Experiential Remote Lab Learning with E-Portfolios
Integrating tele-operated experiments into environments for reflective learning

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Abstract—The use of laboratories in Higher Engineering Education is an adequate opportunity to implement forms of experiential learning like research-based learning in material sciences. Introducing remote laboratories gives the opportunity to the student to do self-directed research and by that having own and unique learning experiences. Recently finished research projects e.g. like the PeTEX project implemented research-based learning by deploying real laboratory equipment without being physically in the laboratory but having access via the internet. The question in this context is how the student can document his/her own learning processes on the one hand and how the teacher can guide the student through these processes on the other. The proposed solution in this paper is an e-portfolio system on the basis of a personal learning environment. With e-portfolios the student is able to individually and collectively document and reflect what he has been doing and can share his outcomes with others. The paper outlines the important role e-portfolios as personal learning environments can play to experience remote laboratory work and to foster the creative attitude.

Keywords—engineering education, e-portfolios, tele-operated laboratories, online engineering education, experiential learning

I. INTRODUCTION

Learning through experiments in general has become an essential part in modern Higher Engineering Education [1]. Students can get to know for the first time lab equipment and working practices of their future professional world [2]. They can practice experimentation and analytical abstraction and are encouraged and sometimes challenged in their scientific and technological self-understanding. This includes, for example, practical implementation of theoretical assumptions, own technical engineering or scientific activities through, the implementation and evaluation of practical experiments and ideally the critical evaluation of their results and of their own approach. But one of the most important factors that hinder the real use of laboratories by students is the cost of such equipment. Especially small universities often face the situation that they cannot afford all the laboratory equipment, or that the students are not allowed to use it, because they could damage the test-stands. That means in many cases that experiments are either only shown via video during the lecture or that the faculty’s staff shows the equipment just during the lecture.

One possible way out of this dilemma – to enable students to conduct experiments and to develop technical skills and scientific competencies – are remote and virtual laboratories [3], [4]. With them laboratory equipment can be shared with separate universities and places, and even more, very risky experiments can be conducted completely virtually.

Important research on the use of tele-operated in teaching was done by universities from Dortmund (Germany), Palermo (Italy), and Stockholm (Sweden) within a project called PeTEX – Platform for e-learning and Tele-operative Experimentation. The PeTEX project was funded by the European Union between 2008 and 2010 in the Leonardo da Vinci sub program of the Lifelong Learning Programme. The Dortmund part was carried out by the Institute of Forming Technology and Lightweight Construction (IUL) and the Center for Higher Education. Within this project, fundamental research in using tele-operated laboratories in teaching was done and a network of three prototypes in the field of manufacturing technology was developed [5], [6], [7], [8], [9], [10].

The work presented in this paper will base on the achievements of the PeTEX project, will deploy its technological infrastructure, and will improve the concept by extending the possibilities. The conception of the further development which will be carried out as a subtask of the new project ELLI–Excellent Teaching and Learning in Engineering Education. ELLI is funded by the German Ministry of Research and Education until 2016.

II. PEDAGOGICAL FOUNDATION

A. Learning in the Mode of Research with Tele-Operated Laboratories

Once they graduated, and no matter if they go for a career in a company or in the academic sector, engineering students will work with real technical equipment and they will work on creative solutions for real problems. But will they get the opportunity to have intense experiences with lab equipment during their studies? [1]

One possibility to change this fact is the use of laboratories in teaching, by deploying experiential learning [11] or research-based learning [12]. To bring the students into contact with laboratory equipment means to bring them in contact with the technical equipment of their future profession and to give them the opportunity to develop essential competences for their future career [12].
In his learning cycle theory, [11] explains that at the beginning of each learning process a real learner’s experience happens, followed by a reflective observation. From that point on, the learner tries to conceptualize what he has experienced, starts to experiment actively and generates new experiences, which triggers a new cycle. It is not by coincidence that a research process has quite similar steps, beginning with an experience or a question and ending with real experiments and new research results [13].

That is, why research-based or experiential learning in Higher Education is one adequate way of implementing learner centered teaching. In addition to that, [13] had pointed out the importance of an authentic learning environment for a successful learning process.

Only classical telling of knowledge in lectures in combination with theoretical exercises and without giving the real context may not lead to reach higher order learning outcomes, stated by taxonomies like the SOLO taxonomy [15], Bloom’s revised taxonomy [16], or the thirteen objectives of laboratory learning by Feisl & Rosa [1]. But this authentic learning environment can be offered by teaching and learning activities in laboratories and the students can face the context of real professional activities. By connecting the actions in laboratories in a next step to real problems - e.g. from current research or from the industry - the students are able to go the whole way from the question at the beginning of an experiment to the final use of the results and they can see the relevance of their work. This process requires reflective thinking and independent learning, which obviously differs significantly from classical lecture-based engineering courses [17].

Using tele-operated laboratories and virtual laboratories gives a whole range of opportunities to implement experiential learning in teaching of Higher Engineering Education. Just one example is the use in addition to a normal lecture about forming technology. Whilst the students discuss basic aspects of metal forming during the lecture, they can simultaneously test and experience what they have discussed by doing experiments on their own, using the tele-operated experiential equipment. Another opportunity is that students receive a real problem in context with material behavior: in small groups they have to solve the task with the tele-operated lab equipment. Finally, they have to present what they have found and they have to solve the task with the tele-operated lab equipment. Another opportunity is that students receive a real problem in context with material behavior: in small groups they have to solve the task with the tele-operated lab equipment. Finally, they have to present what they have found and

In his four-step learning cycle, Kolb explains that at the beginning of each learning process there is a real learner’s experience (step 1) which is followed by a reflective observation (step 2). From that point on the learner tries to conceptualize what he has experienced (step 3), starts to experiment actively (step 4), and generates new experiences. This is the start of a new cycle. With every loop – from the simple to the complex – the student enhances his experiences. Thus, the learning activities are transformed by the learning cycle into a helix of experience-based knowledge, skills and competencies. (see [7] for a concept to integrate three levels of experience).

C. Fostering Creativity

Going the whole way of a research process corresponds to another important aspect of engineering education: fostering the students’ creative potential. Industrial nations are facing tremendous problems. For example, new techniques to tackle climate change, new ideas on how to retain mobility of people or new concepts for energy production without fossil fuels are urgently needed. Engineers play an important role in addressing these challenges. Future prosperity and wealth will depend on their inventions and creativity [18], [19], [20], [21], [22].

III. ACTIVE EXPERIMENTATION USING TELE-OPERATED EQUIPMENT

Using remote and virtual laboratories in teaching gives a whole range of opportunities to implement experiential learning in the field of mechanical engineering following the path of research based learning [6]. One example in the context of manufacturing technology, namely forming technology, will be the use of such a special lab concept for material characterization. This will be organized in addition to a normal lecture or to enhance traditional hands-on labs during the phase, students prepare themselves for the lab, or when they would like to rework some of the test steps, while writing the lab report.

Following the approach based on Kolb’s experiential learning cycle, students can deal with basic concepts of metal forming during the lecture and test and see what they discussed by doing experiments on their own, using the remote lab equipment. Another opportunity will be that students are given a real engineering problem related to material behavior. They are asked to work
on this problem in small groups by planning and carrying out experiments using the tele-operated equipment. Finally they have to present what they’ve explored and what they would suggest to deal with the problem [6].

In order to support this entire process and especially the step of “active experimentation”, one important aspect is that an appropriate level of interaction and feedback needs to be integrated into the tele-operated experimental setup. In the PeTEX project, a complete experimental setup (Fig. 1) has been transformed to a new level by using of innovative engineering design, modern concepts of automation, measurement technology, and robotics, as shown in Fig. 2.

Relevant test parameters (3) can be freely set to configure the experiment. When the test is started (4), the robot positions the specimen into the fully automatic clamping device. During the test, a high level of interaction is provided to the user by manipulating the camera view or pausing and continuing the test. Pausing the test causes a reaction by the material because the load is not further increased for that moment. This phenomenon is graphically visible in the real time diagram (6) and also in the real time test data at the header bar (5). By using of the data base (7) and the graph, comparisons with prior test data are available (6). After the experiment is finished, learners are provided with data package including all the results for further analysis and investigation.

Figure 2. Robot positioning a specimen

Additionally, within the learning content management system Moodle, the entire tele-operated experimental environment was made available. With Moodle we designed the alignment and the integration of the four necessary structural elements for this kind of socio-technical system. This socio-technical alignment for tele-operated laboratory learning consists of the adjustment of the technical, didactical, media and social level. By the implementation into Moodle, as shown in Fig. 5, this socio-technical alignment was put into a usable as well as flexible environment.

An often formulated challenge to such open designed learning concepts is that it turns out, that the teacher is in need of a very sophisticated concept to document and evaluate the learners’ behavior and achievements during the learning processes, which take place in the laboratory. It is obvious that such a concept requires different systems for the instructor to accompany the learner through the learning process and, above all, to evaluate the achieved learning outcomes. Software which seems to be adequate and which is frequently discussed in similar contexts is the e-portfolio [23]. The following passages present the concept draft concerning the learning process documentation in the context of the combination of remote laboratories with e-portfolios.
Figure 3. Interface to the tele-operated experiment

Figure 4. Experiment environment integrated to Moodle
IV. EXPERIENTIAL LEARNING WITH E-PORTFOLIOS

E-portfolios base on the general idea of portfolios. A portfolio gives a learner the opportunity to collect and organize different kinds of documents in a folder in order to reflect one's learning process, to edit and to present it [24]. E-portfolios support the same processes, but they base on ICT, are online accessible and provide the collecting of different kinds of digital data and information like texts, tables, photos, videos, and audio. E-portfolio software, in this case Mahara, will be very easily combined with the Moodle environment already used in the PeTEX context, because there already exists a special e-portfolio application called Mahoodle which is especially designed for Moodle. In the following it will be explained why e-portfolios fulfill the three main requirements in the PeTEX context [25], [26].

A. E-Portfolio as a documentation of the learning process

By creating and designing their own portfolios, users get the opportunity to arrange in different orders all data and information they want to document or to share with others. It works just like a personal page in any social network. For example, they can present experiments and their results, show photos from the test set-up, and can explain their research and their thoughts to themselves and others. Furthermore, they can allow other users, like other learners and teachers, to see their e-portfolios. By creating such an e-portfolio learners can document their own learning and research processes, and start to reflect on their experiments during their research-based learning processes [27], [28]. This reflection is an important aspect because they need this step in their personal learning cycles. Especially for students the e-portfolio can give a kind of orientation and checkpoint in fields of their own research. [9],[27],[29]. By the same way, teachers too can evaluate the actions of learners with looking into their e-portfolios. Since other persons are able to see the collection in the portfolio, it can be said, that it is not only a way of individual documenting the learning processes, but as well a way of communicating. Thus, a collaborative learning process can be achieved. This leads to the next use of e-portfolios within the PeTEX context.

B. E-Portfolio as software to build up a learning community

The deployment of the e-portfolio as software for documentation and evaluation is just one possible use of the system. A constructive enrichment in using the e-portfolios is the community building. Every author of an e-portfolio can document their own learning and research processes, and start to reflect on their experiments during their research-based learning processes [27], [28]. This reflection is an important aspect because they need this step in their personal learning cycles. Especially for students the e-portfolio can give a kind of orientation and checkpoint in fields of their own research. [9],[27],[29]. By the same way, teachers too can evaluate the actions of learners with looking into their e-portfolios. Since other persons are able to see the collection in the portfolio, it can be said, that it is not only a way of individual documenting the learning processes, but as well a way of communicating. Thus, a collaborative learning process can be achieved. This leads to the next use of e-portfolios within the PeTEX context.

While working on their e-portfolios, students anticipate that their "product" will be valued by others. Therefore, they will seek to make them more attractive for others, for example by bringing in new aspects or by considering that their ideas must be understood by others as well, which requires a non-contradictory and simple presentation. They can see what others are especially interested in, can start discussions about it, can give comments, can help each other in the case of a problem during the conducting of the experiment and the reflection, and lastly can share their experiences.

By this way, a specialized community on remote laboratories emerges within the PeTEX context (e.g. see www.vrlcom.com. It is an excellent example for a community on the topic of remote and virtual labs and worlds).

C. E-Portfolio as a bridge between the university and the workplace

The PeTEX system is designed for the usage in higher education and for workplace learning. That means that in a first step, students and workplace learners both can use the e-portfolios in the explained way of use. A further future thought is to use the e-portfolio as a lifelong system. One can document all competences gained from studying at the university, and can continue to document one's challenges, experiences, and advancements during the whole professional life. This should be explained by an example in three steps:

- **Step 1** - An engineering student starts working with the PeTEX system at the university. He uses the system in order to document his experiments. During his studies he does different experiments, collects all documentation of his research in his e-portfolio, and reflects on his own learning paths. The teacher is able to evaluate his learning processes, results, and outcomes. This can be seen as the main use of e-portfolios at university.

- **Step 2** - Since the PeTEX system addresses workplace learning just as well, e-portfolios can be seen as a bridge from university life to professional life. The student can use his e-portfolios to present himself to potential employers, depending on the concrete thematic design of the e-portfolios. The company can see what the student has acquired during his studying in this field, and may decide if he fits to the company’s needs. In this context e-portfolios can support the process of applying for a job.

- **Step 3** - Once the former student and now employee starts to work in a company, he must not stop working with his portfolio. He still can work with his collection and by documenting new experiments as well as gained knowledge and competences in his job. By doing so, the employee will not stop reflecting on his learning processes. His e-portfolio grows and with every year it more and more turns out to a better presentation of his professional life and his competences. Especially the last aspect works perfectly together with the advantages of the PeTEX system: small and medium sized companies can use the system to skill up their workers by experiencing research with the PeTEX hardware. In addition to that, they can use the e-portfolios for implementing a system to document and measure of skills and competences of their employees.

D. E-Portfolio as a means for mobile learning

Another frequently mentioned new concept in context with higher education is mobile learning. Mobile learning means the
deployment of mobile devices for supporting the learning processes - like cell phones, smart phones or tablet-computers [30]. Only one of the advantages of mobile learning is that unplanned periods of time can be used for learning and that learning processes can be initiated virtually everywhere [30]. In our context we will focus on the fact, that the users carry their mobile devices actually at every time and because of that, they can use them frequently in order to work with their e-portfolio software and the related laboratory equipment [31].

E. E-Portfolio as a tool in creative moments

Consider a student who is thinking of his experiments while sitting at home and watching TV or while he is staying at a boys night out with his friends. But he is unable to concentrate on soccer and beer because he really is struggling with his research work, is thinking about his parameters, his results and why his experiments offer these results. While he is listening to his friends and how they are ordering the next round of cold beer, he suddenly has an idea for a hypothesis and wants to check it by rereading his last experiments in the portfolio, or even by conducting a new sequel of experiments. Since he can use the software for connecting with the experimenting environment via his tablet computer, he doesn't need to wait until the next day or week for doing the experiment at the university. He just can stay where he is and even can stay sitting on the barstool for checking his hypothesis. He can immediately put the new results in his portfolios, so that he can document his new steps within his research process. Additionally to this, using a simulation in a virtual laboratory instead of the remote experiment can be a method to firstly (pre)-check the hypothesis and thereby to avoid the risk of damaging of real equipment, and then finally to conduct the real experiment remotely.

Just his mobile device is in a constant danger of being dropped and crushed due to the combination of a wobbly barstool and a thrilling creative flow experience – especially when a soccer goal is scored.

A researcher from the Australian Labshare project told us during a night out at the REV-Conference 2011, that Labshare had been on duty mostly on late Saturday nights and early Sunday mornings. But the reason for that phenomenon hadn’t been investigated, as well as the social situatedness of users.

V. DISCUSSION, CONCLUSION & FUTURE WORK

With this paper we explained why the use of laboratories as a facility for conducting experiments is important for modern engineering education. The essential idea is to engage the students in teaching and learning environments, which are connected closely with their future working environments. In addition to that, the aspect of student-centered learning environments and appropriate approaches gain more and more importance in higher education because this is one essential way for the students to reach the high level of learning outcomes, and hereby develop the basis of fundamental competences for their future professional and personal life, and attitudes like curiosity, agency, and responsibility. Furthermore, we showed the potential of our approach to fostering the learners’ creativity. If students are enabled to evolve their own research questions, to choose a suitable experimentation design and finally to perform the experiment, they will be able to develop some kind of “spirit of research” [27]. This spirit is one important premise for trying to get original ideas. See in the following the central advantages of the presented concept:

- As the equipment of laboratories is either very expensive to have it at every university or not always available for the students, the deployment of remote and virtual laboratories is an impactful means to face this dilemma.
- The using of lab equipment as virtual simulations or remotely from wherever can help the students to do experiments just as a pre-check on personal hypothesis or even when they are not able to attend the laboratory.
- Learning processes that are achieved by the usage of the laboratories can be documented in e-portfolios.
- These portfolios are an adequate possibility in order to document the experiments for the personal use or for the evaluation by an instructor. By examining the portfolios the instructor can see what kind of experiments the students have done and what they learned from it.
- If the portfolios are not kept hidden for other students, but rather are open for other users to look at them and comment on the achievements, there is the opportunity to evolve a community for collaborative learning and working with the experiments. Additionally, the e-portfolio software may be made accessible via mobile devices. This opens new ways of mobile learning, which means that students and some of their learning activities are not bound any longer to specific locations. From virtually everywhere and at every time the user can work on their portfolios and communicate with each other.
- With the possibility of promoting a “spirit of research”, an essential facet of creativity in higher education can be fostered.

Summing up it can be said that all these aspects of deployment of e-portfolios in the PeTEX context can support the idea of experimental and research-based learning – even if there are a couple of challenges to overcome. [15]. The e-portfolios can be used to document and share the research results and learning processes, to build up a specially focused learning community, and to bring university learning and workplace learning together. The step for the coming year will be to integrate the e-portfolio software in the system and making it accessible from mobile devices. Once this has been achieved, first tests with students can be carried out and the system can be formatively evaluated and improved.

ACKNOWLEDGMENT

The authors would like to sincerely thank: Prof. Dr. Isa Jahneke, Umeå University, Sweden, Prof. Dr.-Ing A. Erman Tekkaya and Dr.-Ing. habil. S. Chatti, M. Spiess, M. Sappok, S. Grunert, M. Hoffrichter, TU Dortmund University (IUL), Dr.-Ing. U. Dirksen, Poynting GmbH, Dortmund, Germany, Prof. Dr. J. Wildt, M. Heiner, K. Heyder, M. Schaefer, N. Karacan, TU Dortmund University (ZHB), Prof. F. Micari, Prof. E. Lo Valvo, Prof. L. Fratini, PhD R. Licari, PhD G. Buffa,
University of Palermo, Italy, Prof. M. Nicolescu, P. Johansson, KTH, Stockholm, Sweden, Dr. P. Ilyes, Science and Technology Studies, Institute for Cultural Anthropology and European Ethnology, Goethe-University Frankfurt/Germany; S. Voss, D. Weiβ, A. Mereu, C. Bremer, R. Müller, Dr. A. Tillmann, and Prof. Dr. D. Krömker from studium-digitale, Goethe-University Frankfurt/Germany.

And last but not least the authors sincerely thank all their friends and colleagues in the ELLI project and at TeachING-LearnING.EU – the first Subject Center for Engineering Education in Germany.

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