Tele-Operated Laboratories for Online Production Engineering Education

Platform for E-Learning and Telemetric Experimentation (PeTEX)

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***Abstract*—The development of tele-operated experimentation and its provision to distance learners opens new dimensions for experience-based scientific and engineering education, particularly where experiments are the core elements of teaching and learning. The finalized EU-funded project *PeTEX–Platform for e-Learning and Telemetric Experimentation* has developed a prototype of an e-learning platform based on the learning and content management system *Moodle* for the design and implementation of educational and training applications in the field of production engineering. The principle goal of this project was to establish individual and group oriented learning for different target groups like students and professional workers within a platform-system capable to serve a multi-lingual learning community. Hence, an educational model was designed which integrates the tele-operated experimentation platform with teaching content and learning activities in order to support a successful learning walkthrough for different target groups.**

***Index Terms*—Production engineering education; remote laboratories; interactive learning platform; online learning; socio-technical learning**

I. INTRODUCTION

In the near future, conducting tele-operated experiments in remote laboratories will more and more become every day practice in engineering education. These new lab services will offer students as well as workplace learners not yet provided with the necessary technological and scientific prerequisites new possibilities to practice *engineering online* and to learn how to practice new ways of professional and academic *online engineering* with remote equipment. A wide range of online systems for laboratory learning have been developed and designed over the last twenty years, particularly in electronics, microelectronics, control engineering and robotics [1]. However, remote "hands on" laboratories in *production* engineering education, surprisingly, have not been developed until now. Particularly in production engineering new possibilities will soon emerge for sharing highly expensive resources, like machines or a certain infrastructure with other locations, which do not dispose of these valuable specialized machineries. New forms of laboratory practices will evolve, facilitated by new developments in the intersection between Web technology, socio-technical systems, and distance education.

The goal of the EU funded project *PeTEX - Platform for E-Learning and Telemetric Experimentation* was to design and develop a prototype as proof of concept for new teaching and learning arrangements in the field of cost-intensive production engineering education, involving live experiments by way of an interactive remote access to three physical-real laboratories, and considering both the theoretical point of view and the process potential for actual industrial applications (see Fig. 1). To get an exemplary comprehension of the domain specific material processes, the portfolio of the PeTEX prototype provides experimental learning for material testing and machining capabilities in the paradigmatic production engineering fields forming, cutting, and joining [2], [3], [4]. These actual experiment set-ups are located in the three European countries of Germany, Italy, and Sweden and have been designed and developed by four partners:

- Institute of Forming Technology and Lightweight Construction (IUL), TU Dortmund University, Germany,
- Center for Research on Higher Education and Faculty Development (HDZ), TU Dortmund University, Germany,
- Department of Mechanical Technology, Production and Management Engineering (DTMPIG), University of Palermo, Italy, and
- Department of Production Engineering, Stockholm Technology University (KTH), Sweden.

Each of the three production engineering departments tackled successfully all technical developments, preparing at least one of their laboratory test beds for tele-operated remote access, and delivered all relevant teaching and learning content, while HDZ contributed to the development of the educational model, the set-up of the learning platform, the design of the web-based training courses, and moderated all collaborative designing processes during project lifetime.

II. OBJECTIVES OF TELE-OPERATED EXPERIMENTS IN PRODUCTION ENGINEERING

According to Feisl & Rosa "engineering is a practicing profession […]. The overall goal of engineering education is to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature" [5], and Pester & Auer [6] point out that "the use of laboratories is essential for the education in engineering and science related fields at a high qualitative level. Laboratories

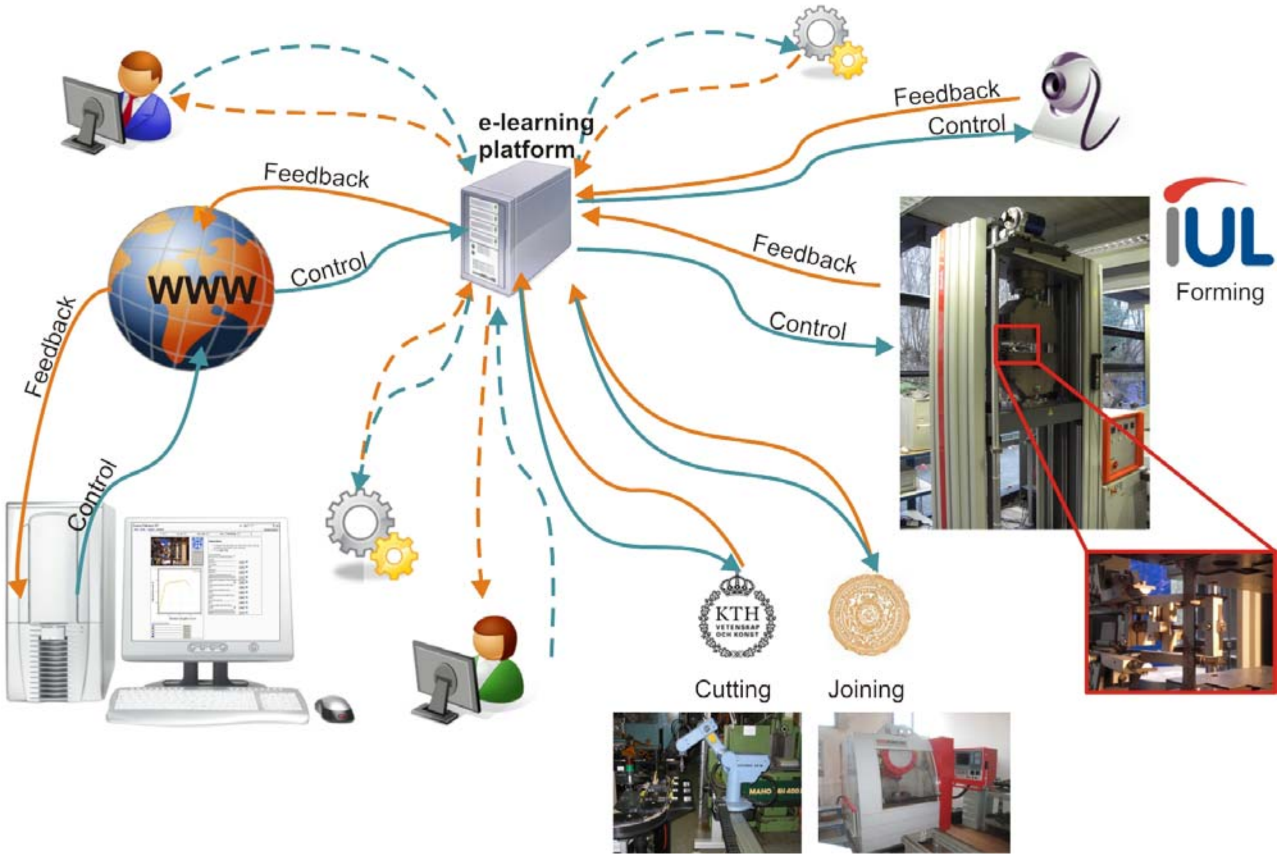

Figure 1. Principle framework of the overall PeTEX system. Tele-operated experiments like tensile test, cutting, and welding are connected with the e-learning platform by Internet. Learners can access the learning environment with the integrated experiments accessible via the e-learning platform on their computer screens.

allow the application and testing of theoretical knowledge in practical learning situations. Active working with experiments and problem solving does help learners to acquire applicable knowledge that can be used in practical situations. That is why courses in the sciences and engineering incorporate laboratory experimentation as an essential part of educating students".

An interactive experimental online-environment should facilitate the analysis of experimental results. This requires process accompanying theoretical and experimental learning tasks as well as the development of appropriate learning tools with a module-oriented layout. From the beginning, the PeTEX-team decided to put the laboratory practice into the center of their design and development strategy, considering both the theoretical foundation of laboratory work and the authentic experience of experiment-based learning activities.

During the PeTEX prototype stage, the objectives of tele-operated experiments in production engineering are to enable learners

1. to carry out material characterization tests with the uniaxial tensile test. Within the subject of forming, one of the most important tests for material characterization – the uniaxial tensile test – has been adapted for tele-operated usage (see Fig. 2).
2. to weld metal sheets using the innovative technique of friction stir welding (FSW). Furthermore, the aspect of joining has been included in the telemetric experiment for friction stir welding (FSW), a solid-state welding process. It allows students to remotely control and use a FSW tool mounted in a CNC milling machine in order to perform a number of FSW experiments and to investigate the joints via online access mode, and
3. to set up the appropriate parameters for an effective cutting process as well as to gain knowledge in advanced material and machining process monitoring and optimization.

A. Sectors to apply tele-operated experiments in manufacturing engineering

These experimentation capabilities are deployed in a great variety of academic as well as professional manufacturing engineering's fields of work, e.g.

- ground-based and advanced research,
- product development,
- manufacturing optimization,
- quality control to achieve safe, accurate and efficient materials, and
- component and structural testing.

The field of friction stir welding is a case in point. The wider diffusion of the FSW process and its specific characteristics have positive effects on the local transportation industries. Typical examples are Sicilian small and medium enterprises manufacturing nautical products. Here, joining is a crucial technology to obtain effective hybrid joints (between composite laminates and metallic blanks)

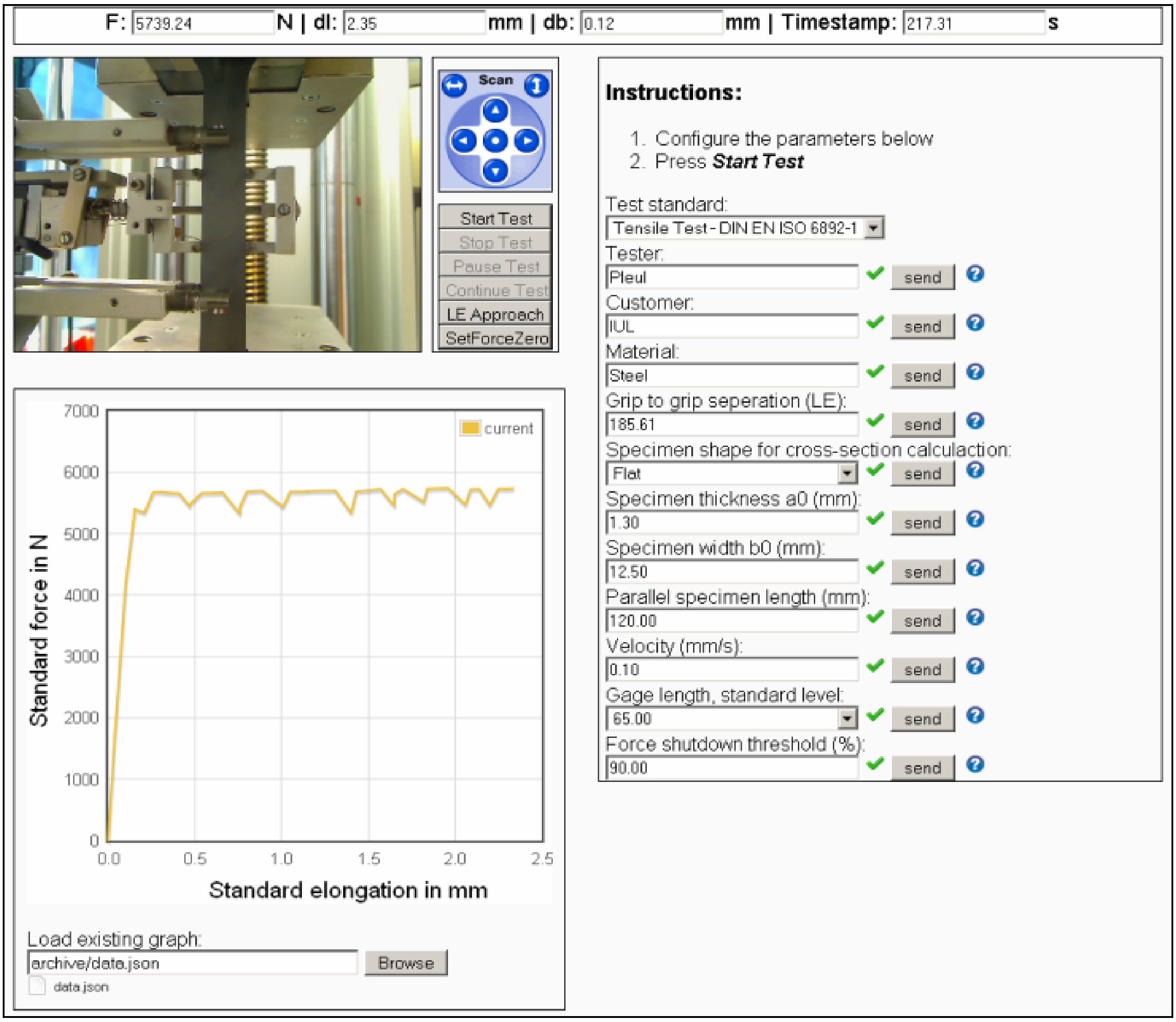

Figure 2. In-house developed interface of tele-operated tensile test: real-time values (top bar); video stream with buttons to control and interact with the experiment (upper left); set-up panel for test configuration (right); real-time diagram including access to the test archive (left)

but also between lightweight material parts. Today, we are facing a growth of the market of nautical products: on the basis of data from UCINA (Unione Nazionale Cantieri Nautici e Industrie Nautiche ed Affini) it can be stated that, as far as Italy is regarded for instance, the value registered for the Italian production of pleasure crafts for the year 2005 amounted to approx. 2.5 billion Euro, with a 9% increase over the previous year..

B. *Target Groups and Potential Impacts*

According to the *UK National Institute of Adult Continuing Education* “Workplace Learning is that learning which derives its purpose from the context of employment. It should address the needs and interests of a variety of stakeholders including employees, potential employees, employers and government” [7]. The institute points out three central aspects of the learning process:

- it enables individuals, employers, and organizations to respond to the changing nature of economic activity;
- it contributes to improved efficiency and productivity in employment;
- it meets the personal and career development needs of individuals.

An additional aspect is that

- it responds to new domain specific developments and progress.

Hence, the two main target groups of the PeTEX-learning community are students at the partner universities as potential employees and employees of the associated partners. On the basis of their technical background, the potential knowledge seekers from the manufacturing industries can be further classified into two groups (Fig. 3). The members of the first group are already technically qualified and wish to update their knowledge and skills with regard to current improvements and changes in manufacturing technologies. The members of the second group come from technical areas other than manufacturing engineering and are interested in gaining a fundamental knowledge of production science.

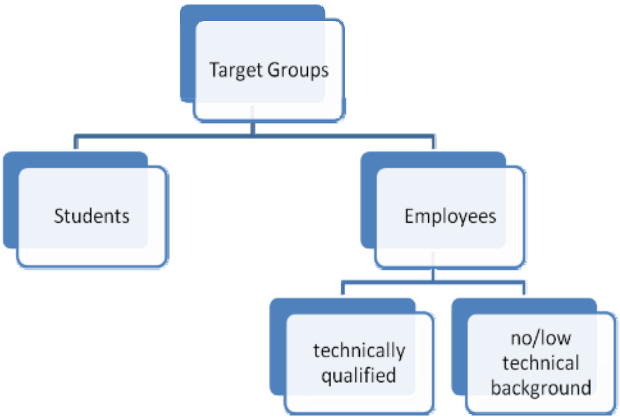

Figure 3. Proposed target groups

Considering the potential impact on, and the benefits to, the target user groups, the project aims at

- improving conditions for lifelong learning,
- acquiring specialized knowledge in manufacturing technology from different European institutions,
- increasing convergence,
- opening the educational program to different groups from industry and academia,
- facilitating intercultural exchange,
- increasing virtual mobility and new flexible forms of access to knowledge, and
- enhancing the communication and cooperation competencies.

The main advantage of PeTEX for small and medium-sized companies is the opportunity to enhance their technological skills. Moreover, telemetric experimentation will allow companies to try innovative material characterization tests without facing huge expenses (machines, fixtures, technical upgrades), and provides 24/7-access to innovative learning contents, as well as access feedback from experts and/or a wide community of users.

III. EDUCATIONAL FOUNDATION

Contemporary debates in university education focus on the "shift from teaching to learning" [8]. Concepts promoting this turn from teacher-centered teaching to student-centered learning are nothing new. They make a distinction between teaching and learning and posit that a new balance between teaching and learning is essential for supporting creativity and best learning effects. Learner-led approaches require a re-orchestration of teaching and learning preparations where learning is organized and conceptualized from the students' viewpoint.

The present paper defines learning is defined with a social constructivist approach, positing that "Learning is an active process of constructing rather than acquiring knowledge and instruction is a process of supporting that construction rather than communicating knowledge" [9]. "Individuals make sense of their own world and everything with which they come in contact by constructing their own representations or models of their experiences" [10]. Learning is not defined simply as the transmission of data from one individual to another, but as a social process whereby knowledge is co-constructed in a situation within a community of practice [11], [12]. e.g. at Internet-connected companies' workplaces and workers' or students' 'home offices'.

According to [13], "exploratory learning is an active process in which a learner (…) finds out and constructs his own meaning". Learners "… interact with the world by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments" [14]. This means learners explore something (e.g., hypotheses, ideas, and results) without a given narrow solution path. This type of learning model is demonstrated e.g., in case-based or project-based scenarios. An extended concept of this learning model is linking students' learning with research [14]. This model of 'inquiry learning' is based on exploratory learning approaches also known as discovery learning [13].

Similar to discovery learning, Kolb's "experiential learning theory" [15] covers four steps to complete a full learning cycle:

1. **concrete experiences** (being involved in a situation, doing something),
2. **active experimenting** (testing a theory by making a plan and following it),
3. r**eflective observing** (looking at an experience and thinking about it),
4. and **abstract concept-making** (forming theories about why an experience happened the way it did).

In the PeTEX project, experimental learning is defined as combined forms of discovery learning and experiential learning, leading into competence development activities. Following [4], a range of sufficient complex learning activities can be designed in order to achieve knowledge-oriented, skill-oriented, and performance-oriented learning outcomes.

IV. COMPETENCE DEVELOPMENT AS SOCIO-TECHNICAL E-LEARNING WALKTHROUGH

Instances of learning and teaching in socio-technical environments provided by the participatory design discourse suggest that new approaches should be situated in a specific context and embedded within social interactions and didactical methods [16], [17], [18]. The approach of socio-technical systems and networks provides a framework for the integration of technical, educational, and social dimensions in the design [19], [20]. Learners acquire skills by "walking" through specially designed modularized learning objects (see Fig. 4), such as instructions (domain-specific information, methods, tools, etc.), learning activities (exploring the instrumentation of the tele-operated laboratory test-stands, formulating hypothetical suggestions about material behavior, analyzing and interpreting the experiment data, writing summaries, structuring, questions, answers, etc.), and performance activities (collaboration, collection, producing glossaries, portfolio work, discussions, etc.). Fig. 4 shows the various modularized activities in the learning environment: a learner "walks" through these modularized learning activities, exploring research questions, conducting tele-operated experimentations, finding answers, making interpretations (discovery learning), and, finally, discussing results with peers and teachers and writing a report (final assessment).

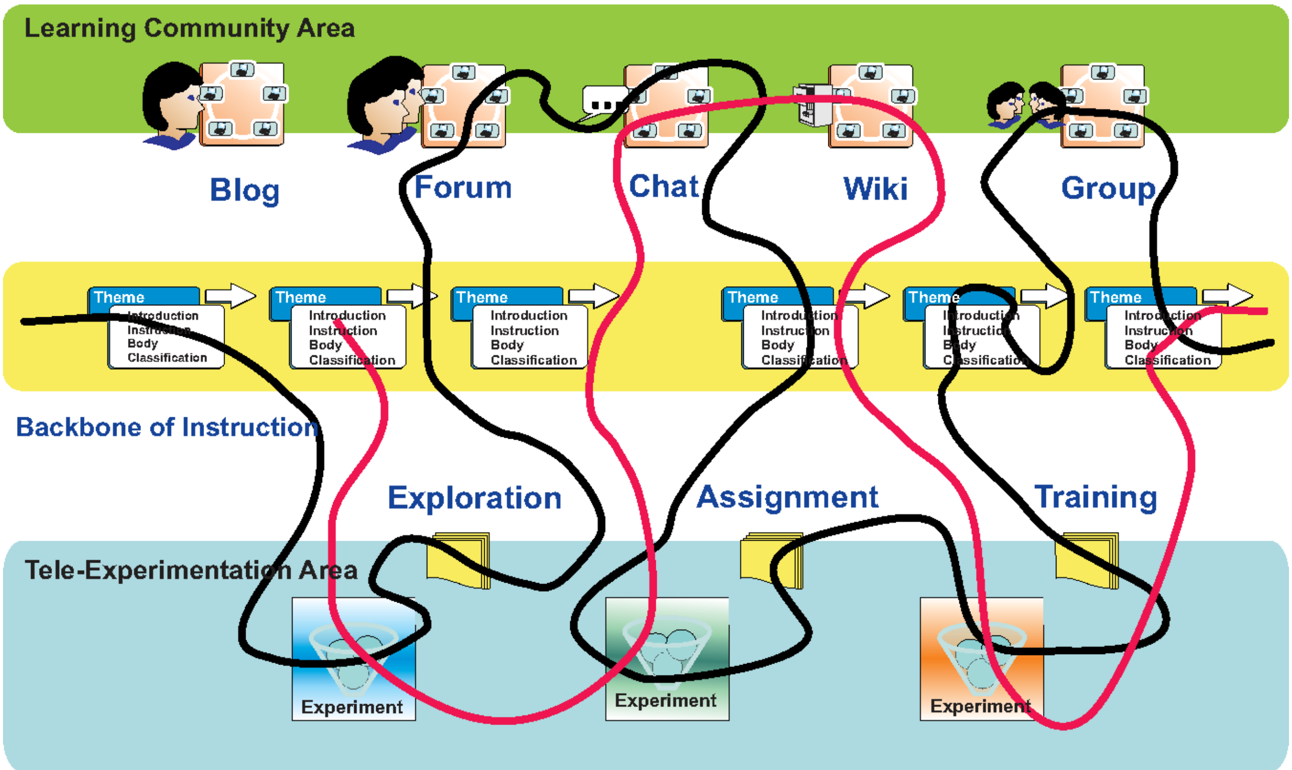

Figure 4. Experimental online learning (Screenshot PeTEX). In the background, the Moodle graphical user interface is to be seen. All PeTEX learning objects are integrated in or accessible via the Moodle-LMS

a) The green bar represents 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, forums, blogs, wikis, chat-channels, etc.

b) The yellow bar represents the *Backbone of Instruction*, integrating the interactive learning modules. These comprise the necessary theoretical foundations of the three experimental test beds.

c) The blue bar represents the three remotely accessed experimental test beds, and the related interactive software interfaces.

This framework facilitates the configuration for 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 of navigating through the entire environment, with the opportunity of interacting with all learning objects, and finding solutions for complex problems.

For the current prototype stage, PeTEX has defined three consecutive learning levels:

1. The beginner-level students will receive a specified guideline for "walking" through the learning environment, and for carrying out a predefined experiment.
2. Intermediate-level learners will have to solve a subject-specific real-world scenario, applying the learning objects and experiments in a self-directed way.
3. Advanced learners will have to design their own research questions. They will have to write a proposal and discuss it with their supervisor. After her or his agreement, learners will get full access carrying out their own experiments.

In order to increase the complexity of the learning levels it is also intended to combine the different test beds within evermore complex scenarios and research questions. Additionally, other facilitators will be provided with the opportunity to add their own learning materials and new scenarios and tasks around the experiments within the platform according to their specific contexts.

V. ONLINE ENVIRONMENT MOODLE

An interactive experimental online-environment should facilitate the analysis of experimental results. This requires theoretical and experimental learning tasks as well as the development of appropriate learning tools with a module-oriented layout. The PeTEX project-team decided to deploy Moodle ("Modular Object-Oriented Dynamic Learning Environment", available at: http://moodle.org/) as the basis for the PeTEX-system. Moodle is an online platform integrating learning objects in a highly modularized way. Hence, Moodle facilitates e-learning design for individual as well as community activities in the form of path-oriented and self-directed walkthroughs. The characteristics of Moodle are compatible with the social constructivist approach, which holds that a new balance between teacher-led instructions and learner-led construction must be achieved.

All learning-objects are integrated into, or accessible via Moodle. Fig. 5 shows the entire Moodle screen with the opened friction stir welding-course, consisting of seven lessons. The foreground shows:

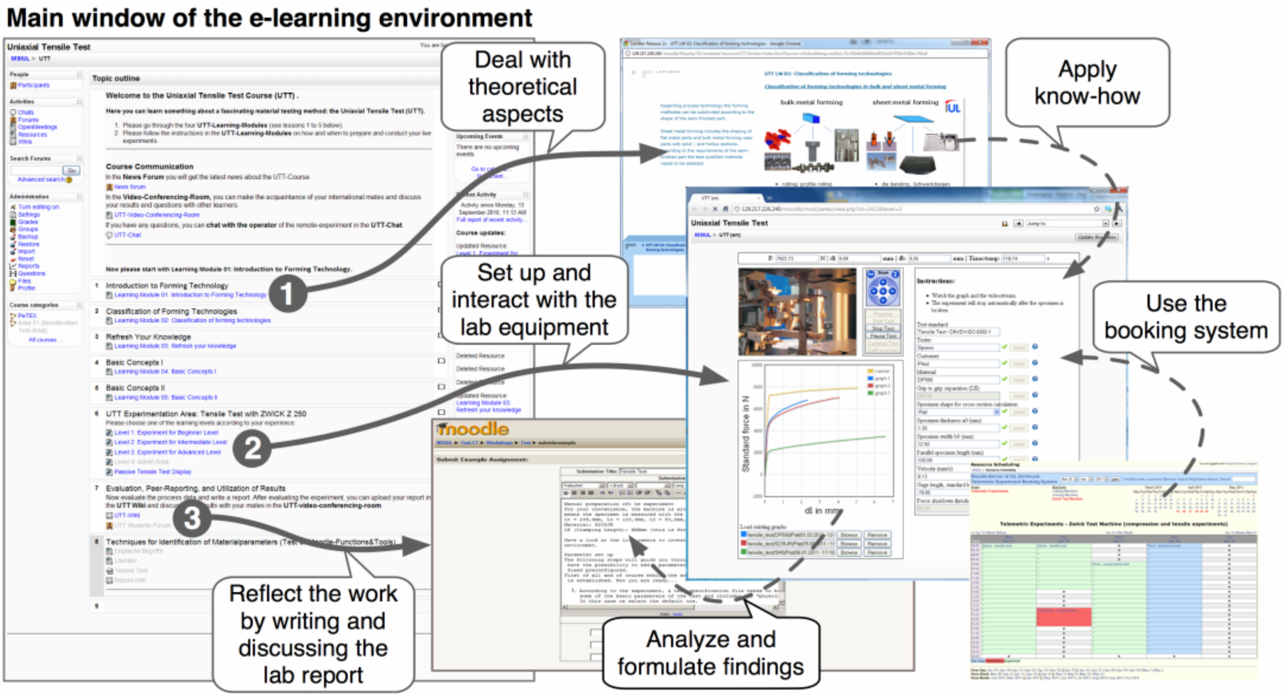

Figure 5. Experimental online learning (Screenshot PeTEX. In the background, the Moodle graphical user interface is to be seen. All PeTEX learning objects are integrated in or accessible via the Moodle-LMS

1. an interactive learning module, designed with the e-learning authoring tool "Lernbar" (available at: http://lernbar.uni-frankfurt.de),
2. the Moodle-window for conducting the experiments,
3. and the window with Moodle-tools for peer-reviewing.

The *openmeetings* plug-in (available at http://www.openmeetings.de/) is installed to allow for convenient video-conferencing with integrated screen sharing functions e.g. for collaborative discussions on the interactive whiteboard about uploaded presentations, both within the entire learning-community as well as in the domain-specific courses.

VI. CONCLUSION

The *Platform for e-Learning and Telemetric Experimentation* (PeTEX) presented by this paper aims at sharing valuable resources like machines and other infrastructure between dispersed locations. A collaborative learning environment is considered to be crucial for enhancing the learning results. The collaborative learning environment deployed allows for all PeTEX learning objects and communication-tools to be integrated into or accessible via the Moodle-LMS.

The project combines various types of learning: it provides individual and group oriented knowledge acquisition in the field of manufacturing engineering as well as learning in a multi-lingual community. A free access to limited e-learning modules and remote experiments will remain an important incentive for new users.

This modular prototype will be further extendable, incorporating new nodes into the network, i.e. new laboratories connected to the platform, in which further experiments will be carried out, and increasing the level of automation of the remote-controlled experiments (see Fig. 6 and Fig. 7). To further increase the difficulty of the learning levels and the attractiveness of the learning tasks it is also intended to combine the different test beds within evermore complex scenarios and research questions from the various fields of production engineering. It is also intended to provide other facilitators with the opportunity to design and adapt their own learning content and new scenarios and tasks around the remote lab experiment set-ups within the platform according to their specific contexts.

Making those systems better known will form a basis for sustainability and continuous development of online engineering education practices according to the vision of the project.

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