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Improvements of Multi-disciplinary Engineering Study by Exploiting Design-centric Approach, Supported by Remote and Virtual Labs*

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In the current paper the design-centric approach for mechatronics and smart product design is presented. The novel aspect of the proposed solution is a comprehensive learning concept and environment which includes remote labs, mobile hardware, methodology, learning material and web environments. The whole concept supports fast and student-oriented learning process for acquiring knowledge and practical skills of integrated systems. The concept is applied into practice in the course of several stages. The most recent case study is described in this paper and the course setup proposed. The feedback from students indicates the time spent by the student on the activity, when the course follows the proposed concept. It is apparent that students spend considerably more time than the curriculum requires. At the same time, workload of the supervisor is lower. However, the quality and learning outcomes are higher than those of previous related courses, but without using novel technologies. In the current paper special attention is paid to remote and virtual labs related to the proposed learning concept.

Keywords: distance learning; virtual micro controller; design-centric study; robotics

1. Introduction

With fast advancement of technologies and design methods for developing smart products, demands for future engineers are also rapidly increasing. Future engineers have to be open to innovations and find optimal solutions for problems in very complex engineering environments. In general terms an engineering environment is a complex mix of customer requirements, marketing aspects, engineering tools and creativity. This leads to the need for changes to engineering education in the multi-disciplinary domain. Conventional teaching and studying methods often do not provide necessary knowledge and are not suitable for Internet era learners. To be successful in teaching multi-disciplinary systems, e.g. smart products, it is necessary to bring the learning activities to the Internet, disconnect hands-on learning from fixed places and focus on practical problem based study instead of the standard lecture-exercise method. This can be successfully implemented by taking a real-life problem related to clear industry needs as basis of the study program. Some problems require an innovative approach and creative thinking on students' behalf. To make that kind of engineering study attractive and convenient to students, new tools must be implemented and integrated into the study process. In this paper the design-centric approach of teaching mechatronics and robotics is described and several innovative tools are presented, including modern web technology based online engineering environments. The approach is piloted in Estonia and other countries and is a key component of the Tallinn University of Technology micro controller and mechatronics courses. Fig. 1. represents the simplified tree of the described process and tools involved.

The current paper is divided into the following parts: State-of-the-Art summarizes briefly the existing solutions and indicates deficiencies; the next section introduces the design-centric study process and the open learning path of international mechatronics curriculum on master's level; the following chapter concentrates on the remote laboratory solution which is a key component of novel e-learning in engineering fields; the Blended Learning Concept chapter describes the background and tools used in the proposed study methodology. Finally, the example course setup is described in greater detail and a previous course is analyzed. To conclude, the paper sums up the discussions. In the conclusion the next steps of development are described and approved future projects introduced.

2. State-of-the-art

As project based study and design-centric approaches are both widespread in engineering study at present, no special examples of these pedagogies are included here. However, a design-centric approach requires appropriate tools and learning environment, e.g. special purpose labs, experiments in practical training, etc. It should be

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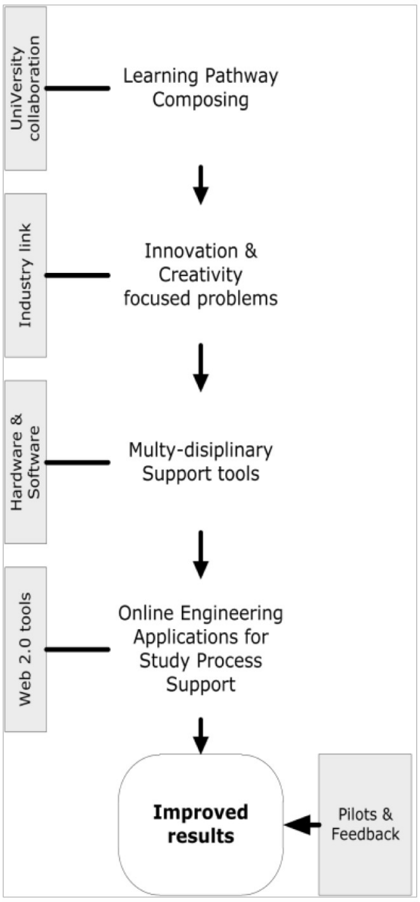

Fig. 1. Simplified learning environment and process tree.

considered that in recent years the Internet has become the main source of information for learners, thus is not possible to ignore it. Although hands-on experiments may seem hard to perform over the Internet or at distance, many new technologies already exist.

Different solutions have been developed and applied to the study process, many of them on an experimental level.

The overview about trends in online engineering and learning experience in remote labs are briefly covered in the guest editor paper [1]. Many initiatives are related to a specific course. For example, one of the most virtualized lab types are found in Electrical Engineering domain. A well known lab has been established in France [2] for conducting remote experiments. DSP based remote experiments are presented in paper [3]. There are several other labs set up by different institutions. Most developers build their own interfaces and have control over their labs.

The general common shortcoming of current remote labs is the course centric approach. It means that the remote lab is designed and developed for supporting a specific course and is not related to other courses and tools. We prefer remote labs as part of more general concept and support practical experience over the Internet in addition to other relevant tools, e.g. mobile hardware—Robotic HomeLab kit. These labs provide valuable practical training in the learning and teaching concept and are not intended to be used independently. Distance engineering study needs not only one option, e.g. remote lab but also real hands-on, conventional supporting material, guidance, etc. Although this paper concentrates mostly on remote labs, other parts of our concept are provided in [4–7].

3. Design-centric approach for smart product studies

At the beginning of teaching engineering studies it is important to consider the personality of the learner, his/her ability to acquire new information and possibilities of arranging study forms. For example, continuous education learners have several limitations of taking part in time consuming lab practices. The proposed approach offers creating a personalized learning utility for establishing a full individual learning program, composed of modules offered by different educational institutions. Obviously, agreements between organizations and active collaboration are expected. In our case international collaboration between universities from Estonia, Germany, Finland, Great Britain and Lithuania has been established and study modules are offered for local as well as foreign students. Students get personal and international learning practice consisting of modules selected by the learner. Fig. 2 describes the master study program where specialty modules (A1–A3) can be selected from different universities considering the learner's personal interest. TUT denotes here the Tallinn University of Technology from Estonia, HBO—Bochum University of Applied Sciences from Germany, KTU—Kaunas University of Technology from Lithuania, etc.

All learning programs comprise consistent modules offered by a certain university, while modules consist of single or continuous courses providing particular knowledge or skills in a relevant field. The course program presented in Fig. 2. has been developed for the smart product course in the Mechatronics curriculum. The study focuses on the design-centric approach where a real-life problem is assigned to student teams and where the successful solution requires creative thinking and integrated activities in a multi-domain space—mostly electrical engineering, mechanical engineering, software design, management and production technologies. These activities have to be performed on time by

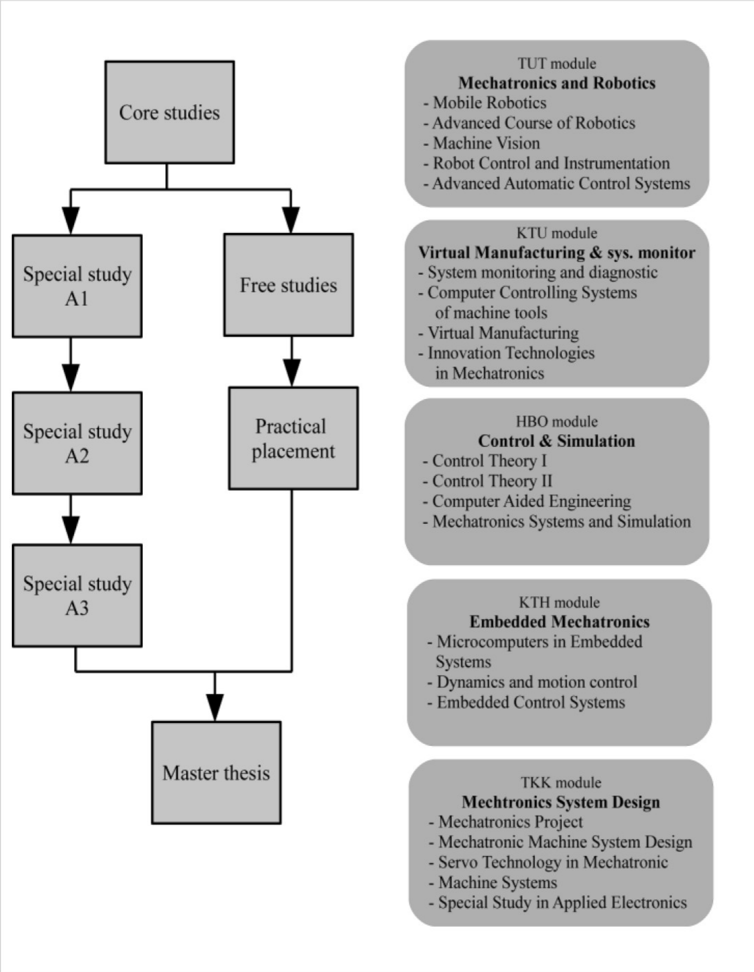

Fig. 2. Learning program and available selective modules for special study.

following budget guidelines and using project management techniques.

The described creation of learning program and personalized study content is not unique; nevertheless it is not easy to work with modules provided by different universities from different countries. The solution takes full advantage of current technology and provides interfaces and access to equipment at distance. It is very important to bring engineering study to the learner's environment, that is today the Internet. However, quality and hands-on experience must not suffer by relocating experiments to the Internet or learners' homes. Standard e-learning systems (like Moodle, Blackboard, etc.) do not provide relevant functionality (practical work) to engineering studies and cannot guarantee fulfillment of this requirement. They are only useful for conventional e-learning activities like presenting static or dynamic material, performing tests and providing communication functionality. However, practical experiments are an essential part of engineering studies, and without the 'learning-by-doing' approach it is impossible to expect good quality learning outcomes. The proposed solution provides several tools and e-systems based on modern web technology to enhance significantly e-learning functionality. The process tree and learning environment links are presented in Fig. 1. Multi-disciplinary support tools consist of hardware sets designed as a modular system for mobile use. Students can use the experiment equipment at home, in their work place or even when abroad. Only a standard computer is needed in addition to the mobile lab set. The same set is already commonly used at school computer classes and libraries. The kit is based on micro controller module and additional modules like sensor, motor, communication and vision modules. The solution is called Robotic HomeLab kit and it is developed in cooperation with universities and private companies from Estonia and Germany. The kit has a specific support environment—Network of Excellence (NoE), providing comprehensive support and resources for Robotic HomeLab users. The important aspect here is that the single functional upgrade does not provide the necessary quality leap, but the combination of conventional and new tools perform the task. The online engineering applications are described in detail in the next chapter.

3.1 Remote and virtual labs

The important part in proposed concept is a set of online engineering tools offering remote lab functionality and providing real and virtualized hardware access.

The remote lab system providing access to hardware is denoted as DistanceLab. The platform enables to control or monitor real equipment placed in the university lab. The DistanceLab can use LabView or any other custom built interface to access different hardware. In our example the mobile robot interface is developed and implemented providing wireless access to small mobile robot running on the university lab. Students can book one device and start practicing to control the system by programming its core controller. The results of the work can be monitored over real-time video feedback. Several tasks can be assigned to teams to develop system behavior on different complexity levels.

The system exploits a three layer physical system where the user interface is served by the standard web server and the user can access it with his/her everyday browser. The web interface is developed by using common LAMP (Linux, Apache, MySQL and PHP) server platform and the system architecture following the Model-View-Controller concept. The second layer is a program server which runs currently on embedded Linux operating system and communicates directly with lab devices. Where the communication between web server and program server uses standard Internet link i.e. TCP/IP, the communication between program server and devices are performed wireless. The reason for using the wireless link is that the devices in the remote lab are mobile robots. They can move around in an arena and it is impossible to run the mobile device with a wired link. For tasks, like 'resetting' and 'remote programming' the device a wireless communication is initiated and the device stops current program and uploads a new one. The wireless link exploits a ZigBee protocol enabling great distance and cost effective wireless solutions. The feedback of the device action is streamed over IP cameras providing real-time feedback to the student.

The other part of the remote lab system is a virtualized micro controller unit and peripheral modules VirtualLab (VMCU). The VirtualLab has virtual versions of the hardware modules from real experiment hardware from Robotic HomeLab kit. The modules are visualized and users can generate as many instances of the specific module as needed. Thus, several users can work at the same time with the same (software) unit. When using the real equipment only one user at a time can control it. According to the concept, solutions have to be tested and practiced on the virtualized module. Next, teams that have passed a pre-defined level can move to the real hardware. All described activities can be performed over the Internet utilizing a standard web browser. Thus, practical exercises can be performed remotely but still using the real or virtualized equipment according to the need or course arrangements.

The main component of the VirtualLab is a micro controller simulation engine built up on the Avrora framework [8]. On the VirtualLab a visual interface was developed and different peripheral devices (modules) are provided. Peripheral devices enable studying different smart system functionalities, e.g. digital input-outputs, analog-digital converter, pulse with modulation, etc. The functionality study is related to real world components. Students link the functionality with a real device. For example, digital inputs are studied by use of buttons, outputs by use of LEDs. The analog-digital conversion is studied through temperature sensor producing an analog output reflecting the measured temperature. All peripheral modules in VirtualLab are described by XML where all single components on the modules simulate precisely the real component according to the manufacturer's datasheet. Fig. 3. illustrates the integration of DistanceLab, VirtualLab and HomeLab kit.

As stated in previous sections, engineering study needs practical hands-on experiments and also system control in order to provide necessary knowledge and skills. It is not easy to provide the same hands-on experience over distance. Here the described online tools help to solve the dilemma between distance learning and hands-on experiments. Use of the described tools in the study process follows the student's personal study achievements and the logical course or curriculum structure. For example, in mechatronics one study module can use tools in the following order and purpose.

In first stage, the single functionality, e.g. micro controller interrupts are studied, practical exercises are performed on the VirtualLab User Interface module. When the virtual solution functions, one can continue with the real hardware, i.e. Robotic HomeLab kit and experiment the same solution on it. This can be done at home, if the hardware is available for home use, at school or library (this depends on the university policy in most cases). After the single functionalities are studied and exercises performed the student can book an experiment device, i.e. mobile robot on the DistanceLab.

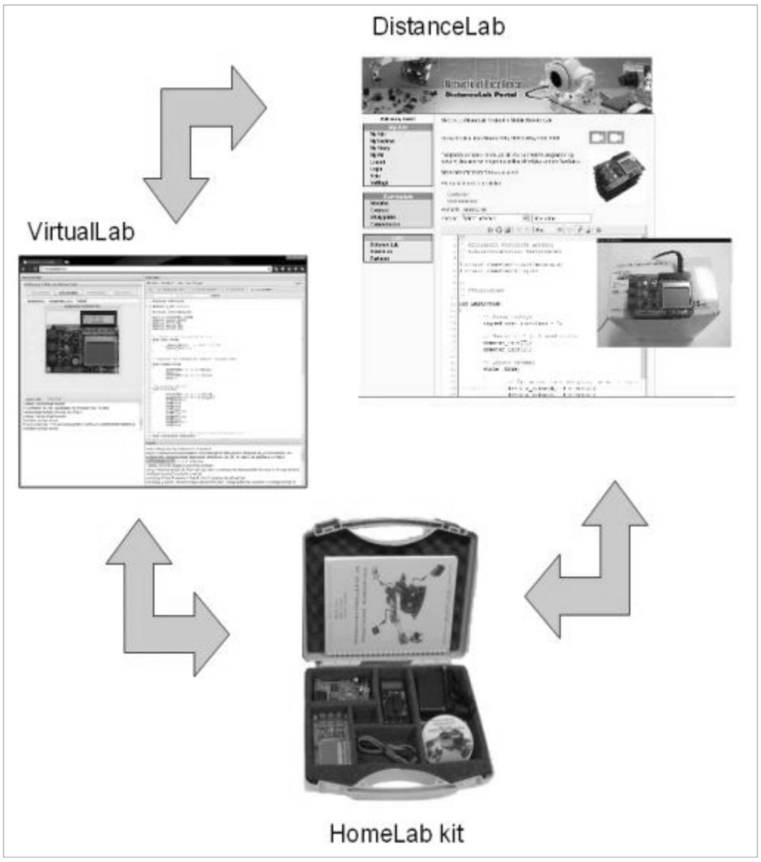

Fig. 3. Set of practical tools.

The experiment device is usually a small system which exploits all single functionality as a functional system. It enables testing his/her acquired knowledge and skills on the system which is usually much more complex than a single function. However, practical experiments with online and mobile tools are part of the study and need local manuals, as well as several other supporting tools and environments. The next sections give a brief overview of the concept supporting online tools and study process in general.

3.2 The blended learning concept

The Blended Teaching & Learning Concept (BTLC) [6] does not cover only the university education but starts at primary school and evolves into lifelong learning. The concept frames teaching and learning environments, tools and methodologies. All education levels use the same platform and tools but on different complexity level and under different guidance. The concept has been applied into practice step-by-step on all educational levels in Estonia since 2007. The results are promising and interest among young people has increased considering the intake competition rate on mechatronics curricula at the Tallinn University of Technology.

As mechatronics and robotics are very practical domains, the constant hands-on experience has to support theoretical studies on every level. It is especially important to introduce robotics to newcomers and young people in an attractive way and assure them of their ability to do engineering and easily program a robot. According to our experience, the Lego Mindstorm NXT robotic set is a good tool to start with. Thus, robotics can even be taught in kindergartens, although the first acquaintance with robotics is usually done in primary school. That ensures fast results important for keeping the motivation up for robotic studies. Several standard Lego NXT robotic solutions are built, used in school competitions held during autumn and spring holidays. On secondary school level the robotic platform is changed to the Robotic HomeLab kit, developed by our consortium. It is important to offer the next step as Lego may bore students after they have played with it for a while. Therefore, the concept offers the next logical step where teachers introduce a convenient micro controller based platform. In Fig. 4 the kits used in our concept are set on the axes. When moving from a simple platform to a more complex one, graphical programming is replaced by C/C++ source code programming although the algorithm remains as a model of the system. In that way students learn that

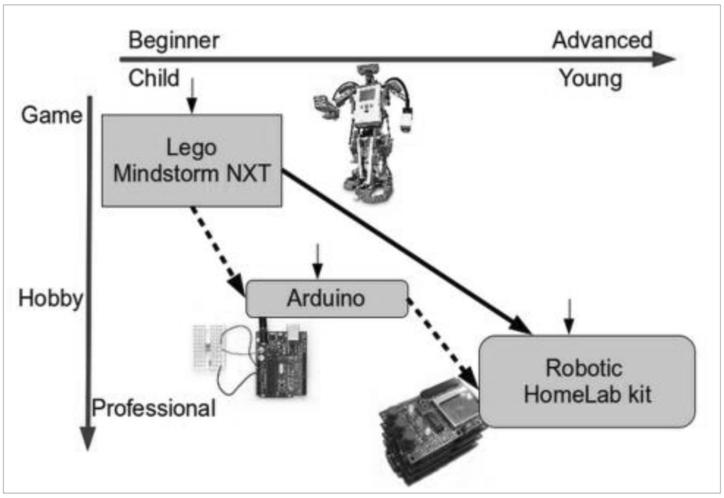

Fig. 4. Robotic educational platforms.

the system behavior can be independent from the target physical system. However, the main concept of robotics: sensor-control-actuator is already familiar and therefore easy to be moved to a new platform. The content of practical projects is also integrated into real life systems (e.g. intelligent control of the smart house). This two-step approach enables a fast start, without losing the motivation and students can reach a high level at the end of secondary school with a minimal study load. If the change feels too rapid for some students, an optional middle course is offered with the Arduino platform. The Arduino micro controller [9] prototype boards have had lots of attention during recent years and can be considered a means to launch from toys to the professional world.

The mechatronics course is very often organized around a design-centric focus. In many cases the course consists of a practical application designed and manufactured by the students. The application is usually a moving robot and at the end of the course a competition is held. Several popular robotic contests are held in Europe, including sumo robot contests, Eurobot [10], etc.

The following case study describes the design-centric mechatronics course where innovative tools were used and remote hands-on experiments applied.

3.3 Course setup

The case study course was added to the mechatronics curriculum during last semester in bachelor study studies and students had to work intensively for two months before presenting their thesis. Although the course was meant for the bachelor degree students, the same structure and concept is

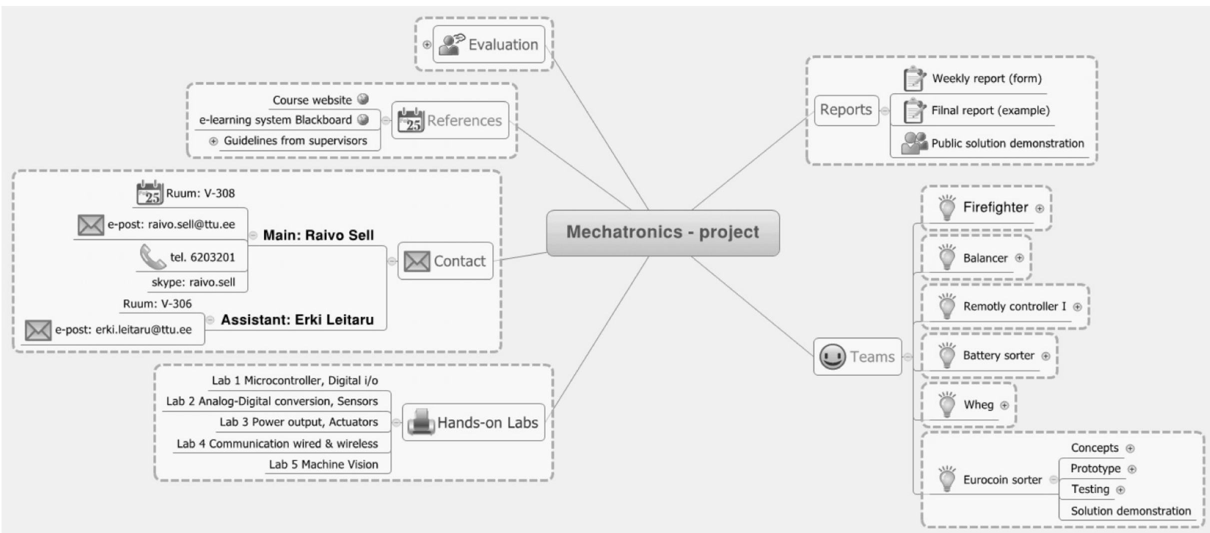

Fig. 5. Mindmap of the course.

currently used at higher vocational schools (but on another level of complexity). The main purpose of the course is to put knowledge acquired during previous studies into practice by designing and building an integrated mechatronic system—smart product within limited time and with modest budget. The work is performed in groups following the basic project management process. The course is described by supervisors by one graph using Mindmap technique. In Fig. 5 the course setup in spring 2011 is shown.

The course setup is based on Blended Teaching & Learning Concept, described in previous chapter and works [6, 7] and utilizes most of the aspects and resources the concept offers. The introduction and most on-site practical experiments were performed by Robotic HomeLab kits [11] either in a classroom or at student's home. The mobile lab kit allows carrying all necessary hardware easily, and often the experiment was started at school and continued at home. Thus, there are no time limitations and the team could finish solving a study problem at home. At the same time, the VirtualLab environment was available for all students and those who lacked access to real hardware could meanwhile test the source code on the virtual micro controller and experiment boards. The solution is designed to be identical between real hardware and virtual hardware modules. This solution boosted the development process and there are no time or location limitations for performing practical programming or experiments. As the main goal of the course is to design a real product based on their acquired knowledge, all teams were provided with different product ideas. In all cases, these ideas smart products where the results to achieve were the combination of smart mechanics, reliable electronics and control logics. The main components of the smart product were taken from the HomeLab kit box. At the same time the real mechatronics system built upon the same components was available via the DistanceLab. Small size mobile robots were accessible over the Internet to test one's knowledge and perform experiments by using the system. As real hardware is always limited, every group can book and control only one device without being interrupted. The feedback is provided as described before via the DistanceLab cameras. As soon as the robot's battery runs out it goes automatically to charging station and is back in operation after charging.

Most of the work was performed with the support of hands-on tools like DistanceLab and VirtualLab but without direct guidance of the supervisor. Presentations were held every two weeks to ensure smooth working and to fix practical problems. In addition to practical tool support the special web environment—Network of Excellence was used to provide all necessary data and a reporting environment. An important aspect of the course was the final public demo of the developed system. The public demonstration forces the students to finish all activities in time and work on marketing and presentation aspects. Experience has shown that students are happy and proud to present their work in public even if they had initial doubts.

4. Discussion

The current versions of BTLC and the online tools are operational in Estonia and Germany and are being implemented in Finland, Lithuania and latest in Turkey. Currently, active development is run by integrating new interfaces for the DistanceLab system to control more different experiment devices found at universities. Recent projects have been approved and are launched in October 2011 focusing on the establishment of a network of DistanceLabs and VirtualLabs where universities can share resources and cooperate actively in the engineering field without border limits and having free access to labs. A second approved project focuses on the Virtual Academy concept where a common platform for distance education, utilizing HomeLab kit and DistanceLab, as well as Network of Excellence will be developed. This platform can be seen as an integration platform. In addition, this project provides a component for European Credit Points for Vocational Education (ECVET), featuring a detailed description of learning tasks.

At the beginning of 2012 new feature Learning learning situations will be developed and integrated into BTLC. Learning situations are introducing an engineering problem, providing background information and setting up a task for a student or student group which can be solved by using online engineering tools described in this paper.

Several issues have to be considered when using or setting up online access to hardware. Some key points considered in our online tools and implemented in software systems are raised briefly here, but the scope of this paper precludes detailed discussion. First of all, security has to be considered, the system has to be secured from misuse and system faults, especially if heavy hardware and moving devices are involved. In case of mobile devices there is difficult to provide constant electrical connection for power source and programming and it may necessary to develop an automatic charging system and power monitoring. The availability for the VirtualLab is easier to achieve as it depends on the server computing power. The flexibility of the system is an important factor as technology develops rapidly and new labs may need to be integrated into the system.

5. Conclusion

Practical hands-on experiments are absolutely essential in engineering studies and cannot be avoided. On the other hand, distance e-learning is increasing in all fields of studies. At present the Internet is central to social and educational life of most students. If they cannot find information about engineering studies, they may assume it does not suit for them at all. In the current paper we described the concept and online tools developed to solve this dilemma and we were successful in putting theory into practice, from primary school level to continuous education courses. Online engineering tools are used daily in several universities and schools in Europe. It is time to take the next step of networking remote labs and initiating further international collaboration.

During recent years this concept and the online engineering tools have been applied in various courses. This paper has analyzed one of the courses and its benefits. The main result of the described case study was the drastically increased time spent voluntarily by students on the course. The second main aspect was the acquired knowledge and practical experience of problem solving and developing a smart product without much additional help by the supervisor. Students appreciate the novel concept of the course study process and feedback has indicated they prefer it to the conventional course. We believe that our approach has successfully combined distance learning and engineering practical work requirements, while study quality has improved. However, there are several possibilities and interesting challenges to work with and develop an all over Europe network of remote labs.

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