Integrating Remote Labs into Personal Learning Environments

Experiential Learning with Tele-Operated Experiments and E-Portfolios

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***Abstract*—The use of laboratories in Higher Engineering Education is an adequate opportunity to implement forms of experiential learning like problem-based or research-based learning into manufacturing technology. The introduction of remote laboratories gives students the opportunity to do self-directed research and by that having their own and unique learning experiences. Recently finished research projects, e.g. the PeTEX project, implemented research-based learning by deploying real laboratory equipment without being physically in the laboratory but by accessing it via the Internet. One essential question in this context is on the one hand how the student can document his/her own learning processes and how the teacher can guide the student through these processes on the other hand. The proposed solution in this paper is a personal learning environment that integrates a remote lab and an e-portfolio system. E-portfolios enable the student to individually and collectively document and reflect what he/she has been doing and to share his/her outcomes with others. The paper outlines the important role that e-portfolios can play as personal learning environments to experience remote laboratory work and to foster creative attitudes.**

***Index Terms*—personal learning environments, e-portfolios, tele-operated laboratories, online engineering education, experiential learning.**

I. INTRODUCTION

The experience of learning through experiments in general has become an essential part in modern Higher Engineering Education [1]. For the first time during their education, students can get to know lab equipment and working practices of their future professional world [2]. They can practice experimentation methodes 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, 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 approaches.

However, one of the most important factors that hinder the real use of laboratories by students is the initial and running costs 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 demonstratively shows the equipment just during guided tours through the laboratory.

One possible way out of this dilemma – in order 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 by separate universities and places, and even more, very risky experiments can be conducted completely virtually. The experience of remote experimentation can be delivered to the learner by technically and didactically integrating the labs into collaborative learning systems like monolithic learning and content management systems (LCMS) or cloud-based personal learning environments (PLE): "A PLE driven approach does not only provide personal spaces, which belong to and are controlled by the user, but also requires a social context by offering means to connect with other personal spaces for effective knowledge sharing and collaborative knowledge creation" [5].

Important research on the use of tele-operated experiments in LCMS-based teaching and learning was done by universities from Dortmund (Germany), Palermo (Italy), and Stockholm (Sweden), within a European project called **PeTEX – Platform for e-learning and Telemetric EXperimentation**. 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 "design-based research" in using tele-operated laboratories for teaching and learning was done [6], [7], [8], [9], [10]. A network of three fully functional prototypes in the field of manufacturing technology was developed step by step, formatively evaluated [11], [12], [13], [14], [15], [16], [17] and finally demonstrated [18].

The work presented in this paper will be based on the achievements of the PeTEX project, will enhance its technological infrastructure to a personal learning environment by integrating e-portfolio software, and will improve the concept by extending the didactical possibilities with an experiential learning approach.

Further development of an e-portfolio-based personal learning environment (PLE) 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

"The most compelling argument for PLE is to develop educational technology which can respond to the way people are using technology for learning and which allows them to themselves shape their own learning spaces, to form and join communities and to create, consume, remix, and share material" [19].

"The development and support for Personal Learning Environments would entail a radical shift, not only in how we use educational technology, but in the organization and ethos of education. Personal Learning Environments provide more responsibility and more independence for learners. They would imply redrawing the balance between institutional learning and learning in the wider world" [20].

A. *E-portfolios as Personal Learning Environements*

Personal Learning Environments can play an important role to foster and facilitate student-centered learning: "Personal Learning Environments are systems that help learners take control of and manage their own learning. This includes providing support for learners to set their own learning goals, manage their learning; managing both content and process, communicate with others in the process of learning, and thereby achieve learning goals. A PLE may be composed of one or more sub-systems: As such it may be a desktop application, or composed of one or more web-based services" [21].

E-portfolios as one manifestation of personal learning environments are based on the general idea of portfolios. A portfolio gives learners the opportunity to collect and organize different kinds of documents in a folder in order to reflect their learning process, to edit and to present it [22]. E-portfolios support the same processes, but they base on ICT, are accessible online and provide the collection of different kinds of digital data and information like texts, tables, photos, videos, and audio. E-Portfolio-based PLE software, in the presented case Mahara, can be very easily combined with the PeTEX LCMS based on Moodle. For another example of an e-portfolio like system, see [23] which is based on Wiki software. The integrating application Mahoodle combines the properties and functions of the teacher-led LCMS Moodle and the learner-led e-portfolio Mahara into a PLE, which can be deployed as "a facility for an individual [or a group of individuals] to access, aggregate, configure and manipulate digital artifacts of their ongoing learning experiences" [24].

B. *Kolb's Experiential Learning Cycle*

The basic understanding of learning and its use for laboratories in teaching and learning environments can be traced back to [25]: "Learning is the process whereby knowledge is created through the transformation of experience". Kolb states that learning involves the acquisition of abstract concepts that can be applied flexibly in a range of situations. In Kolb's theory, the impetus for the development of new concepts is provided by new experiences. Kolb's concept of experience is defined in his experiential learning theory, consisting of a four phase cycle in which the learner traces all the foundations of his learning process:

- *Concrete Experience:* A new experience of a situation is faced, or a reinterpretation of an existing experience takes place.
- *Reflective Observation:* The new experience is analyzed, evaluated, and interpreted. Of particular importance are any inconsistencies between the experience and the understanding of it.
- *Abstract Conceptualization:* Reflection gives rise to a new idea, or a modification of an existing abstract concept.
- *Active Experimentation:* Transforming the new abstract concept into operation, the learner interacts with the world around him to check what emerges.

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 [12] 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 [26], [27], [28], [29], [30].

Engineers, who embody the creative inventors and tinkerers more than any other occupation group, carry an important contribution (or even the societal responsibility) to solving current problems. However, engineering education has not been known to be particularly creative or to foster creativity [31].

III. EXPERIENTIAL 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 mainly 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 [25] or research-based learning [32]. 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 [32].

It is not by coincidence that a research process is quite similar to Kolb's learning cycle theory, beginning with an experience or a question and ending with real experiments and new research results [33].

That is why research-based or experiential learning in higher education is one adequate way of implementing learner centered teaching. In addition to that, [34] 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 [35], Bloom's revised taxonomy [36], or the thirteen fundamental objectives of laboratory learning, published and discussed by [1]. But this authentic learning environment can be offered by teaching and learning activities in laboratories where students can face the context of real professional activities. By connecting the actions in laboratories in a next step with real problems – e.g. in current research or the industry – students are able to go the whole way from the question at the beginning of an experiment to the final use of the results which makes them see the relevance of their work. This process requires reflective thinking and independent learning which obviously differ significantly from classical lecture-based courses [37].

Using tele-operated experiments and virtual laboratories gives a whole range of opportunities to implement experiential learning into teaching in the field of Higher Engineering Education. Just one example is its additional use next to normal lectures about forming technology. While students discuss basic aspects of material behavior relevant for forming processes during the lecture, they can simultaneously test and experience what they have discussed by independently doing experiments with the use of tele-operated experimental equipment. Another opportunity is that students receive a real problem in the context of 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 out, and what they would suggest for solving the problem [12].

A. *Active experimentation using tele-operated equipment*

Using remote and virtual laboratories in teaching gives a whole range of opportunities to implement experiential learning into the field of mechanical engineering following the path of research based learning [12]. 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 in order to enhance traditional hands-on labs during the phase in which students prepare themselves for the lab. Moreover, the special lab concept helps students to rework some of the test steps while analyzing the data for 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 in class by doing experiments on their own. With this they construct their own knowledge using the equipment provided by the remote lab. Another opportunity will be that students have to face 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 have explored and what they would suggest for dealing with the problem [12].

In order to support this entire process and especially the step of "active experimentation", one important aspect is the integration of an appropriate level of interaction and feedback 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 innovative engineering designs, modern concepts of automation, measurement technology, and robotics, as shown in Fig. 2.

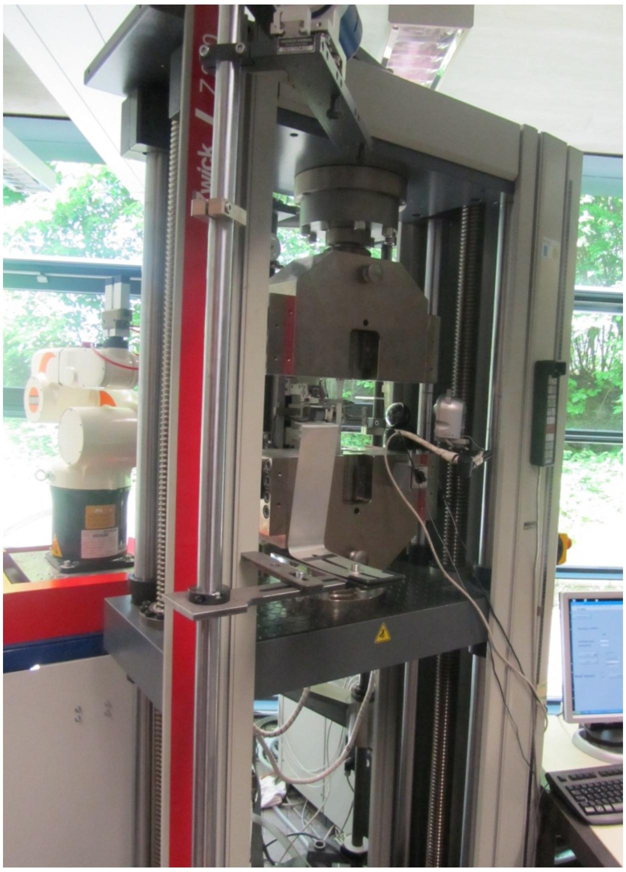

Figure 1. Automated material testing machine

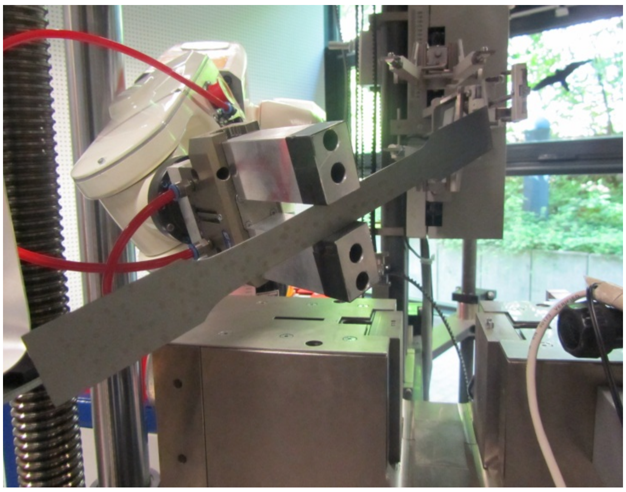

Figure 2. Robot positioning a specimen

All aspects have been connected by developing a clear, usable, and interactive real time feedback user interface of the running experiment. Fig. 3 shows the “window” of the developed graphical user interface of the uniaxial tensile test.

When using the live camera stream (1), users can investigate the surrounding test apparatus, e.g. sensors or clamping devices. Afterwards, the learner initiates the preparation of the experiment (2) by using the integrated 6-axes robot to select and check an appropriate specimen. 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. Interrupting the test causes a material reaction 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 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.

Additionally, within the learning content management system Moodle, the entire tele-operated experimental environment was made available by a developed Moodle module. 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. 4, this socio-technical alignment was put into a usable as well as flexible environment.

A challenge that is often formulated when talking about such openly designed learning concepts is that the teacher is in need of a very sophisticated concept to document and evaluate the learners’ behavior and achievements during the learning processes taking 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 [38]. The following passages present the concept draft concerning learning process documentation in the context of the combination of remote laboratories and e-portfolios.

B. Experiential Learning with E-Portfolios and Tele-operated Experiments

“ePortfolios are hardly a new idea in the fast developing field of Technology Enhanced Learning” [39]. In the following it will be explained why e-portfolios on the basis of Mahara fulfill the three main requirements in the PeTEX context [40], [41].

1) E-portfolios as a documentation of the learning process

By creating and designing their own portfolios, users get the opportunity to arrange all data and information they want to document or share with others in different orders. 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 results and thoughts to themselves and others. Furthermore, they can allow other users, like other learners and teachers, to have a look at 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 [42], [43]. This reflection is an important aspect as they need this step in their personal learning cycles. Especially for students, the e-portfolio can be an orientation and checkpoint in fields of their own research [44], [45], [46]. By the same way, teachers also can evaluate the actions of learners by 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 individually 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.

2) E-portfolios 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 community building [47], [48]. Every author of an e-portfolio is able to invite other users to look at the entire or just parts of his portfolio, and it works vice versa, too: one can be invited to see other e-portfolios. That means that learners, while conducting experiments in the PeTEX system and filling in their e-portfolios, can get into contact with each other via the portfolio software.

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. This 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 conduction of the experiment and its reflection, and lastly can share their experiences [49].

In 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.

3) E-portfolios as a bridge between 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 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 study in this field, and can 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 does not have to stop working with his portfolio. He can still work with his collection and document 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 each year it more and more turns out to be 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 letting them experience research with the PeTEX hardware. In addition to that, they can use the e-portfolios for implementing a system to document and measure skills and competences of their employees.

C. *E-portfolios as a means of mobile learning*

Another frequently mentioned new concept in context with higher education is mobile learning. Mobile learning means deploying mobile devices for the support of learning processes – like cell phones, smart phones or tablet-computers [46]. 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 virtually initiated everywhere [46]. In our context we will focus on the fact that users actually carry their mobile devices at any time and because of that they can frequently use them in order to work with their e-portfolio software and the related laboratory equipment [49].

Figure 3. Interface to the tele-operated experiment

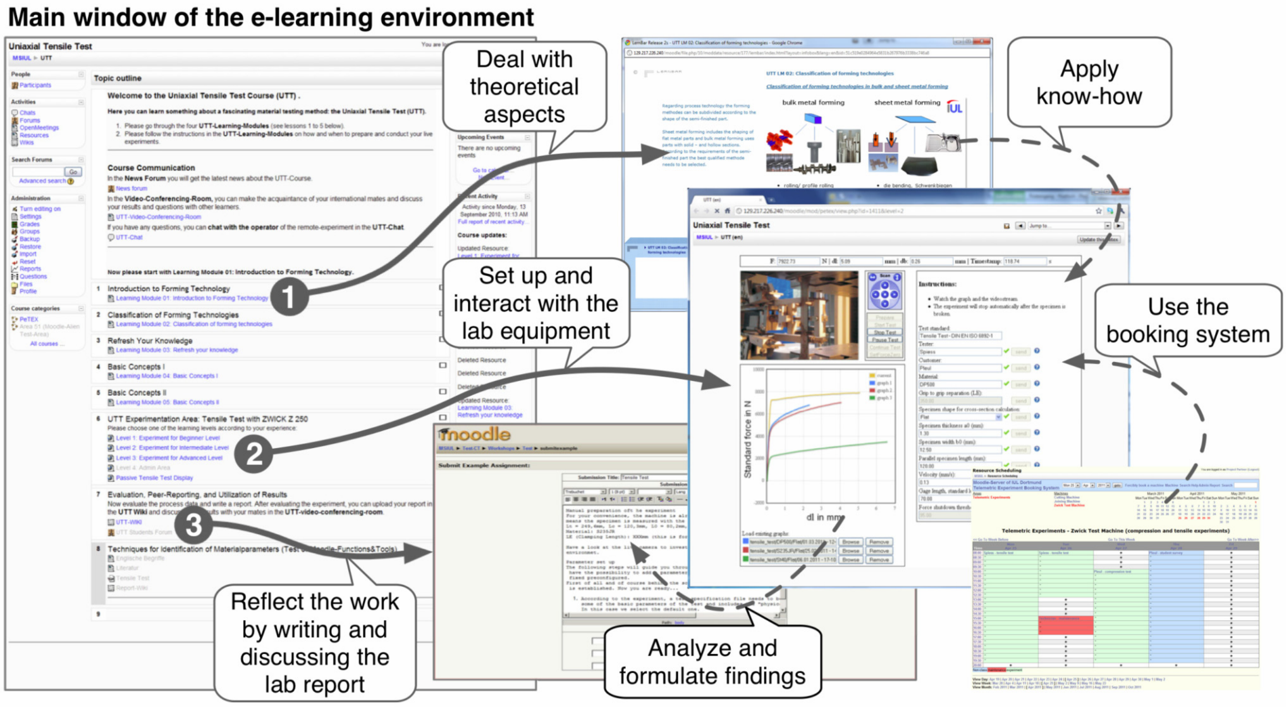

Figure 4. Experiment environment integrated to Moodle

D. *E-portfolios as a tool in creative moments*

Consider a student who thinks of his experiments while sitting at home and watching TV or while being at a boys' night out with his friends. However, he is unable to concentrate on soccer and beer because he is really 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 e-portfolio, or even by conducting a new sequel of experiments. Since he can use the software for accessing the experimenting environment via his tablet computer, he does not need to wait until the next day or week for doing the experiment at the university. He can just stay where he is and even can stay on the barstool for checking his hypothesis. He can immediately put the new results in his e-portfolio in order to document the new steps within his research process. To celebrate this new step with his friends, he can immediately order a next round of beer remembering that the student is still sitting at the bar.

A researcher from the Australian Labshare project told us during 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 had not been investigated, as well as the social situatedness of users.

IV. DISCUSSION, CONCLUSION & FUTURE WORK

With this paper we explained why the use of laboratories as a place 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 combination of personal learning environments like e-portfolios and appropriate student-centered approaches gain more and more importance in higher education. This is one essential way for students to reach the high level of learning outcomes, and hereby develop the basis of fundamental competences for their future professional and personal life, as well as attitudes like curiosity, agency, and responsibility. Furthermore, we showed the potential of our approach for fostering 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 a kind of "spirit of research" [26], [31]. This spirit is one important premise for developing original ideas. See in the following the central advantages of the presented concept:

- As the equipment of laboratories is either very expensive to provide at every university or not always available for students, the deployment of remote and virtual laboratories is an impactful means to face this dilemma.
- The use of lab equipment as virtual simulations can help the students to do experiments just as a precheck on personal hypotheses. Using it remotely from any place they want, it can help them to conduct research 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 e-portfolios are an adequate opportunity to document experiments for 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 have learned from it.
- If the e-portfolios are not kept hidden for other students but are rather open for other users to take look at them and comment on the achievements, there is an opportunity to evolve a community for collaborative learning and working with experiments [50]. Additionally, the e-portfolio software will 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 anywhere and at any time, the user can use the lab equipment, work on his e-portfolio, and communicate with others [51].

- 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 the deployment of e-portfolios in the PeTEX context can support the idea of experiential and research-based learning – even if there are a couple of challenges to overcome [36]. The e-portfolios can be used to document and share the research results and learning processes, to build up an especially 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 to make it accessible from mobile devices. Once this will have been achieved, first tests with students can be carried out and the system can be formatively evaluated and improved.

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