIS environment in general on one hand due to its functionalities such as forums, wikis and chat and on the other hand the various learning resources prepared for each experiment in this environment offer an efficient learning platform for the participants. In Figure 1 the first step in OnPReX course cycle is learning the theoretical background of remote experiments. In Figure 2 we show the web page of ISIS for the OnPReX -modern physics. Each course management environment was divided into six parts. Every part, leading to a remote experiment contains the following learning resources and functionalities:

- learning resources
  (1) Script: a script contains the theoretical background of the experiment, the experimental setup, a guideline to conduct the experiment and the experimental tasks to be done. These scripts are an initial help for students and should facilitate the process of conducting experiments, data analyzing, and reporting.
  (2) Simulation: Simulations of the remote experiment produce the same physical quantities for measurements as in real experiment. The demonstration of similarities and differences between the theory, simulation and the experiment results in better understanding of the physics behind the experiments (Jeschke *et al.* (2007)). In Figure 4 we show a simulation related to the inverse square law of radioactivity. The association of this simulation with the radioactivity remote experiment offered in the Remote Farm helps in understanding similarities and differences between simulation and real experiments.
  (3) Remote experiment: The link from ISIS to the remote experiment. The remote experiment is the central point of the OnPReX. The course participants run the remote experiments through the web page of Remote Farm (Remote-Farm (2009)), which will be explained in Section (2.2.2).
- functionalities
  (1) Forum: Each experiment has a separate forum, where participants discuss about the experiment, its theoretical background and the experimental issues and problems. The question and the comments can be edited and categorize every semester. The result of discussions can be also added to the wiki.
  (2) Wiki: We added to every experiment a wiki page to give the participants the possibility to create and edit the contents related to the experiment. With this functionality we aimed to provide the opportunity for participants to have a role not only as an user of learning resources but also as a content provider (a characteristic of authentic learning environment). These wikis should emerge as collections of learning resources and simulations and information about the theoretical background of experiments. The teaching tutors, mentioned in Section 2.3 moderate the formation of the wikis in terms of categorization and sorting and also the editing of the contents provided by the students.
  (3) Chat: Each experiment field has a chat room, where the student can chat about the experiments. We added this functionality to the ISIS page and motivate the students to use it to find out if this functionality is convenient to be used in OnPReX. The evaluation of the course shows (Section 4.2), that this functionality is not used often by the participants. The participants of the course prefer to communicate via email write in forum or chat through other instant messaging services like Skype, Yahoo Messenger and et cetera.

2.2.2 Conducting experiments via Remote Farm: Step 2 in course cycle

As shown in Figure 1 the second step in course cycle is conducting remote experiments. The web interface, in which the students conduct the remote experiments is the Remote Farm (Figure 3) (Remote-Farm (2009)). remote experiments are real-life settings, built up at the TU Berlin in Remote Farm (Remote-Farm (2009)), with all devices (like power supplies, voltmeters, stepping motors, Laser...) connected to a PC. All remote experiments are controlled by the software LabView (LabVIEW (2009)) provided by "National Instruments". LabVIEW has a built in web server enabling the gain of control over all devices. LabView can be used from

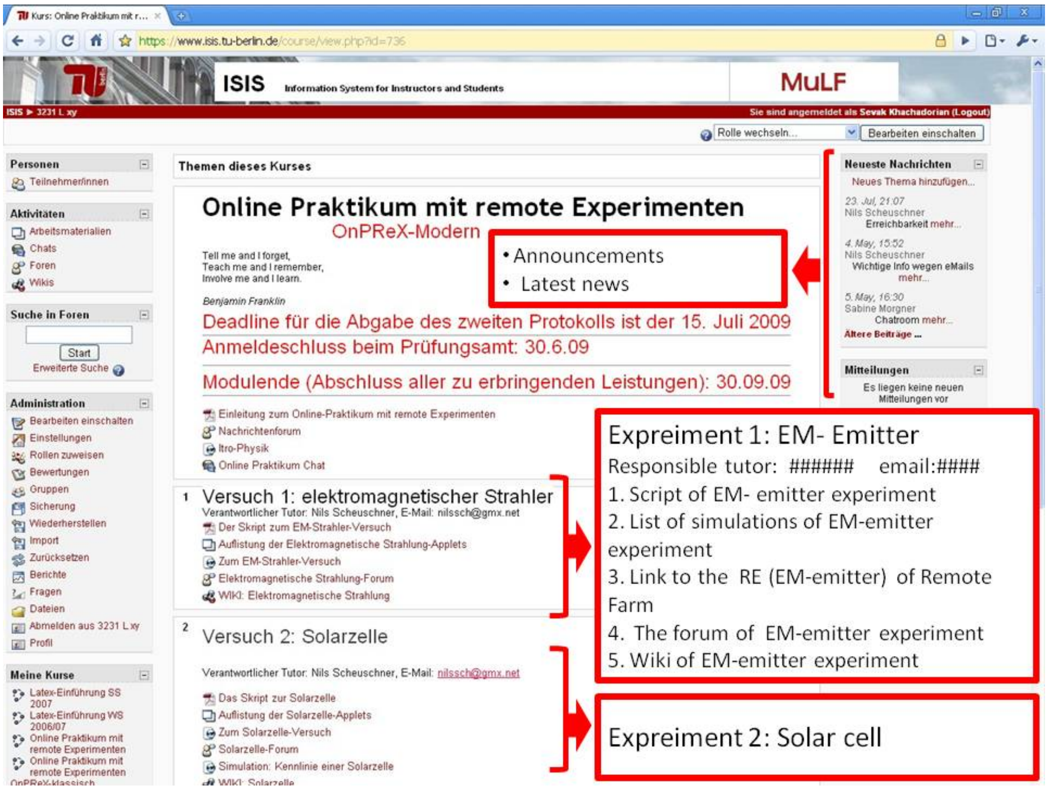

Figure 2. Information System for Instructors and Students (ISIS) learning platform of OnPReX on the web page of TU Berlin.

every computer within a browser window through the Internet. The LabView run-time engine (RTE) needed for this is free ware and available in the Internet. The provided experiments of the Remote Farm (Remote-Farm (2009)) are freely available for everyone with access to the Internet. The OnPReX provides an adapted framework for TU students to use the Remote Farm. On the Web page of the Remote Farm we provided 12 remote experiments, 6 of them deal with classical physics and the remaining 6 with modern physics. The experiments dealing with classical physics are: coupled pendula, forced oscillatory circuit, interference of light experiment (single and double slit), e/m [1] apparatus, the parallel plate capacitor and the ideal gas experiment. Modern physics experiments are: electromagnetic emitter experiment, Raman spectroscopy, experiment on radioactivity, the characteristics of a solar cell, transistors and magnetic hysteresis experiment. In Figure 5 we show the control panel of the radioactivity- remote experiment.

The schematic setup of this remote experiment as shown in Figure 6 consists of a radioactive (Radium 226, 3.7 kBq) source and a Geiger-Müller counter as detector. The Geiger-Müller-counter can be arbitrarily moved in vertical direction by means of a threaded bar, gear wheels and a step motor. Another step motor moves a sheet with 8 boreholes, each borehole containing one of eight different materials such as aluminum, lead, iron and plastics with different thicknesses each. By varying the distance of the Geiger-Müller-counter, the distance law of the radioactive radiations by different materials and different thicknesses of absorbers can be measured. In this experiment the experimenter can study the absorption coefficient of various materials and Newton's inverse square law. The experimenter can compare the obtained data from the remote experiment related to the inverse square law with

[1] e/m is the charge of an electron over its mass.

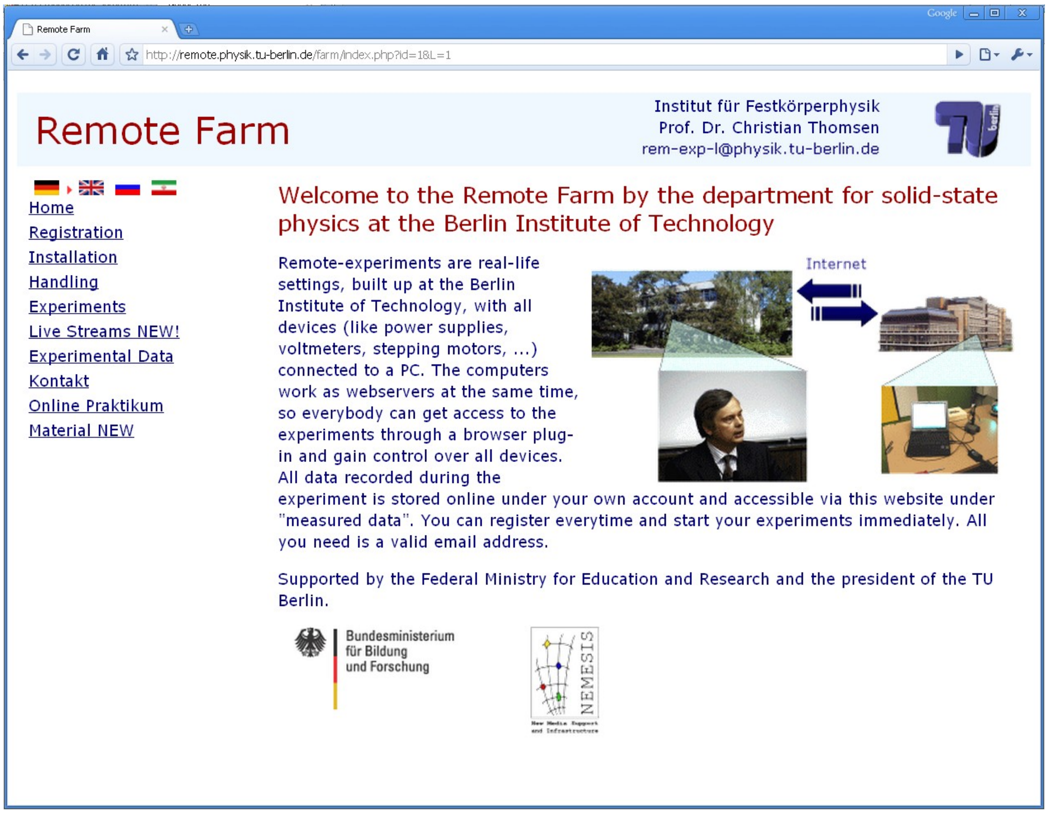

Figure 3. The web page of Remote Farm. From this web interface the students conduct the remote experiments.

the theoretical values obtained from simulation, shown in Figure 4.

2.2.3 Data analysis: Step 3 in course cycle

One of the many advantages of remote experiments is the ability to acquire real experimental data. The core skills for scientists and engineers is the ability to collect, analyze, and interpret data. Moreover, the engineers must learn to form and support conclusions and make order of magnitude, judgments and use measurement unit systems and conversions. This is important when reviewing experimental results and others work. Analyzing and representing the experimental results are one of the key skills taught in this course. The measurement data must be evaluated and analyzed with the suitable data processing programs. The experimental data from the remote experiments are afflicted with experimental errors. The calculation of these errors, identifying unsuccessful outcomes due to faulty equipment, construction, process or designs are also skills that the students learn through OnPReX. To make the learning of "data analyzing basics" for OnPReX-participants easier we prepared an introductory script where the basics of data analysis and some data analyzing software products are introduced. As we showed in Figure 1 (fourth step in course cycle) by online tutoring we support the learning of data analyzing skills. As shown in Section 2.3 the teaching tutor team supports the OnPReX participants to solve the problems due to the data analyzing. The OnPReX-participants exchange information and know-how among each other and also with the tutors via email, forum, chat and wiki. The communication of the tutors and the students becomes easier through the ISIS Platform.

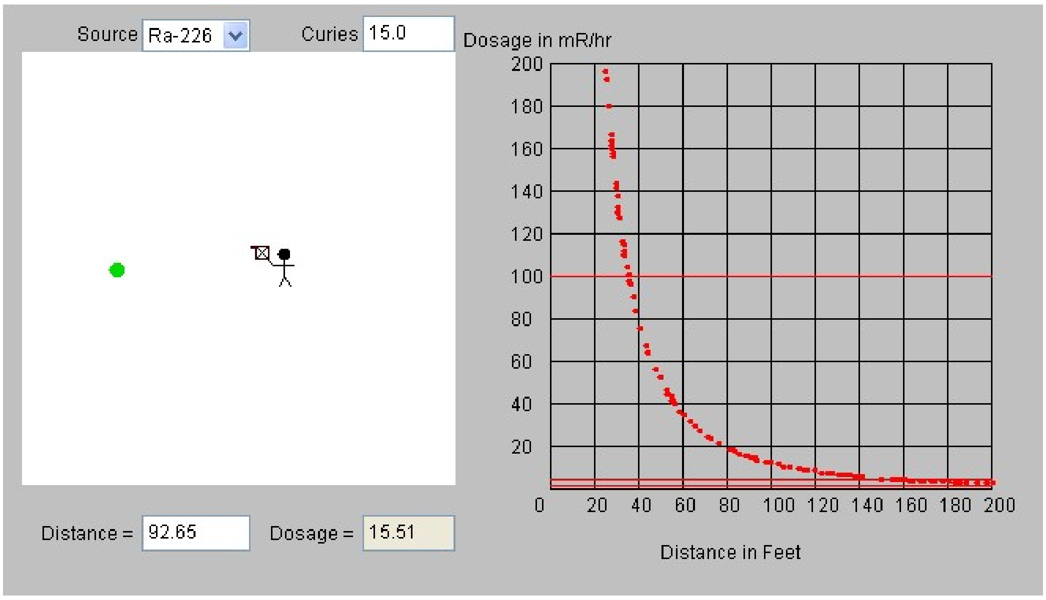

Figure 4. The simulation of radioactivity experiment taken from NDT Resource Center NDT-Resource-center (2009).

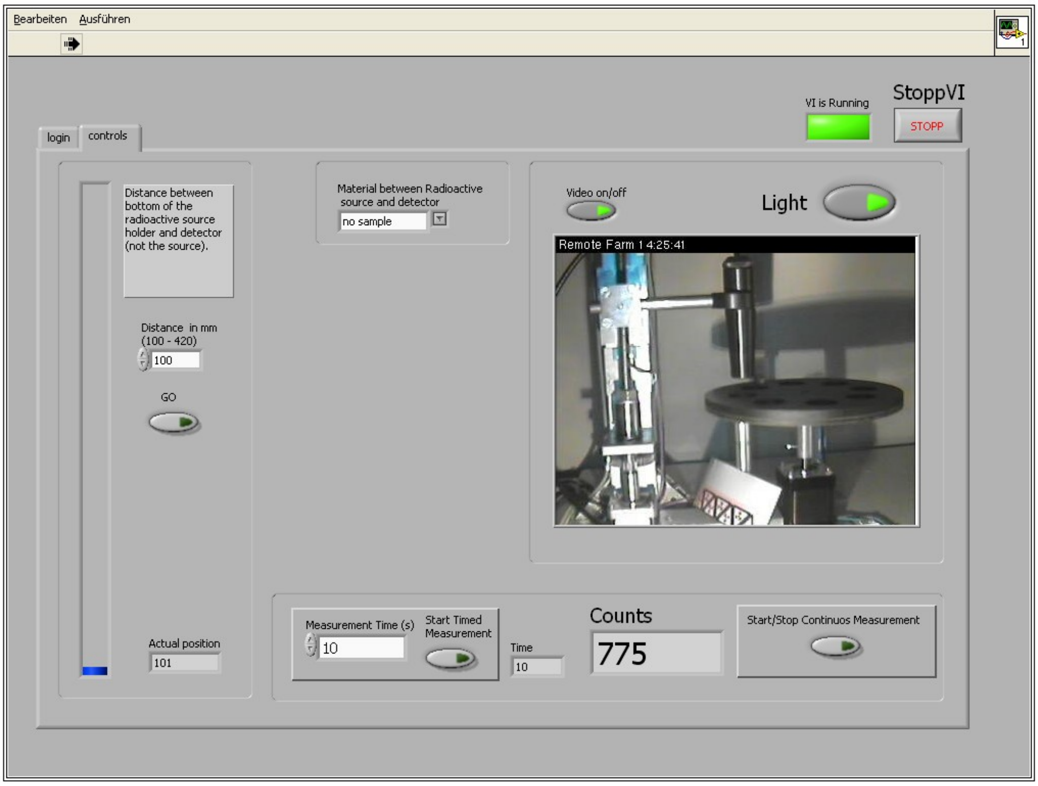

Figure 5. The control panel of radioactivity experiment.

2.2.4 Reporting: Step 4 in course cycle

The main purpose of writing scientific reports at universities is to communicate the results of experiments. The process of writing a scientific report also includes valuable practice in articulating the theoretical and empirical basis of a particular experiment, and the significance of the interpretation of results. With this train-

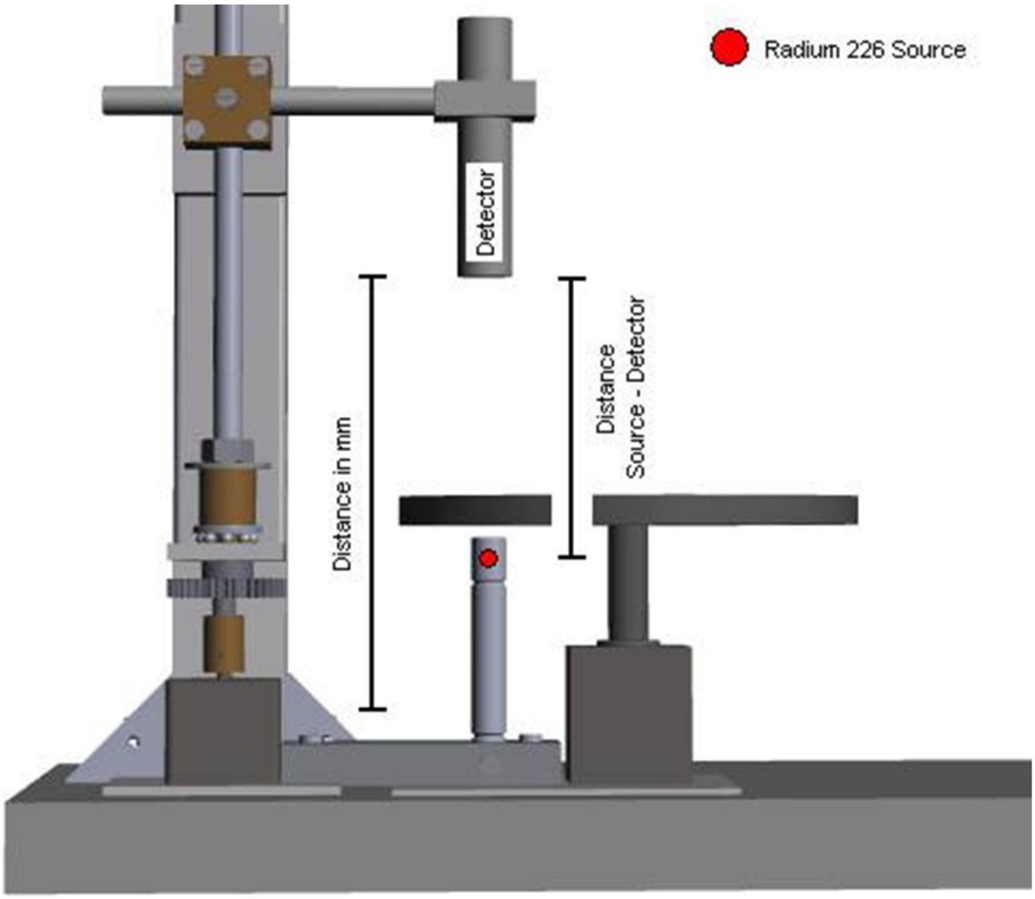

Figure 6. The schematic image of the radioactivity experiments setup.

ing undergraduate students are well prepared to produce reports for postgraduate studies and communicating their findings to the scientific/technical world. In an introductory script we give a general idea of the sections of scientific reports. The rest of this skill can be learned in the form of learning by doing with the assistance of tutors (teaching tutor team Section 2.3).

2.3 *Organization*

Any course involves challenges in organization and managing it. To manage the OnPReX-course we needed two tutor teams: the technical support team and the teaching tutor team:

- Technical tutors team (the organization of Remote Farm): The tutors in this team design, build and program the experiment. The maintenance of existing experiments and debugging the technical problems are part of their duties. This team consists of three tutors two of them deal with the programming and the electrical part of experiments and one of them deal with designing and building the mechanical setup of the experiments. This team is responsible for the activities in Remote Farm and works under supervision of a team leader.
- Teaching tutors team (the organization via Moodle environment of OnPReX): This team consists of three tutors. Every tutor is responsible for two of the remote experiments. The teaching tutors provide support to the OnPReX participants, understand the theoretical background of the experiments, analyzing the data, and writing the reports. They also correct the reports and consult the students to

solve the problems. These tutors regularly answer the students questions in the forum. This team works under supervision of the course instructor. The teaching tutors work in the ISIS environment.

3. Authentic learning as the frame of reference for the OnPReX didactics

An authentic learning activity defines as an experience of personal relevance that permits learners to practice skills in an environments similar to those in which the skills will be used (Lebow (1993)). Herrington, Oliver, and Reeves (Herrington *et al.* (2003)) conducted a literature review related to the 10 characteristics of authentic activities. We now discuss one example of the 10 criteria by Herrington et al. Characteristic number 4 is providing the opportunity to collaborate. This characteristic fits to the OnPReX course as the participants of OnPReX conduct most of the processes in groups. This collaboration process is enhanced by the functionalities offered in ISIS portal, discussed in Section 2.2.1. We summarized the 10 characteristics in Table 1 and discuss the 9 learning activities matched in OnPReX.

4. Experiences from OnPReX

Organizing the OnPReX was a great experience for us and was a time-consuming project (6 months lead time). In this section we present our experiences in more detail. These 6 months were needed to compose and collect all the learning resources mentioned in Section 2.2.1, to prepare the ISIS portal and also to make a organizational structure for the course.

4.1 *Motivation*

To attract attention of students to the OnPReX additional to publishing the OnPReX in the TU Berlin course guide we used an alternative way to incorporate the students in OnPReX. The institute of solid state physics offers a physics service lecture for engineering students in the first and second semester. This course consists of one semester of classical physics and one semester of modern physics. The precondition for students in these courses to take the exam is a tutorial certificate. To obtain this certificate the student must take part in tutorials and also pass two of three written exams. An alternative way to get this tutorial certificate is pass the OnPReX traineeships.

4.2 *Evaluation*

Collecting feedback from the students is a valuable tool for any instructor who is designing and managing a course. To get the most of your investment in the development of the course, evaluation of the content, design and methods is an important component that needs to be built into the structure of the course itself. OnPReX course assessments are used to improve the quality of teaching and learning through feedback to the course developers. The practical course with remote experiments is a relatively new course form that continually needs to be improved. There is some good evidence that student evaluations are good indicators of effective teaching (see, Aleamoni (1999), Cohen (1982)). The process of (a) gathering information about the impact of learning and of teaching practice on student learning, (b)

Table 1. The characteristics of authentic learning environment and their analogies in the OnPReX.

Nr.	Characteristic of an authentic learning environment [a]	Learning activities and competences in OnPReX
1	Real world relevance	The competence of dealing with remotely controlled machines for the future as an engineers, the ability to analyze and present the experimental results and to prepare a scientific report.
2	Comprise complex tasks to be investigated by students over a sustained period of time	The students work on each experiment over days. It begins with the learning of theoretical background, continues with experiment, and data analysis, and ends with the report. Over this period of time they deal with the same physical content.
3	Provide the opportunity for students to examine the task from different perspectives, using a variety of resources	Diversity of the learning resources such the scripts, films, animations, simulation, and remote experiments provides the opportunity to deal with the same content from various perspectives. The different roles as the questioner (content user in forum) and also as answerer (content provider in forum and wiki) help the better understanding of physical contents.
4	Provide the opportunity to collaborate	The participants of OnPReX do the experiments, analyze the data and write the report in the groups. The groups and also the participants can also collaborate together. The forums and the mediation by the tutors make the collaboration easier.
5	Provide the opportunity for learners to make choices and reflect on their learning individually and socially	The course participants are free to choose the remote experiment and their chronological order. There is no fixed schedule for doing the experiments but a deadline for the reports.They can search for the learning resources and the Softwares etc., which are suitable for them (self managed learning).
6	Integrated and applied across different subject areas and lead beyond domain specific outcomes	The final outcome of OnPReX is the scientific report. Preparing a scientific report requires a sets of skills such as dealing with text editing programs, and data processing programs, remote controlling and online competence. All these skills are required for writing the report.
7	Create polished products valuable in their own right rather than as preparation for something else	The scientific Report is the the final product of this course, containing the whole skills that the participants have learned during OnPReX.
8	Allow competing solutions and diversity of outcome	In oder to prepare the outcome (report) the participants make their individual decision related to the text editing and data processing softwares. The participants can also write (in forum and wiki) about their choices and also discuss about the advantages and disadvantages of these individual solutions among themselves.
9	Seamlessly integrated with assessment	In OnPReX the students and their works assess with these three criteria: ability to deal with remote experiments, to prepare a report and to the ability to argue about the experimental results. These three criteria reflect the real world assessment.
10	Ill defined activities, requiring students to define the tasks and sub-tasks needed to complete the activity	No analogy

[a] The authentic learning environment characteristic are take from (Herrington *et al.* (2003)).

analyzing and interpreting this information, and (c) responding to and acting on the results, is valuable for several reasons (Cohen (2006)). We conducted an online evaluation for the 2008 to 2009 semester at the end of course. We used an online evaluation software (Unizensus) to evaluate the OnPReX courses. Unizensus is an evaluation software, which has been used in the Berlin Institute of Technology (Faculty of science) over years. Unizensus gives the possibility to design a ques-

Table 2. The results of Evaluation.

Nr.	Question[a] (general goals)	1	2	3	4	5	mean value
1	improvement of text the editing skills	1	4	4	1	1	2.7
2	improvement of data processing skills	0	5	2	3	1	3
3	learning the standards of reporting	2	3	3	3	0	2.6
4	the importance of dealing with remote experiments as engineer	4	3	2	1	1	2.3
	Question[a] (experiences)						
1	usefulness of introductory script	1	4	4	2	0	2.5
2	usefulness of simulation, animation and interactive graphics	3	5	4	0	0	2.2
3	independence related to the place and the time of conducting experiments	8	1	1	0	1	1.6
4	user friendliness of remote experiments	1	5	4	1	0	2.4

[a]Rating scale: 1 = Excellent, 2= good, 3= satisfying, 4= acceptable, 5=poor.

tionary and send it to the OnPReX participants. The result of evaluation were analysed also with Unizensus. In this evaluation the questions are divided in two categories. In the first category we tried to find out if the general goals of OnPReX are achieved, and in the second category of questions we tried to get responses from the participants in order to develop the OnPReX course further. We present some of the important results of the evaluation in Table 2. The participants were beginners and were short on experience due to physics practical course (91% of the interviewees never passed a physics pactical course before and 63.5% had no experience with writing a report). The general goals introduced in Section 1 are mainly achieved in the view of participants according to the evaluation(see first category of questions in Table 2). The number of 73% of the participants shows that the participants believe their online competence ameliorated through OnPReX. 73% of the interviewees think that they learned the standards of reporting. 64% of the participants believe, that dealing with remote experiments is "very important"(good or excellent) for a future occupation as engineer. They further believe that this ability has real world relevance. 81%, and 55% of interviewees believe that the OnPReX helped to improve their text editing and data processing skills, respectively. From the second category of the evaluation-questions we read that the independence in time and place is "very important" for the participants (73%). From specific comments we learned that the graphical interfaces of some Experiments are "user unfriendly" and that some setups are "unstable". We used this very helpful input to further improve our experiments. We were very happy read that 82% of the interviewees recommend OnPReX to other students. Remote experiments are advantageous specially where the experiment is dangerous for the experimenter. For example 37.5% of interviewees raise concerns over working directly with dangerous experiments such as radioactivity. The results of our evaluation show that the OnPReX can be further developed to afford even better conditions to the students. This applies for the improvement of text editing (mean value: 2.7), data processing (mean value: 3) and reporting (mean value: 3) skills. In summary we feel that the outcome of the evaluation is very positive and helped us to greatly improve our online course.

5. Conclusion and outlook

In conclusion we have presented an online practical course with remote experiments for bachelor and intermediate diploma engineering students. We showed that the online learning environment used including the learning and coaching activities, are consistent with an authentic learning environment. We showed that the association of the remote experiments, online literature and simulation with online tutoring system can result in an online practical course, which can be very useful in engineering education. We believe that the OnPReX can be very helpful for the engineering students through their academic studies and also the career as engineer. OnPReX motivates also the self managed online learning. Definitely we need to develop OnPReX further. Firstly we must stabilize the existing remote experiments, and in parallel design and build new experiments. Secondly we need to test the capacity of OnPReX concerning the number of participants we can serve in a semester. In winter semester of 2009 to 2010 we are aiming to offer the OnPReX as a compulsory subject choice for the students of "Natural Sciences in the Information Community". This is a bachelor course of studies where the students should pass during the first and second terms two physic practical course with 12 ECTS points. We offer the students in the first term the OnPReX classical and modern course for 6 ECTS points. In the second term the student take the regular physics practical course offered by their faculty. Herewith we are going to test the capacity of OnPReX concerning the number of the participants. To find out if the OnPReX updates after the first evaluation were sufficient, further evaluation is needed. We need to provide a simulation for every remote experiment to make the comparison of obtained data from remote experiments and simulation possible. We are aiming to integrate the OnPReX course in the Lila project. The LiLa project "Library of Labs" (LiLa (2009)) is a European Community funded project to network remote experiments and virtual laboratories. By means of this integration we will be able to offer the students more manifold and better collection of remote experiments, simulations and learning resources.

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