Tele-operated Laboratory Experiments in Engineering Education. The Uniaxial Tensile Test for Material Characterization in Forming Technology

Christian Pleul
Institute of Forming Technology and Lightweight Construction (IUL), TU Dortmund University (Germany)
e-mail: christian.pleul@udo.edu

Claudius Terkowsky
Center for Research on Higher Education and Faculty Development, TeachING-LearnING.EU, TU Dortmund (Germany)

Isa Jahnke
Department for Applied Educational Sciences, Umeå University (Sweden)

A. Erman Tekkaya
Institute of Forming Technology and Lightweight Construction (IUL), TU Dortmund University (Germany)

1. Introduction

Engineering seen as a method consists by itself of experimentation [8]. Especially where experiments are a core element in traditional [3, 9] as well as in modern curriculums [1, 24], laboratory experimentation has been identified as a crucial part [4], particularly in engineering education [6, 7].

Especially in the field of manufacturing technology in engineering education, the apparatus for laboratory experiments are generally very expensive to buy and take up a lot of space to be used appropriately. Additionally, laboratory equipment often requires certain environmental

© University of Deusto - ISBN 978-84-9830-398-8

conditions (e.g. for material characterization) and needs maintenance at regular intervals, which adds a considerable running cost factor. Only considering the cost factor already makes this kind of resources very interesting in terms of sharing it as tele-operated equipment. But only sharing a technologically highly sophisticated and interactively usable but stand-alone tele-operated experiment does not release the entire added value possibly gained through this approach of tele-operation. Experimental facilities need to be holistically integrated into the learning process as a whole-system approach, which intends to connect theoretical learning material with the process of applying the acquired know-how to accomplish physical and real-time experiments in a tele-operated modality as part of contextualized engineering situations. Students dealing with theoretical aspects of a certain subject are therefore provided with the possibility to integrate their experimental work as seamlessly as possible. However, for several reasons, the various laboratory facilities are not always available when they should be as a meaningful as well as essential part of the learning process.

Considering the progressive development of information and communication infrastructures, the enabling technologies provide access to and control of comprehensive physical laboratory test beds. In engineering, most tele-operated experiments exist in the fields of electrical and mechanical engineering with frequent applications in electronics, robotics, automation and mechatronics [7, 8]. In terms of tele-operation and the holistic integration of tele-operated experiments in the learning process, there has been no comprehensive approach to manufacturing technology in engineering education by now. Additionally, these experiments are mostly application-oriented, which makes them highly appropriate to be holistically integrated into the learning process by use of a special customized e-learning environment.

In the project PeTEX (Platform for e-learning and Telemetric Experimentation), the team developed three tele-operated experiments in the field of manufacturing technology as outlined in Figure 1 and integrated these interactively into an e-learning environment based on a didactic conceptualization of the learning process for the development of different competences. The following explanations focus on the tele-operated uniaxial tensile test for material characterization developed at the "Institute of Forming Technology and Lightweight Construction" in cooperation with the "Center for Research on Higher Education and Faculty Development" of TU Dortmund University, Germany [19, 22].

The project "PeTEX" was made possible by funding from the European Commission and the KARL-KOLLE-Stiftung. The authors sincerely thank the entire PeTEX team for their fruitful and constructive cooperation.

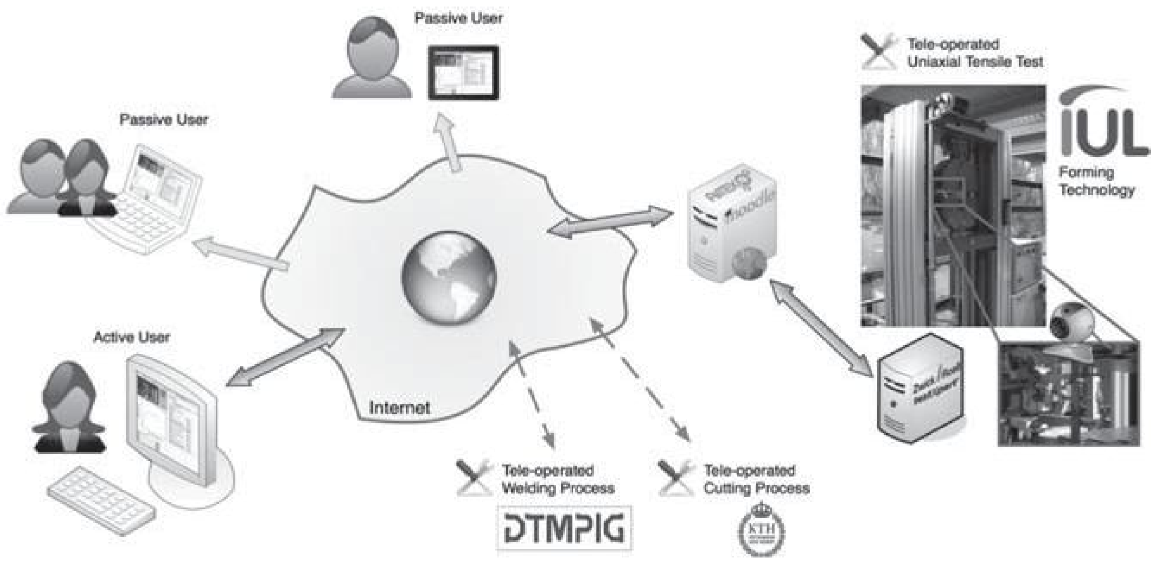

Figure 1

The principle of PeTEX shown at the uniaxial tensile test and how active and passive users are connected

2. Scenario

In PeTEX, comprehensive tele-operated experiments were developed in the field of manufacturing technology in the disciplines of forming, joining and cutting with partners from the University of Palermo, Italy and the Royal Institute of Technology, Sweden. In conjunction with the corresponding discipline, specific theoretical material for background information was integrated into a Moodle™[1] based e-learning platform, following the developed pedagogical model for experimental e-learning.

To start the journey, students as well as teachers need to log in to the customized e-learning platform Moodle™ by using a modern web browser.

Here, as an example, a student named McFly is going to login as shown in the screenshot of Figure 2.

2.1. *Students' Point of View*

The following descriptions visualize a typical "walk through" by a student using the e-learning platform for studying the basics of forming technology in conjunction with the integrated tele-operated uniaxial tensile test for material characterization in this field of manufacturing technology.

[1] Moodle™ is an Open Source Course Management System (CMS), also known as a Learning Management System (LMS) or a Virtual Learning Environment (VLE) [5].

© University of Deusto - ISBN 978-84-9830-398-8

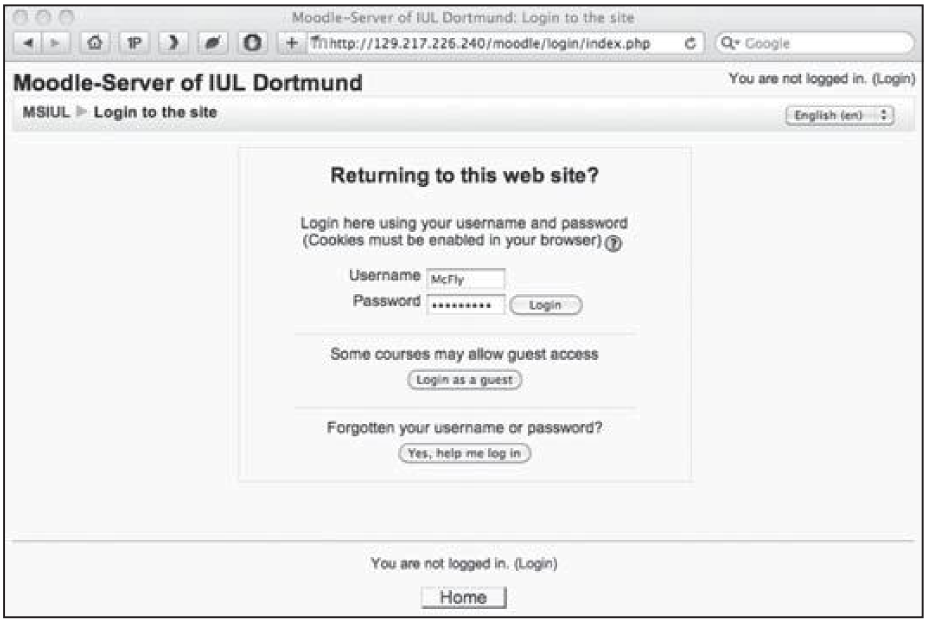

Figure 2

McFly is login to Moodle

As could be seen in the first screenshot, student McFly enters the Moodle™ platform of PeTEX. After this, he starts browsing around on the platform and checking out different subjects in different languages. Finally, McFly chooses the most interesting course for him: the uniaxial tensile test in forming technology in his preferred language – English (Figure 3).

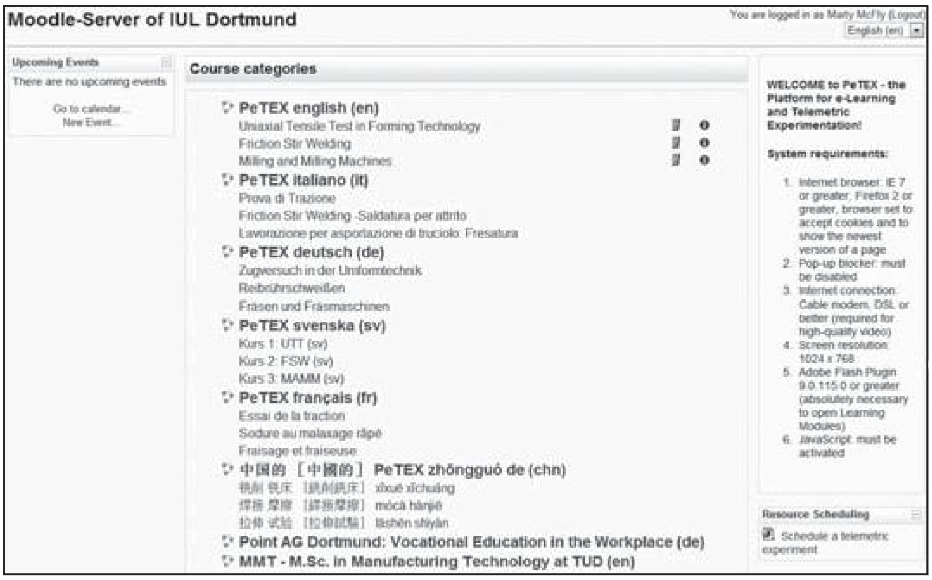

Figure 3

McFly chooses the uniaxial tensile test

At the top of the course welcome page, a short introduction on the learning levels is given, e.g. beginner, need to start with "1 Introduction to Forming Technology" and advanced students should proceed to lesson 8 dealing with a research orientated approach (Figure 4).

As the PeTEX prototype includes three different learning levels, the same was developed for the tele-operated experiment as access levels allowing different degrees of interaction for setting up a test during the whole learning process.

Additionally, different ways of communication, e.g. chat or forum, are available to the students.

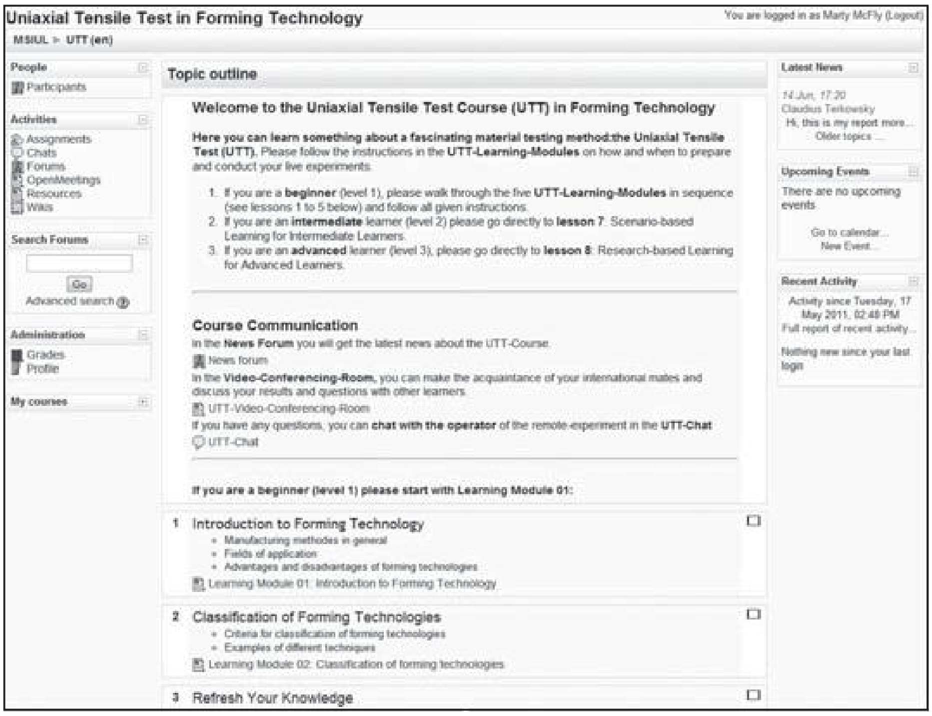

Figure 4

McFly sees the course

McFly finished the first module last time, so he decides to continue today with the second module "Classification of Forming Technologies" and walking through the modularized interactive material including self-test sections as well as video sequences of different forming processes. McFly also finds out that planning a process for forming a material does not only consist of selecting the appropriate machines but it is also important to know the behavior of the used material when it is loaded and formed to a precise shape.

One of the most important material tests is the uniaxial tensile test, e.g. for a sheet specimen. A specimen of a standardized shape is precisely loaded in axial direction and its elongation according to the applied force is logged. So, McFly is directed to the experiment (Figure 5).

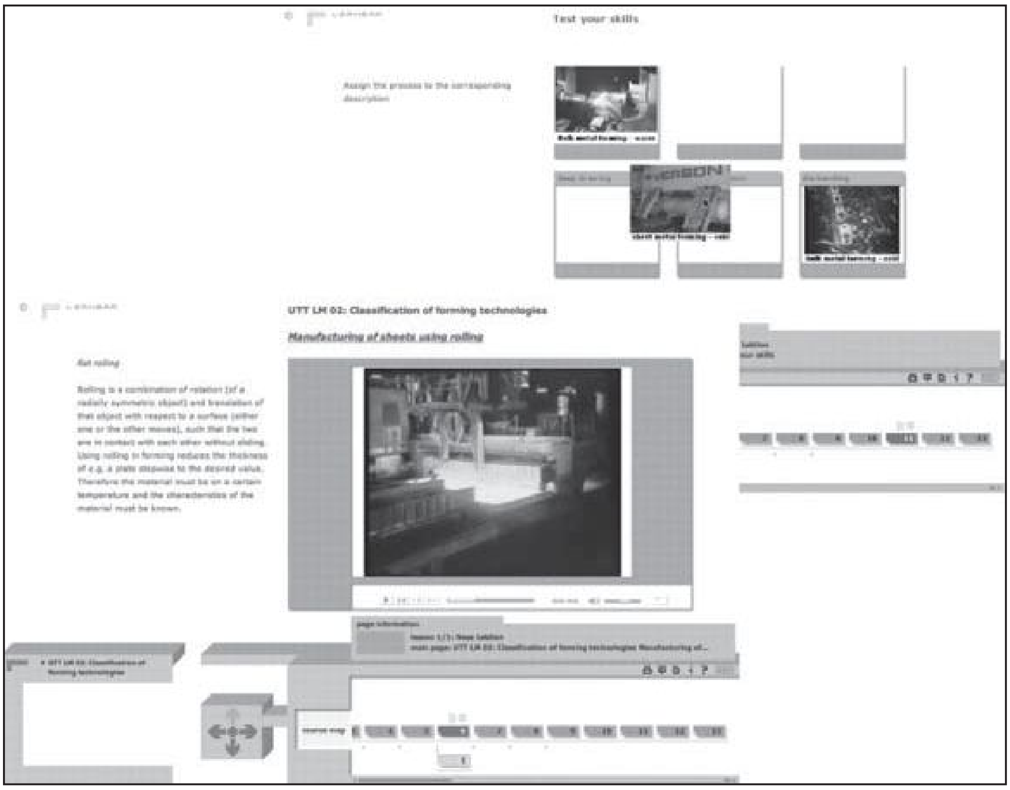

Figure 5

McFly accesses the experiment

Since McFly is still a beginner, he continues with the level 1 experiment and restricted access to test parameters. During the preparation of the tele-operated tensile test, a 6-axes robot precisely places the selected specimen uniaxial to the direction of loading of the machine. Afterwards a special device clamps the specimen automatically and the sensors to detect geometrical variations during the test are attached.

McFly now starts the test by pushing the start button. A continuously increasing force is applied to the specimen, which can be followed by a developing real-time graph. After finishing the experiment, McFly adds previous graphs in order to compare his material behavior with the one analyzed by students before him.

Finally, the platform provides McFly the test data for his own analyses. McFly now starts preparing his own preliminary lab report by using the Moodle™ integrated wiki and improving his results with his fellow users in an asynchronous mode (Figure 6).

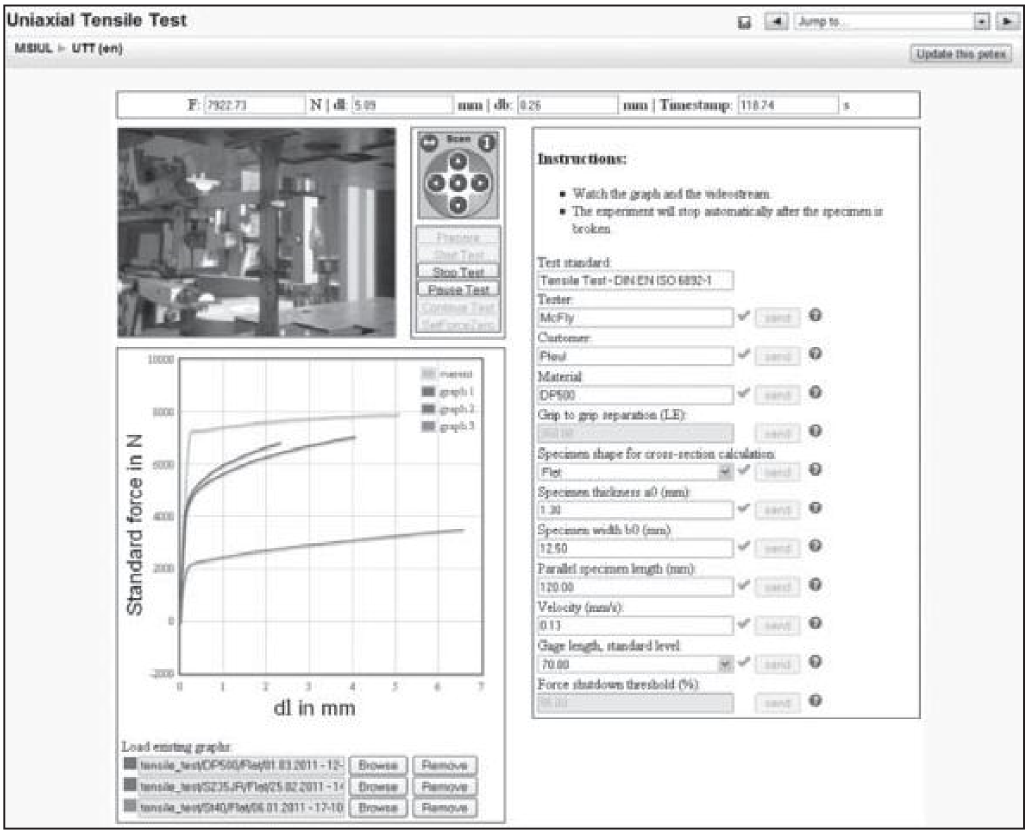

Figure 6

The experiment and data

After finalizing his report, McFly discusses it with his supervisor Mr. McTensile in real-time by using the platform integrated OpenMeetings plugin, a video-conferencing system with an additional screen-sharing function.

In Figure 7, McFly presents a photograph of selected tested specimen. He discusses his experimental investigations of variations in material behavior according to the applied forces and corresponding elongations. He explains his observations and his theoretical assumptions about the necking processes and breaking points of his series of specimen according to his previously defined research questions.

Mr. McTensile looks very satisfied and reconfirms the results of his student by giving a well-balanced motivating positive and critical constructive verbal feedback accompanied by corresponding facial expression like an encouraging smile.

© University of Deusto - ISBN 978-84-9830-398-8

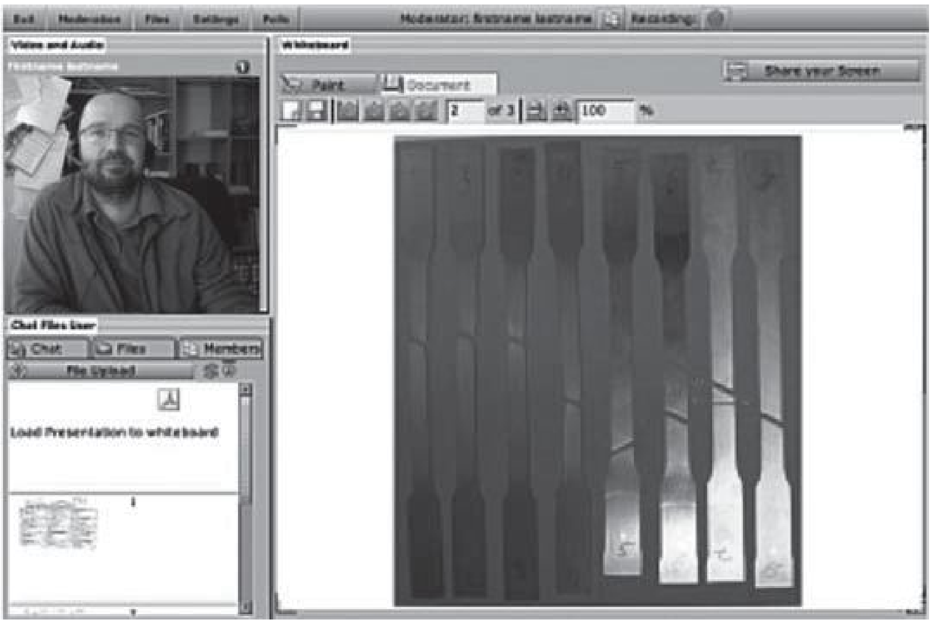

Figure 7

McFly asks McTensile about the experiment with a photograph of it

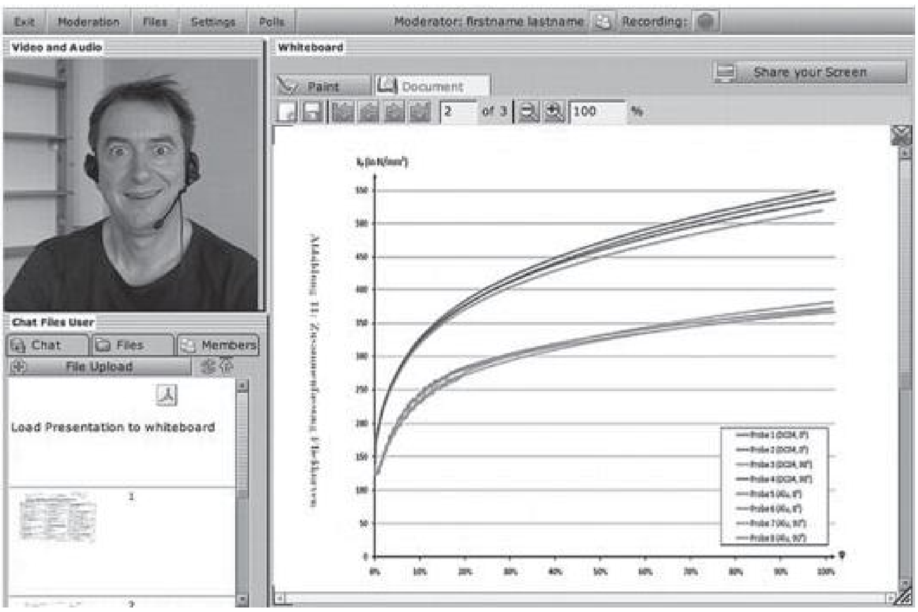

Figure 8

McFly is happy with the feedback received from McTensile

As one can see in Figure 8, McFly's tenseness immediately dissolved after receiving the very optimistic feedback from his supervisor: Now, McFly has a feeling of achievement. After the discussion of his results, McFly improves his report according to the remarks of his supervisor as soon as possible and uploads his final version in the uploading section of the learning platform for final review.

As a typical workplace learner, he needs – and likes – learning with remote labs very much. Since he works with a manufacturing engineering company engaged in a highly competitive global market, he depends very much on flexible and comprehensive education facilities to complete his extra-occupational master program during more and more extending office hours.

2.2. *Teachers' Point of View*

As a teacher, it should be very easy to get used to the combination of Moodle™ and LernBar to produce interactive e-learning content. LernBar is an e-learning course authoring tool to easily create pages and add text, graphics, and other media. It provides a page and lesson organizing framework allowing learners to navigate reliably. It gives a course designer the capability to create and establish didactical structures without the need to care about the layout or the navigation through the content [12, 17]. The implementation of LernBar in the PeTEX project makes it therefore easy for educators acting as authors to focus on creating and designing learning content and the appropriate integration of tele-operated experiments. In order to allow an appropriate learning media design, LernBar consists of several components that support a course developer: LernBar studio is the course developer environment providing page and navigation design presets, a story board template for the rapid design of interactive content pages as well as designing test and assessment activities pages, style templates which emulate all design presets of LernBar studio for quick page design, and LernBar player to play the courses.

To support the learner's cognitive attention to the learning modules and to support a successful uninterrupted e-learning process, it is necessary to produce learning modules of an appropriate duration, not longer than 20-25 minutes. Time consuming sessions will cause McFly to skip his concentrated engagement and will make him switch to his favorite soccer blog.

To prepare an appropriate balance of all content elements and related organizational issues, the didactic team figured out a diagrammatic framework to design learning modules as sequences or strips of content and activity pages according to the LernBar page presets.

Deploy the diagramatic framework to adapt your original learning content to e-learning facilitates a sequence of two or three learning bars

© University of Deusto - ISBN 978-84-9830-398-8

in each learning module, each consisting of 2 or 3 *entry pages*, giving basic information about the title and the learning objectives of the module, 1 or 2 *entry activity pages* to activate the learner with some opening questions, 5 to 10 *interactive pages* presenting the actual learning content, and not more than 2-3 *additional pages* to give sideline information, 2 to 5 *final activity pages* to ask the learner review questions testing to what extent he has understood the content. Each module should not consist of more than 2 or max. 3 *bars*, each bar not longer than 5 to 7 minutes duration (see Figure 9).

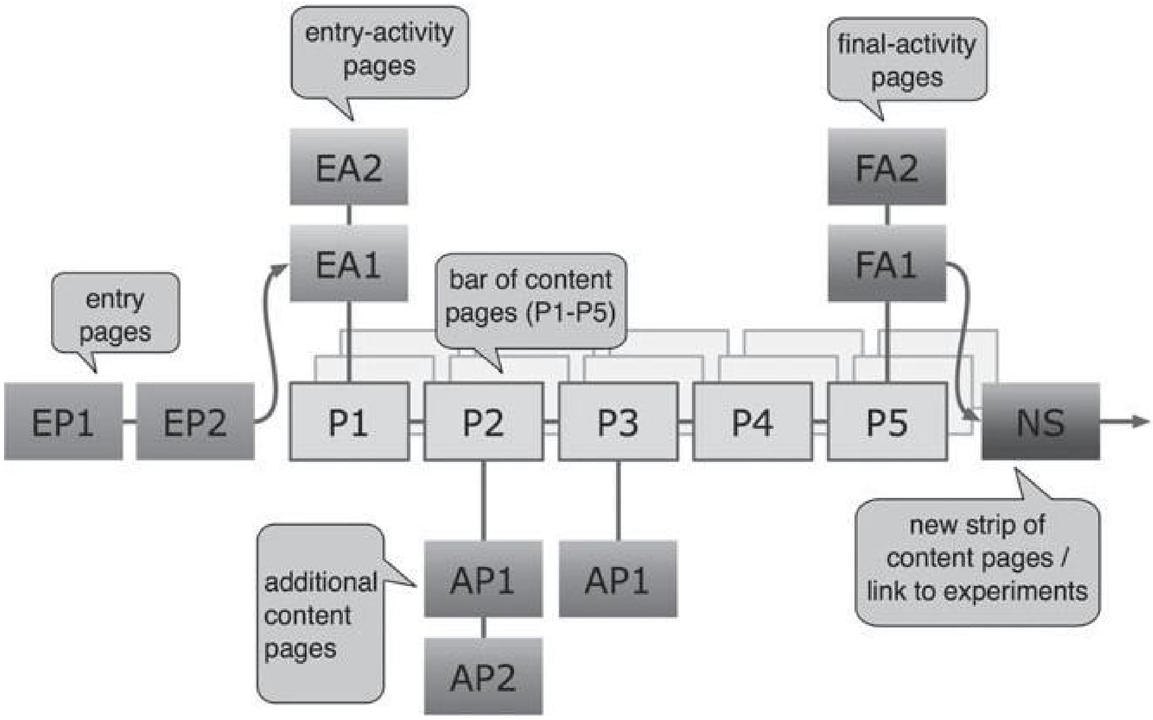

Figure 9

Diagramatic Framework

For a further adaption of the learning content to the LernBar page presets, it is advisable to apply the style templates and the storyboard templates, both based on MS Word. The LernBar style templates, which give an overview of all design presets of LernBar studio, outline the limits of amounts of plain text characters, marginal notes, captions, image sizes and or media sizes according to the used style and according to the outline of the overall page. It is necessary to decide which page design should be the appropriate one to present the content (see Figure 10).

Style Sheet:	1F_4	1F_5
plaintext:	ca. 1680 characters	ca. 1680 characters
marginal notes:	--	--
size of image: (with caption)	264 x 288 px	264 x 288 px
caption:	ca. 100 characters	ca. 100 characters
size of image: (without caption)	264 x 342 px	264 x 342 px
media bar available:	yes	yes

Figure 10

LernBar style templates

To create a storyboard, LernBar provides templates as predesigned MS Word pages to develop a course. The design of every LernBar page, that means amount of letters in plain text, marginal notes and caption, number and size of images etc., can be defined and evaluated within the sheets.

Furthermore, all necessary organizational issues like page numbering and order, headlines, sub-headlines, media integration and multi-lingual spell checking can be managed with the storyboard templates (see Figure 11).

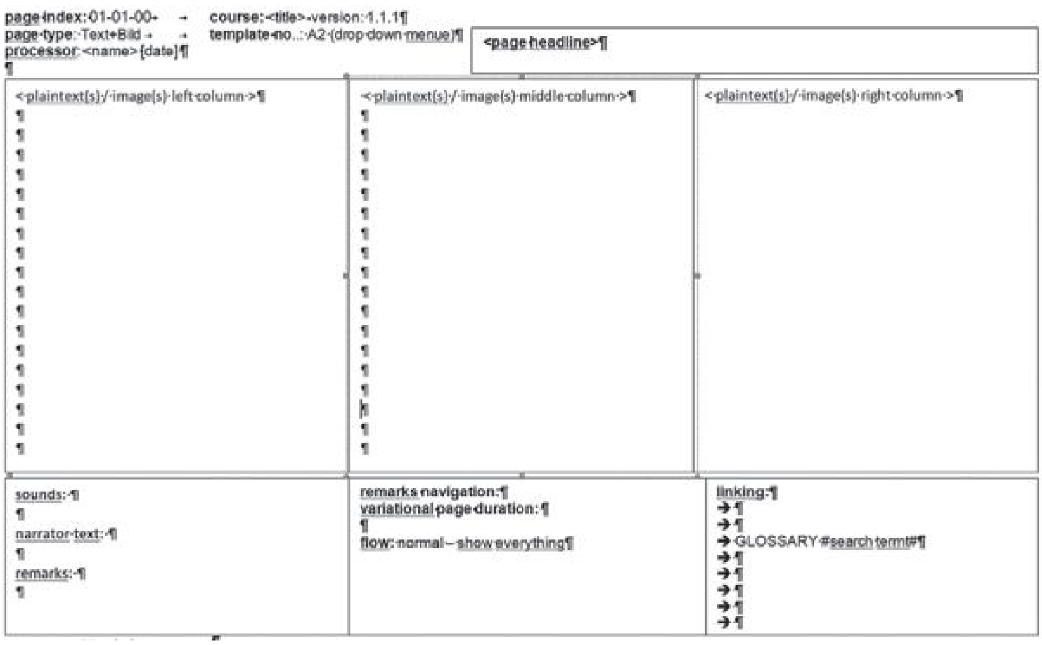

Figure 11

LernBar storyboard template

© University of Deusto - ISBN 978-84-9830-398-8

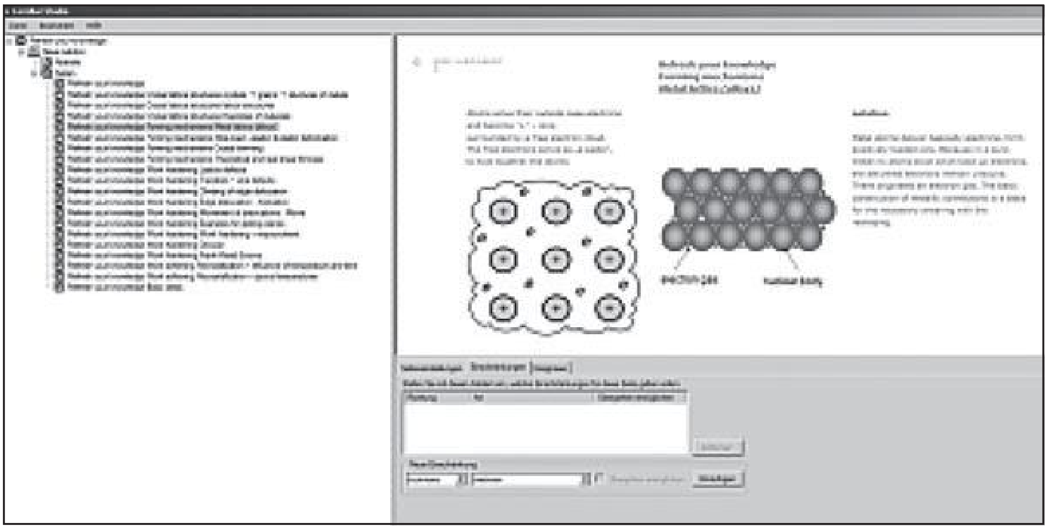

Figure 12

Using LernBar player

Once all text and multimedia content elements are well prepared and all page elements are correctly predesigned with the templates and guidelines provided by LernBar, they are ready to be mounted with the LernBar studio environment into a complete course.

The LernBar studio window shows the page sequence on the left and the actual page editor on the right.

Above in section 2.1, a drag and drop test and a video sequence integrated in LernBar studio is shown and can be presented to the learner with the LernBar player (see Figure 12).

One didactic design principle is that the experimentation activities should be the core of the learning activities. For that purpose, experimentation activities are integrated into the sequenced content pages: e.g. the LernBar page on the right side is integrated in a course and it is part of a sequence of different experimentation activities which increase in complexity. It gives the instruction to jump back into the experimentation area inside the Moodle™ environment and gives detailed information about test stand settings. Various links referring to different experiment levels and different levels of learning achievements are incorporated (see Figure 13).

3. Technical & Didactical Background

The fundamental concept of the environment design is the holistic integration of tele-operated experiments into a didactical framework. Therefore, in the PeTEX project, the development of the technical and

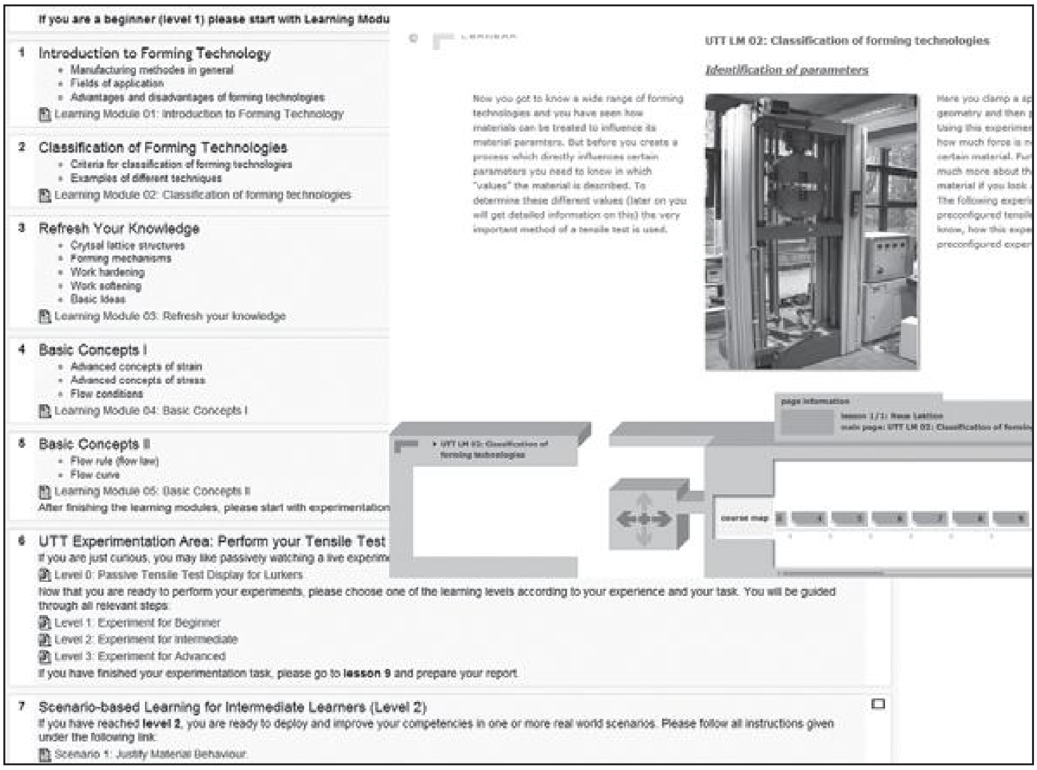

Figure 13

Moodle page of the course

didactical conceptualization was fundamentally tied to each other and based on the hands-on experiment of a uniaxial tensile test as performed by students during their studies of forming technology. All of the used physical experiments have therefore been extensively adapted and expanded for their use as tele-operated test stands, consisting of specifically developed technologies regarding automation and the overall handling of the entire process. Students can therefore focus entirely on subject-related issues, such as material behavior and process phenomena.

According to the structured approach and complex procedure of carrying out a precise uniaxial tensile test as hands-on experiment from *test preparation* and *set-up* to the *test procedure* itself as well as the *test examination* and *data analysis*, the following key sequences have been identified to be used with the tele-operated experiment within the learning process:

1. get a picture of the experimental apparatus by visually investigating the environment,
2. load the machine, i.e. align and clamp the specimen,
3. set-up the experiment using relevant geometrical values of the used specimen,

© University of Deusto - ISBN 978-84-9830-398-8

4. interact with the experimental set-up by starting, pausing and finishing the experiment,
5. visually follow the experiment and the real-time data as well as the developing, graphically displayed, material behavior, and
6. get and analyze the test data produced during the experiment.

Aspects 1 and 3-6 are directly considered within the software development process, while aspect 2 is mainly related to sophisticated engineering design, robotics, and automation. The combination of these aspects provides the learner with an interface to interact comprehensively with tele-operated physical experiments for material characterization holistically integrated in an e-learning platform. This provides the learner the possibility to study the phenomena of material behavior in conjunction with the procedure of performing an entire experiment according to engineering rules.

For the e-learning environment, a customized installation of the learning management system Moodle™ was chosen. The system was enhanced to provide the interactive interface to the experiments to the user in conjunction with the theoretical learning material referring to the subjects at different levels. In accordance with the different learning levels, the experiments have been holistically integrated with correspondingly varying degrees of interaction and elaborateness. Figure 14 shows how all the developed pieces work together.

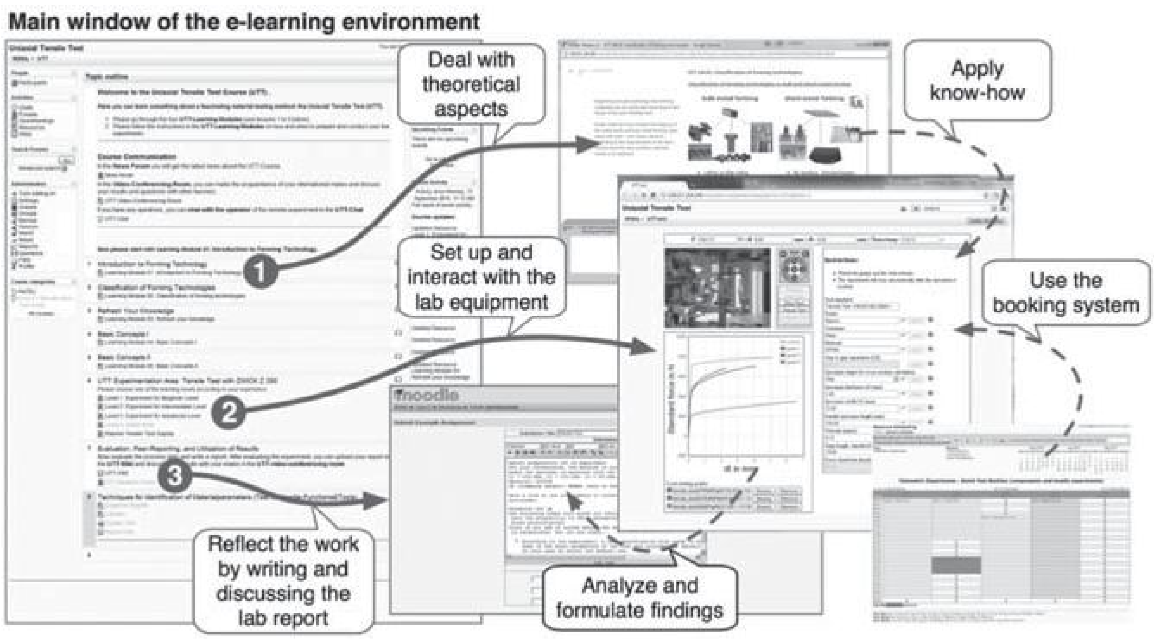

Figure 14

Pieces of PeTEX and how they work together

© University of Deusto - ISBN 978-84-9830-398-8

3.1. *Technical Background*

Technically, the PeTEX prototype as shown in Figure 15 consists of two parts: one is related to information and communication technology (ICT) and the one to mechanical engineering including design, automation and robotics. For the latter, a flexible workstation for the 6-axes robot has been designed and manufactured (see Figure 16). This unit includes the entire robot control, the precise positioning system for the robot and the control of the automated clamping units as shown in Figure 17.

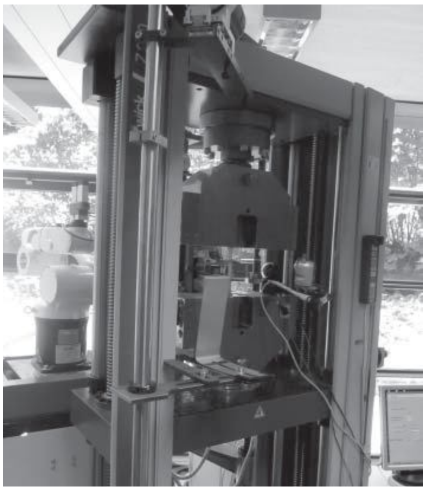

Figure 15

PeTEX test stand for tele-operated material characterization

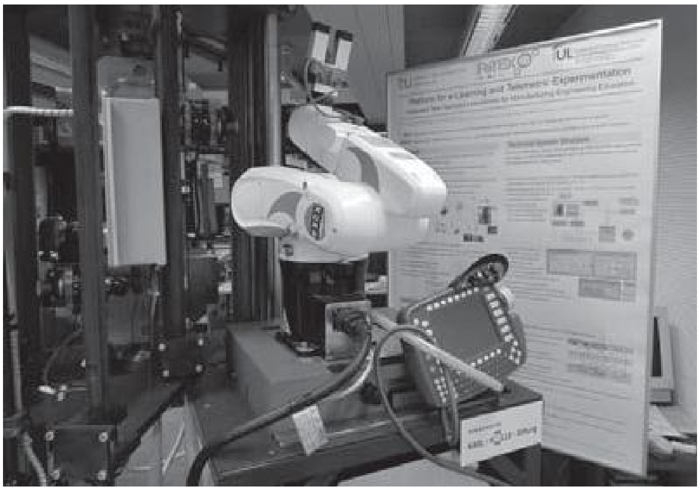

Figure 16

Self developed flexible work station for 6-axes robot used for automated set-up of the experiment

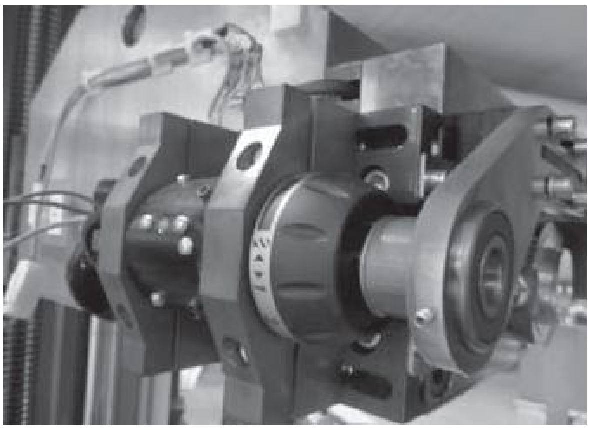

Figure 17

Self developed automated clamping unit (force and distance controlled)

© University of Deusto - ISBN 978-84-9830-398-8

For the application of the mainly hand-operated equipment as sophisticated tele-operated experiments, the procedure in the PeTEX project started with the conceptualization of the layout for data communication which was followed by the transfer into an appropriate IT structure. The layout for data communication shown in Figure 18 illustrates that the experiment (1) is controlled via a control PC (2), which is again connected to the PeTEX server (5) including the customized Moodle™ environment. The active user (6) – known as McFly from above – is able to control the experiment and the camera (3) to follow it. Passive users (7) are able to watch the experiment.

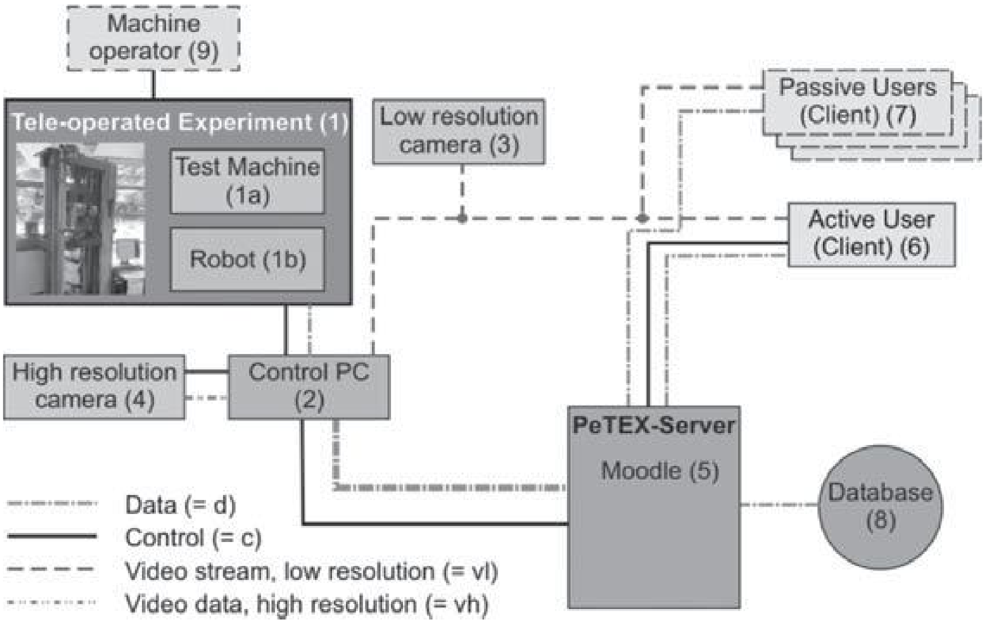

Figure 18

Layout for data communication in PeTEX

Once the system for data communication has been laid out, it is transferred to an architecture based on a client- and server-side concept. Since the test machine is controlled by the control PC including the testing software, which provides the basic test configurations and the machine control system, this software has been extended for remote access and automated internal processes for real-time test data and experiment data delivery. The developed web service is based on a strict object-oriented schema and modularized structure, which makes it flexible and able to be integrated into a wider infrastructure of tele-operated experiments. As the web service could be understood as the "control center" of the experiment, the entire coordination of the involved components, including the test software as well as the robot, is done by this service.

The client side is based on a modern PHP and JavaScript file structure and the user is provided with real-time data of the running experiment. Taking into account the aspect of security again and a flexible integration into a learning platform, a set of configurable access levels have been developed. Using these levels, the degree of influence by the user can be directly restricted to a certain range of interaction. If the user accesses the experiment for instance at an early stage of the created learning path, the possible interaction with the experiment interface is limited to e.g. start, pause and stop the procedure. When the learner continues through the theoretical material and has already carried out some of the more restricted experiments, a more flexible set-up of the test stand is provided.

3.2. *Didactical Background*

A "new balance" between teaching and learning processes is essential to support creativity and best learning effects. This point of view promotes a re-orchestration of teaching and learning arrangements. Learning processes have to be regarded from the viewpoint of the learners [2].

An interactive experimental online-environment facilitates the analysis of experimental results. This requires a process accompanying theoretical and experimental learning tasks as well as the development of appropriate learning tools with a module-oriented layout. In the PeTEX project, learning has been defined and implemented as competence developing tasks. The acquisition of competences can be achieved by distinguishing and pedagogically structuring the learning environment into knowledge-oriented, skill-oriented, and performance-oriented learning outcomes [6] so that they can provide the basis for learning activities.

The development of competences has been designed as a "walk-through" activity, navigating through modularized learning objects, framing several individual and cooperative reading, performance and learning activities.

Figure 19 shows the whole socio-technical media structure of the various modularized activities in the learning environment: a learner "walks" through these modularized learning activities, exploring research questions, conducting tele-operated experiments, finding answers, making interpretations (discovery learning), and, finally, discussing results with peers and writing a report (final assessment).

- The green bar stands for the *learning community* area, where the social software components for course communication, user-generated content, and resource sharing have been integrated, e.g. a video conferencing tool with screen-sharing functions, and the Moodle™ tools for peer reviewing, forums, blogs, wikis, chat channels, etc.

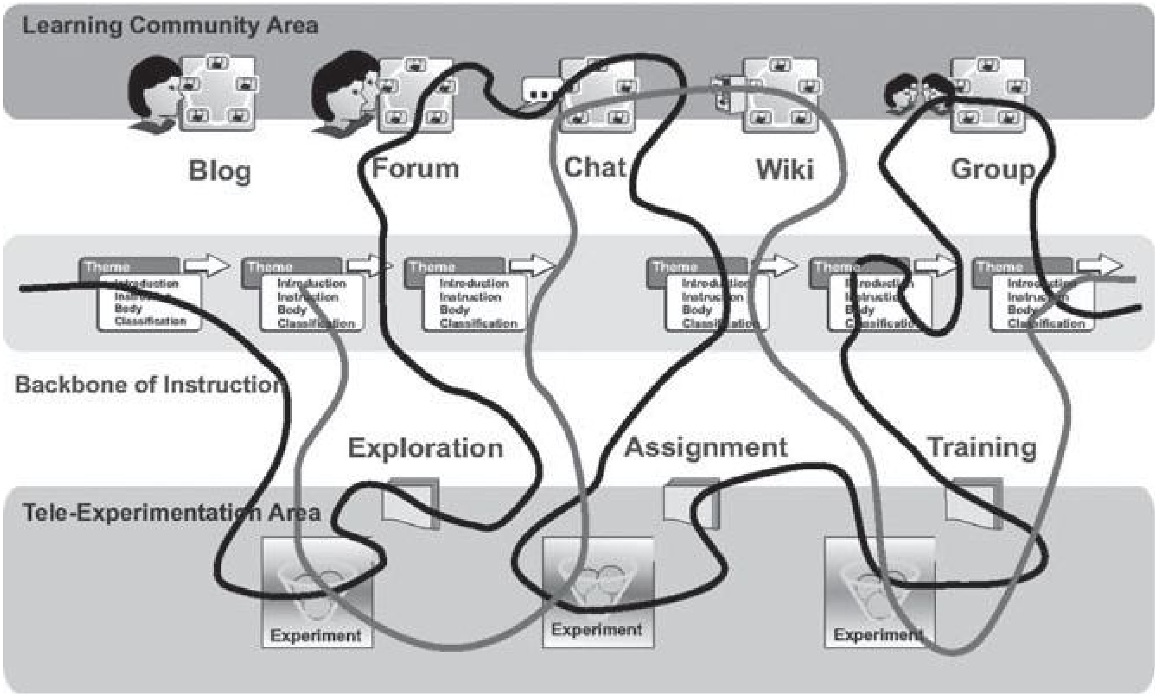

Figure 19

The socio-technical media structure in the PeTEX project

— The yellow bar represents the *backbone of instruction*, integrating the interactive learning modules. These comprise the necessary theoretical basis of the three experimental test beds.
— The blue bar stands for the three remotely accessed *experimental test set-ups*, including related interactive software interfaces.

This framework allows the configuration of walkthroughs as specific training sequences for different levels, from beginner to advanced levels. The latter, more complex self-directed exploratory- and problem-based learning walkthroughs will have comprehensive means to navigate through the entire environment with the opportunity of interacting with all learning objects and finding solutions for complex problems. The PeTEX tele-operated experimentation platform offers experimental learning on the basis of a continuous monitoring of visible material behavior and varying parameters as well as on the basis of guidance through experiments for theoretical understanding. For the current prototype stage, PeTEX has defined three consecutive learning levels during the testing phase:

1. beginner-level students will receive a specified guideline for "walking" through the learning environment, and for carrying out preconfigured experiments,

2. intermediate-level learners will solve several subject-specific real-world scenarios, applying the learning objects and experiments in a self-directed way,
3. advanced learners design their own research questions. They conceptualize a proposal and arrange it with their teacher. If he agrees, the student will have full opportunity to carry out his/her own experiments.

4. Quality

PeTEX's main objective has been to design a prototype that supports experimental planning and test set-ups including interaction, observation and measurement of data. One challenge has been to implement Internet-mediated real experiments from almost any computer workstation and to customize the didactical concept to such an online learning scenario (see technical aspects in more detail in [21]). From the perspective of an educational modeling and learning design, five elements play a central role in the development of the e-learning environment:

— design of knowledge base, instructional methodology, and experiment environment (instructional and knowledge design),
— pedagogical conception and modeling of e-learning (educational design),
— design of coaching, learning process, and learning communication (communication design),
— multi- and hypermedia conception, formats, interfaces (media-oriented design),
— concepts of scalability, extendibility, maintainability and sustainability.

Due to the project's interdisciplinary nature, researchers, educational experts, online learning experts and, in particular, the target groups – teachers and students from engineering – have been involved in the educational modeling processes by deploying *Design-Based Research* with the *e-Learning Oriented Walkthrough* method (DBR/eLOW).

4.1. *Design-Based Research (DBR)*

In recent years, the approach of Design-Based Research (DBR) has emerged [20]. Researchers, working together with educators and teachers, seek to refine theories of teaching and learning by designing, studying, and refining rich, theory-based improvements in realistic learning environments.

DBR is a "systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" [23]. DBR consists of *several* phases of analysis (reflection) and design (interventions for improving learning models). DBR in practice means to combine methods for data collection, analysis (e.g. formative evaluation) and development. Adapted from [10], the e-Learning Oriented Walkthrough method (eLOW) [14] supports such a design process in developing online learning environments. A method for development is eLOW, described below.

4.2. *e-learning Oriented Walkthrough (eLOW)*

From the domain of socio-technical systems [26] and participatory design [16] it is well known that one success factor for cultivating online groups is the engagement of future members as early as possible–in particular in the process of prototype building. According to the "Socio-Technical Walkthrough" (STWT) [11], the design of socio-technical arrangements in enterprises requires the integration of all stakeholders and target group members. Thus, the main aspect of its adaption to online learning as eLOW is to organize modeling workshops together with people from the target group (for whom the online platform will be developed); in PeTEX, engineering teachers and students are focused. In these meetings, eLOW supports a group discussion that is connected with the development of a graphical model: teachers and students *walk*–together–*through* the learning processes, trying to anticipate how future learners will make use of the application. The walkthrough is guided by specific questions, for example "What is attractive online learning with tele-operated labs? How does it look like?" Each answer during the discussion has to be visualized by deploying a *software* system for *graphical modeling*. The group discussions during the workshops are the basis for designing a model for online learning within a specific context and implementing a prototype guided by the model.

DBR/eLOW in practice means combining methods for design as well as data collection and analysis. In the phase of analysis, formative evaluation was used to investigate the learning model.

4.3. *DBR/eLOW as formative evaluation*

Formative evaluation is a type of evaluation with the purpose of continuous improvement of something [25]. In the case of PeTEX, seven meetings for data collection, analysis, and development in different social modes were

© University of Deusto - ISBN 978-84-9830-398-8

conducted. Hence, PeTEX has involved intended future learners and facilitators from university as well as from companies in the development of the prototype. The members, teachers and students *walked through* the model while anticipating what possible learners would do in the future. The target groups discussed experimental learning processes, simultaneously designed and co-constructed the model and evaluated it. The collection of qualitative data took place in group discussions which were recorded by audio and video. Notes were taken by an observer and later analyzed using open coding [13]. This procedure was guided by specific questions, e.g. "What is attractive online learning with remote labs? What does it look like?".

The qualitative feedback from the first-year evaluation meetings was very positive in general. The participants confirmed the "attractiveness" of the educational model. See [15] for a detailed discussion of data collection, open coding for qualitative analysis, and dissemination of results with regard to tele-operated experimentation design, social design, technical design, and educational design, especially learning modules.

From the two-year research-based design process (including modeling, development and implementation), the socio-technical-educational prototype has been constructed and evaluated.

4.4. *Usability Test & Thinking Aloud Method (TAM)*

In June 2010, formative evaluation workshops were conducted at each of the three test bed locations as usability testing, deploying workplace studies with the qualitative *Thinking Aloud Method* (TAM), and quantitative questionnaires. A positive result is that the prototype can be used almost intuitively. This was shown by the evaluation results with the TAM including video records and screen-recordings (conducted in project month 19 with students). Regarding the technical system, social processes and the educational-pedagogical concept, the current stage of development can be resumed as follows:

- The student's evaluation showed that going through the learning modules (developed with the LernBar) took much more time than estimated. Actually, the team constructed PeTEX model provided a framework for each module with a maximum of 15 to 20 minutes. The teachers got a template and developed 5 to 6 lessons per online course. However, the evaluation showed that the students needed more time than planned. So, the modules have been re-structured to smaller units.
- In particular, the balance of teaching input and learning activities requires a re-organization. One results of the first external expert

evaluation (in month 6 of the project) was that every 5-7 minutes of passive reading or listening an active task is important to motivate the learners. Otherwise, it could be too boring for the learners. But in fact, the practical implementation needs to be improved. This evaluation result shows clearly that it is not that easy to break or overcome common knowledge- and content-oriented teaching practices by simply agreeing on design guidelines.

— The evaluation showed that students overestimated the attractiveness of experiments. The word "experiment" promotes different expectations and learners expect different things (which can cause problems regarding the learner's motivation). In particular, students need an understanding and a clearer idea of what "experimental learning" is, and what possibilities as well as expectations (by teachers) are connected with PeTEX.

5. Get in Touch

The PeTEX prototype described is available over the Internet and can be accessed using a modern web browser. Although the initial European project was successfully finished in November 2010, the prototype is continuously under development and included in ongoing research projects by the team of TU Dortmund University. Therefore, the system administrators can grant access to the PeTEX platform on request. To do so, an email should be sent to the corresponding author Mr. Christian Pleul (christian.pleul@udo.edu).

6. Conclusion & Prospect

The described scenario shows an innovative and unique approach to connect tele-operated, physical laboratory experiments with modern applied concepts in didactics to construct an interactive e-learning environment based on the development of competences for engineering education in the field of manufacturing technology. Laboratory experiments in general provide the student the environment for practical and experimental work so that processes and phenomena can be directly experienced and investigated by applying theoretical knowledge. In view of the manually complicated set-up of a precise uniaxial tensile test for material characterization, the procedure was entirely automated for the interactive tele-operated use of the entire facility.

Based on the research results, the following findings are formulated:

— The stage of the conceptualization of the e-learning platform should include considerations for supporting learner-centered learning and methods to clarify what technical and social design issues for a learning scenario like PeTEX laboratory didactics are needed.
— A tele-operated experiment should consist of previously defined key sequences based on the underlying hands-on experiment.
— In turn, the key sequences should support the defined learning objectives.
— For further developments, the reduction of complexity of the human-machine interface to intuitively and effectively control the tele-operated test stands should be a core target.
— The providing platform should support the customization of that environment by the user itself.
— Furthermore, "learning stops" can be integrated. These stops can be used as a call for reflecting the learning progress (e.g. questions like "Please, tell me what did you learn regarding the history of UTT" or "What methods are appropriate when you want to test a lightweight car for solar energy?"). In addition, an ePortfolio system could support these learning stops, since it collects all learning stops in one folder.

Finally, it is suggested to start moving away from the perception of just providing sophisticated but stand-alone tele-operated laboratory experiments and proceed more into the direction of implementing the state of the art of such facilities which need to be holistically integrated into the (e-)learning process as prototypically done in PeTEX.

Tele-operated laboratory experiments provide the possibility to operate physical apparatus in real laboratories to produce feasible results, which are unpredictable in detail and therefore always unique. Such test beds offer valuable resource sharing, the opportunity of further integrated laboratories and fosters experimental laboratory learning. It furthermore highlights the need for an innovative learning-object-orientated approach in technologically extended laboratories in engineering education as done with the comprehensive holistic approach as carried out in the PeTEX project, which is unrivaled in this field of manufacturing technology.

Bibliography

[1] ASIIN. *1 FA Maschinenbau/Verfahrenstechnik: Fachspezifische ergänzende Hinweise zur Akkreditierung*. ASIIN, Oktober 2010.
[2] R. B. Barr and J. Tagg. "From teaching to learning - a new paradigm for undergraduate education". *Change*, 27(6):12–25, 1995.

[3] H.-G. Bruchmüller and A. Haug. *Labordidaktik für Hochschulen – Eine Einführung zum Praxisorientierten Projekt-Labor*. Leuchtturm-Verlag, 2001. Schriftenreihe report – Band 40.

[4] J. E. Corter, J. V. Nickerson, S. K. Esche, C. Chassapis, S. Im, and J. Ma. "Constructing reality: A study of remote, hands-on, and simulated laboratories". *ACM Transactions on Computer-Human Interaction*, 14(2):1-27, 2007.

[5] M. Dougiamas. "Moodle, 2011". URL http://moodle.org.

[6] L. D. Feisel and A. J. Rosa. "The role of the laboratory in undergraduate engineering education". *Journal of Engineering Education*, pp. 121-130, 2005.

[7] L. Gomes and S. Bogosyan. "Current trends in remote laboratories". *IEEE Transactions on Industrial Electronics*, 56(12):4744-4756, 2009.

[8] D. Grasso and M. D. Burkins. *Holistic Engineering Education – Beyond Technology*, chapter "Beyond Technology: The Holistic Advantage", pp. 1-10. Springer, New York, 2010.

[9] A. Haug. *Labordidaktik in der Ingenieurausbildung*. VDE-Verlag GmbH, Berlin, 1980.

[10] T. Herrmann. "Learning and teaching in socio-technical environments". In T. J. van Weert and R. K. Munro, editors, *Informatics and the Digital Society: Social, Ethical and Cognitive Issues*, SECIII 2002 – Social, Ethical and Cognitive Issues of Informatics and ICT, pp. 59-72, Boston, 2003. Kluwer Acad. Publ. published 2003.

[11] T. Herrmann, M. Hoffmann, G. Kunau, and K. U. Loser. "A modeling method for the development of groupware applications as socio-technical systems". *Behaviour & Information Technology*, 23(2):119–135, 2004.

[12] W. Horton and K. Horton. *E-Learning Tools and Technologies, a consumer's guide for trainers, teachers, educators, and instructional designers*. Wiley Publishing, Inc., Indianapolis, 2003.

[13] I. Jahnke. "Dynamics of social roles in a knowledge management community". *Computers in Human Behavior*, 26(4):533–546, 2010.

[14] I. Jahnke, C. Terkowsky, U. Dirksen, M. Heiner, J. Wildt, and A. E. Tekkaya. "Experimentierendes Lernen entwerfen – E-Learning mit Design-based Research". In N. Apostolopoulos, H. Hoffmann, V. Mansmann, and A. Schwill, editors, *E-Learning 2009 – Lernen im digitalen Zeitalter*, pp. 279-290, Münster, Berlin, 2009. Waxmann Verlag. Tagungsband der GMW 2009 in Berlin.

[15] I. Jahnke, C. Terkowsky, C. Pleul, and A. E. Tekkaya. "Online Learning with Remote-Configured Experiments". In M. Kerres, N. Ojstersek, U. Schroeder, and U. Hoppe, editors, *DeLFI 2010 – 8. Tagung der Fachgruppe E-Learning der Gesellschaft für Informatik e.V.*, pp. 265-277. Köllen Verlag, 2010.

[16] F. Kensing and J. Blomberg. "Participatory design: Issues and concerns". *Computer Supported Cooperative Work*, 7:167–185, 1998.

[17] D. Krömker. "LernBar-Portal, 2010". URL http://www.studiumdigitale.uni-frankfurt.de/et/LernBar/index.html. 23.04.2011.

[18] D. Lowe, S. Murray, E. Lindsay, and D. Liu. "Evolving remote laboratory architectures to leverage emerging Internet technologies". *IEEE Transactions on Learning Technologies*, 2:289-294, 2009.

© University of Deusto - ISBN 978-84-9830-398-8

[19] C. Pleul, C. Terkowsky, I. Jahnke, U. Dirksen, M. Heiner, J. Wildt, and A. E. Tekkaya. "Experimental e-learning – insights from the european project petex". In *Book of Abstracts: ONLINE EDUCA BERLIN 2009 – 15th International Conference on Technology Supported Learning and Training*, pp. 47-50, Berlin, 2009. ICWE GmbH.

[20] T. Reeves, J. Herrington, and R. Oliver. "Design research: A socially responsible approach to instructional technology research in higher education". *Journal of Computing in Higher Education*, 16: 97–116, 2005.

[21] C. Terkowsky, I. Jahnke, C. Pleul, R. Licari, P. Johannssen, G. Buffa, M. Heiner, L. Fratini, E. Lo Valvo, M. Nicolescu, J. Wildt, and A. E. Tekkaya. "Developing Tele-Operated Laboratories for Manufacturing Engineering Education – Platform for E-Learning and Telemetric Experimentation (PeTEX)". *International Journal of Online Engineering (iJOE),* 6:60-70, 2010. Special Issue: REV 2010.

[22] C. Terkowsky, I. Jahnke, C. Pleul, and A. E. Tekkaya. "Platform for E-Learning and Telemetric Experimentation (PeTEX) – Tele-Operated Laboratories for Production Engineering Education". In M. E. Auer, Y. Al-Zoubi, and E. Tovar, editors, *Proceedings of the 2011 IEEE Global Engineering Education Conference (EDUCON) — Learning Environments and Ecosystems in Engineering Education*, pp. 491-497, Wien, 2011. IAOE.

[23] F. Wang and M. J. Hannafin. "Design-based research and technology-enhanced learning environments". *Educational Technology Research and Development*, 53(4):5-23, 2005.

[24] M. Weiss. *Criteria for Accrediting Engineering Programs*. ABET Inc. – Engineering Accreditation Commission, Baltimore, USA, 2010.

[25] C. Weston, C. Le Maistre, L. Mcalpine, and T. Bordonaro. "The influence of participants in formative evaluation on the improvement of learning from written instructional materials". *Instructional Science*, 25(5):369-386, 1997.

[26] B. Whitworth and A. de Moor. *Handbook of Research on Socio-Technical Design and Social Networking Systems*. Information Science Reference, IGI Global, Hershey, New York, 2009.

Virtual 3D Worlds and Remote Experimentation: A Methodology Proposal Applied to Engineering Students

Roderval Marcelino
SATC/Industrial Automation, Criciúma (Brazil)
e-mail: roderval.marcelino@satc.edu.br

Juarez B. Silva
Federal University of Santa Catarina, Araranguá (Brazil)

Andre V. Fidalgo
Polytechnic of Porto, Porto (Portugal)

Lirio Schaeffer
Federal University of Rio Grande do Sul, Porto Alegre (Brazil)

João B. M. Alves
Federal University of Santa Catarina, Florianópolis (Brazil)

1. Introduction

On recent decades, the New Information and Communication Technologies (NICT) have been assuming a key role on the social representation of the academic reality. They enable transformations that occur at vertiginous speed, originating a new culture and the correct use of available NICTs is becoming the key for improved education quality. Being proficient on these technologies means anticipating the immediate future and employing them for the formative activities is quickly becoming a common practice in the teaching-learning context. Teaching and learning are no longer limited to the classroom activities and both "hands on" and remote teaching processes are being considerably modified, challenging the institutions of higher education (IHE) to find new models for new circumstances. In this context, teaching and learning are no longer solo activities and are being handled as