

# E2LP REMOTE LABORATORY. NEW CHALLENGES IN SYSTEM DEVELOPMENT

Submitted: 19<sup>th</sup> March 2016; accepted: 30<sup>th</sup> May 2016

Rafał Kłoda, Jan Piwiński, Kacper Kurzejamski

DOI: 10.14313/JAMRIS\_2-2016/16

## Abstract:

*The embedded engineering became the key success factor in many segments of human activities. Therefore, the needs for embedded engineers rapidly grew in last years. The engineering education in embedded systems is facing new challenges with the interdisciplinary approach and the high development dynamics of many specific components. The paper presents the results of Remote Laboratory (RL) service for distance learning for Embedded Systems, developed under Embedded Engineering Learning Platform (E2LP) – 7th Framework Programme funded project.*

*This project provides an unified learning platform for embedded engineering over-coming an important problem of the high introduction overload by separate courses typical for embedded engineering studies.*

*The developed E2LP includes the unified platform for typical courses (digital system design, computer system design) accompanied with basic set of exercises. The study efficiency is improved using the RL functionality. E2LP RL delivered secure and open access e-learning portal, which allowed to create full course and provide alternative teaching methods through the real-time experiments.*

*The whole concept was evaluated at partner universities as well as at Warsaw University of Technology, where we introduced the new learning model in Digital System Design course.*

**Keywords:** *E2LP, remote laboratory, Curriculum integration, embedded systems*

## 1. Introduction

As embedded software systems have grown in number, complexity, and importance in the modern world, a corresponding need to teach computer science students how to effectively engineer such systems has arisen [1].

Early exposure to embedded computing systems is crucial for students to be prepared for the embedded computing demands of today's world. However, exposure to systems knowledge often comes too late in the curriculum to stimulate students' interests and to provide a meaningful difference in how they direct their choice of electives for future education and careers [2].

Focusing the necessary changes in computer engineering and computer science education, we are

meeting the next dilemma – what are generic principles which should be covered in the embedded engineering education for variety of using fields. An intuitive approach is to ask industry about needed engineering profiles where educated engineers will act for their lifetime. A joint work between academy and industry certainly improves engineering education programs as it is mentioned in [3] and [4]. But, this approach is facing an issue – the imbalance between technology cycle times and working life times. When technology cycle times, like in the past, are longer than the people working times, industry needs could perfectly define requirements for education which takes more than 10 years (about 12 years for basic and high school education plus about 5 years engineering education). Today, technology cycles are even shorter than the engineering education time, which means that the industry needs today could only express educational needs in the past [5]. Therefore, an inter-active approach between industry and academy with improving loops inside education times will be needed. A concurrent evaluation of systems and processes mentioned in [6] could be a right answer to this challenge. Even an early impact during basic and high school education could help to overcome this race between education and development [7], [8] and [9].

Those aforementioned issues were a genesis to create an unified learning platform, customized to embedded systems curriculum and was the main goal of the E2LP project.

## 2. E2LP Research Objectives

Embedded Computer Engineering Learning Platform (E2LP) is a European FP7 project of three years duration, started in September 2012. [10]. The project's motivations and project research goals are widely discuss in Kastelan *et al.* [11].

The main idea behind this project is to provide a unified platform which will cover a complete process for embedded systems learning. A modular approach is considered for skills practice through supporting individualization in learning. This platform facilitates a novel development of universal approach in creative learning environment and knowledge management that encourage use of ICT. New learning model is challenging the education of engineers in embedded systems design through real-time experiments that stimulate curiosity with ultimate goal to support students to understand and construct their personal conceptual knowledge based on experiments. In addition to the technological approach, the use of cog-

nitive theories on how people learn helps students to achieve a stronger and smarter adaptation of the subject. Applied methodology was evaluated from the scientific point of view in parallel with the implementation in order to feedback results to the R&D.

Embedded systems are invisible electronics and corresponding software that bring intelligence to objects, processes and devices. The main challenge in engineering education for embedded systems is a complex interdisciplinary approach which includes: understanding of various systems based on different technologies and system solution optimizations. As a result, the produced embedded computer engineering learning platform – E2LP ensures a sufficient number of compatible educated future engineers in Europe, capable of designing complex systems and maintaining a leadership in the area of the supply and embedding of electronic components and systems, thereby ensuring that our strongholds in automotive, avionics, industrial automation, mobile communications, telecoms and medical systems are able to develop.

One of the main objective in E2LP project was to provide unified Remote Laboratory for embedded engineering education. In E2LP project a Remote Laboratory is an experiment, demonstration and a process running locally to design and control an experiment board based on a FPGA device, but with the ability to be monitored and controlled over the Internet (E-learning portal). The RL development and implementation phases are presented in detail by Kloda and Piwinski [12].

In the base case, the RL can be an experiment board connected to a computer through a standard interface and with the host computer connected to the Internet, which provides a remote access. The client can be any computer connected to the Internet with an ability to see the same interface as the local host as well as has the same programs, interfaces and modules.

RL framework (Fig. 1) consists of three main elements:

1. E-learning portal [13] This part of RL provides an access to knowledge (on-line exercises, data sheets) as well as remote operations with E2LP main board through a web user interfaces.

2. Laboratory hardware. Main element is E2LP experimental board with programming cable device and other equipment to conduct remote learning process (E2LP server, digital card, serial port server).

3. Laboratory software. It includes the necessary software to programming board and other applications/services/interfaces based on several IT technologies, which provide proper functioning of the whole Remote Laboratory and their hardware components. Here there are also a number of communication ports, which provide flawless operation of specific applications and services in E2LP server, as well as in several cases enable user to individually configure the communication with a given device.

The main advantage of proposed E2LP RL framework is a possibility for students to interact with the real E2LP platform interfaces, implemented as a web services in Moodle [14] (acronym for Modular Object-Oriented Dynamic Learning Environment) and work with software applications, on the same operational level like they are actually operating the same tools and instruments in classic lesson in laboratory.

### 3. Moodle Based Platform for E-learning Course Development

Talking about embedded engineering studies an important question is the learning platform. In practice embedded solutions are implemented on different platforms (hardware and software). The variety and dynamics of used platforms cannot be covered by a unified study program. Therefore, some kind of abstraction and generalization in engineering education has to be applied. A possible overcoming approach

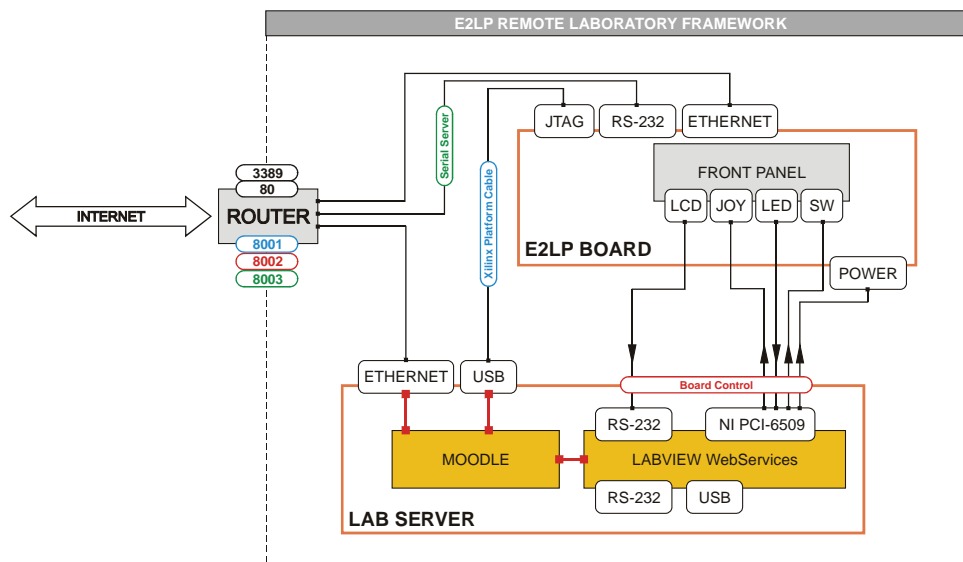


Fig. 1. E2LP Remote Laboratory framework

is proposed in [15] trying to leverage orthogonality, theoretical background and necessary education platforms. Having in mind a crucial point of the embedded systems approach, all problems should be solved by software approach, this platform broadly uses the unified API (application programming interface) approach.

Virtual and remote laboratories (VRLs) are e-learning resources that enhance the accessibility of experimental setups providing a distance teaching framework which meets the student's hands-on learning needs [16] They have been considered as one of the five major shifts in a century of engineering education, thanks to the influence of information and computational technologies [17].

An important study of the implementation of VRLs into learning courses was reported here [18]. This study presents the results of integrating the open remote laboratories into several courses, in various contexts and using various methodologies. These integrations, all related to higher education engineering, were designed by teachers with different perspectives to achieve a range of learning outcomes.

In a traditional laboratory, the user interacts directly with the equipment by performing physical actions (e.g. manipulating with the hands, pressing buttons, turning knobs) and receiving sensory feedback (visual and audio). However, equipping a laboratory is a major expense and its maintenance can be difficult [19].

It should be stressed that Remote Laboratories cannot replace the classical education course. There are of course drawbacks of implementation such tools, mainly in lack of communication between student and course supervisor. This type of systems can isolate students and reduce their motivation in learning process. Furthermore, students could not receive instant feedback from their questions and cannot talk in real-time about results obtained in the learning activities with the teacher. Finally students are required to demonstrate their final projects on the actual hardware, the Massive Open Online Course (MOOC) platforms enable them to prepare for this at home, and then to be able to demonstrate valid hardware results in the laboratory [20]

In E2LP project a Remote Laboratory is a service, which enable students to access the laboratory equipment and execute remote operations to carry out exercises. The main goal of RL was implementation of instant feedback from remote E2LP board in a way that user would operate with the real board as if it was connected locally. This functionality was a purpose to develop the GUI web interface of E2LP board front panel that exactly reflects the real board, which has connections to real signals from the real board.

Connection with the Remote Laboratory is provided via e-learning portal, which is based on Apache server, PHP and SQL server. It provides an access to knowledge (exercises, data sheets) and laboratory hardware through a web user interfaces to enable user to have the full experience of working on the laboratory exercise. The second role of e-learning portal

is management of users, which means enable them access to the laboratory hardware and software (booking functionality and authorization).

In E2LP project the e-learning platform is based on Moodle Platform, which is one of the most popular open source learning management systems.

Moodle is becoming increasingly popular in schools worldwide due to its ease of use and flexibility. Science is the perfect subject to benefit from the features of Moodle as students will find it the easiest to learn with the help of interactive content, rather than reading textbooks. Using Moodle teachers can easily construct richly-textured web-based courses. A course can consist of a number of lessons, with each lesson including reading materials; activities such as quizzes, tests, surveys, and projects; and social elements that encourage interaction and group work between students. Moodle is relatively easy to install, but the real challenge lies in developing a learning process that leverages its power and maps effectively onto the established learning situation.

This platform is a huge community developing, improving, creating science-based resources, and supporting the software that is used all over the world. There are many reasons to use a Virtual Learning Environment (VLE) such as Moodle to enhance teaching methods. These include the following:

Being able to give your students access to course materials 24/7 in a controlled environment, so learning can take place anywhere.

Monitor the progress and keep records of your students learning.

Extending the classroom by providing online discussion, testing, activities, and, most importantly, allowing collaboration and communication for learning.

Make use of exciting multimedia and web-based content, allowing pupils with different learning styles to access the curriculum.

Helping science teachers collaborate, share, and store teaching resources, releasing them to students at your own pace.

#### 4. E2LP RL Functionalities

RL is a gate which provides an access to continuously refreshed interfaces and signals from the real board and enable users to remotely control and program the board directly from their computer at home, having instant visual feedback.

To achieve this, it is necessary to forward data directly to the server over common interfaces or over local network by using dedicated hardware solutions and specified proper router configuration.

The E2LP RL should allow users to do following actions over an Internet connection, which are the list of E2LP Remote Laboratory main functionalities:

1. Dedicated software and hardware solutions provide an access to laboratory equipment and enable students to set them up and operate them at the required level to carry out selected exercises.

2. Users could access the essential data sheets, tutorials and software tools, which are available on the E-learning portal as an introduction to the course.

Each laboratory exercise is presented in transparent form to the user through tabs and such division is implemented into Moodle based platform for e-learning course (Basic information, Theoretical explanations, Instructions, Configure Platform, Feedback, Discussion on results questionnaire for lab evaluation).

3. After booking in a given time slot users could remotely program given set of exercises over the Internet and simultaneously, in real time, could monitor the evolution of the experiment on implemented dedicated Graphical User interface (GUI) of the Front Panel of the real E2LP board .

4. Automatic verification of course assignments will allow an advanced management of assignments and submissions together with feedback information mechanisms for both teachers and students, which will verify, whether the students designs are correct or not according to the specifications.

## 5. RL Implementation

RL presents fully operational and tested system, which is enriched with dedicated modules to E2LP Mother Board, which provide real-time remote control, monitoring and programming. Below we show the main advantages of the system:

- The final laboratory exercise on the web has sections (tabs) to enable user to have the full experience of working on the laboratory exercise. These are Digital System Design course exercises, which aim is to control Switches, JOY Push Buttons, LEDs, LCD output in the front panel of the E2LP board as well as RS-232 port are available for remote operations.
- Advance booking system, which enables to reserve a time slot for individual remotely tests of the solution for a given exercise. Booking functionality enables to access up to 4 remote E2LP boards.
- The fast bit file loading module enables remote configuration and immediate respond of the successful E2LP board configuration, without a requirement for users to have a specialized Xilinx software to do it.
- The user friendly Graphical User Interface of the Front Panel, which reflects to the same panel on the real E2LP board, enables user to monitor and control remotely each switch, button, LED and LCD output. The GUI is enriched with the checking correctness of the solution module, which compares the students solution with a master, created by the teacher.
- Automatic verification module, which is based on regular expressions, checks the correctness of the users solution. The pattern for solution is prepared by the teacher or course creator. After comparison the user is informed visually about correctness of his solution.
- The 'Discussion on results' functionality module consist the output information from check correctness solution module, by showing the log records output from the E2LP board Front Panel and enable Teacher and user to exchange information about given exercise.

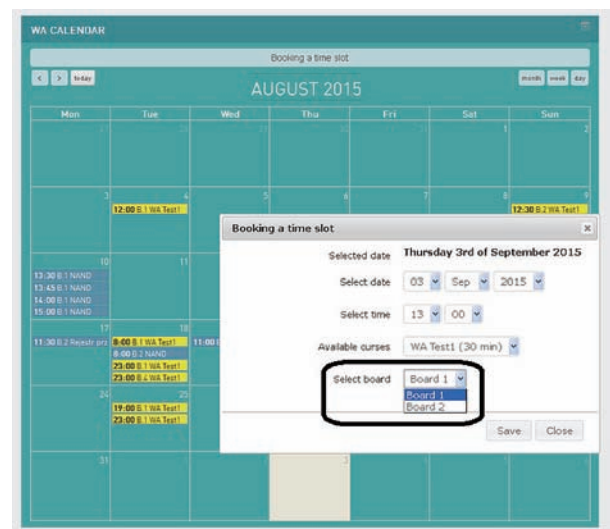


Fig. 2. Multi-board selection

## 6. New Challenges in RL Development

### 6.1 Modularity of Moodle Platform

The use of Moodle open source platform as an user-friendly interface for virtual laboratories provides benefits for every participant in the developer-teacher-student chain. It allows for high level integration of hardware and software with highly configurable control procedures, in the same time supporting the teacher with a variety of administrative tools and the student with an accessible control panel. During the development of the E2LP project the modularity of Moodle platform was used to create custom blocks and modules [21], dedicated for the virtual laboratory. Some of the ideas incorporated an innovative module for the verification of student's solution and the implementation of a multi-device system.

### 6.2. Multi-device Laboratory

The progress in the field of remote teaching provides easier access to the laboratory for greater number of students. That, being a great advantage of such systems, also generates problems connected with occupation of the physical components. Even though the platform may handle many students simultaneously, the hardware itself is restricted to a one-to-one work. Therefore, it is crucial to develop a multi-device system, incorporating multiple hardware components into a unified platform based on Moodle.

The control of physical signals of the hardware (in the case of E2LP an FPGA Embedded System Board) operates on the basis of an active LabVIEW web service. Hence, for a multi-board approach the main web service was replicated, remaining in the exact same form as the original, only with a varying address depending on the device. That way, establishing a connection (from the Moodle layer) with a specific path allows for control of a certain device. During the project, a specific schematic was introduced:

`http://server_address/Device1`

`http://server_address/Device2`

The main advantage of such approach is the possibility of quick and easy change of the number of cur-

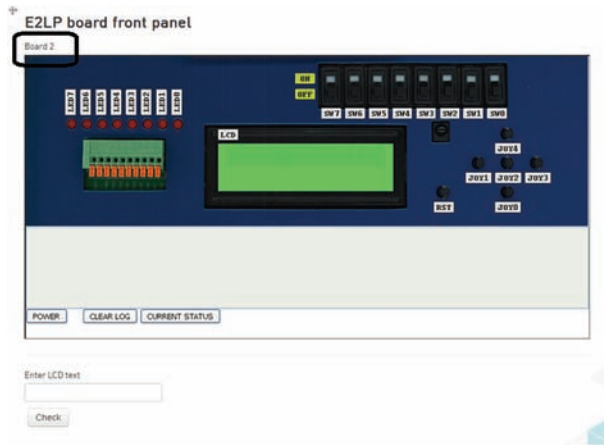


Fig.3. E2LP RL board front panel

rently available devices without the need of modification of the universal web service.

During the reservation of a time slot, students choose from the available boards (the system checks their availability for current time). On the submission of the reservation form, the Moodle database is updated with an information containing all the necessary data, including the device number.

```
$enroll->enroll_date = $time;
$enroll->course_id = (int)$data['course_id'];
$enroll->board = (int)$data['board_select'];
$DB->insert_record('wa_enroll_calendar', $enroll,
true);
```

It is further used to dynamically generate correct user's interface after logging in for a particular course, taking the device number into account while selecting appropriate web service path. That way any possibility of conflict is eliminated, as the user can only gain access to the board he had made a reservation for. Again, a connection with the database is established, retrieving the device number and appending it to the web service URL, without the need of any user's action. The default webservice\_url for any activity is in the form `http://server_address/Board`, so if the device id is for example 2, the resulting URL is set as `http://server_address/Board2`.

```
$result = wafrontpanel_get_board_id();
$device_id=(int)($result->board);
$modified_url = preg_replace('/
Board/',Board.$device_id,$activity->webservice_url);
```

That way the database values are translated into a dynamic creation of URL. Moreover, the default path is provided by the teacher via Moodle administration tools, so if the web service address is changed, no modification of the source code is needed. Below is shown the interface of the E2LP platform after the introduction of the multi-device approach.

### 6.3. "Check Solution" Module

As the project is focused on university teaching methods, it needs an implementation of student's progress verification. Moreover, it should create the possibility of revision of student's performance in order to provide formative assessment from the teacher to maximize teaching efficiency [22]. Moodle platform's custom modules development allows to create a dynamic comparison of predefined patterns,

dedicated for the hardware platform the Moodle interface is integrated with. This approach is open for universal applications, as the teachers are given a simple schematic of answer pattern definition that can be applied in any similar e-learning platform. The student's solution is also recorded in the database, for the needs of further revision.

The procedure of checking the students' solutions is based on the definition of system's required reactions for an occurrence of a certain user's action. It operates on the basis of a dynamic comparison of a predefined answer patterns (generated by the teacher) and the log of user's actions generated while fulfilling an exercise. This method also allows for personalized interaction between the user and the platform (via LCD interface). It is one step ahead of previous solutions suggested for student progress validation, that were based on a one-to-one comparison of the answer patterns, strictly defining the check solution procedure. This time the user is free to test his program in any order and configuration, as many times as he wants, and only the crucial parts of the log will be extracted and compared with the answer pattern. This way the student's responsibility for the correctness of the procedure is removed and he is able to fully focus on the subject of the exercise.

The implemented method comprises two main fields:

- Log checking – monitoring the whole progress of the exercise, and the system's responses for certain actions (e.g. on Button 1 flash diodes three times).
- LCD checking – comparison of the example text and the text that the student managed to display on the LCD.

### 6.4. Log Checking

The previous version of the system was based on a one-to-one comparison between the log and the predefined answer pattern. This approach caused two main disadvantages:

- In order to achieve a positive grade, student's result had to be exactly the same as the answer pattern.
- The correct solution could have been marked as wrong if the student had performed required actions in a different order or the status of insignificant ports had been different (e.g. the position of switches when only LEDs are used).

In order to surpass those disadvantages and increase the algorithm's efficiency an action – result approach was implemented. Instead of a one-to-one comparison, after the occurrence of a specific action (e.g. pressed button), an appropriate result is being searched for (e.g. LED sequence). It bases on a synergic combination of regular expressions and array data manipulation.

Sample log text:

```
LED:11100000,SW:00000000,JOY:11111
,LCD:Hello,RESET:1,POWER:0,EXTERNAL:0
LED:01100000,SW:00000000,JOY:11111,L
CD:Hello,RESET:1,POWER:0,EXTERNAL:0
```

```
LED:00100000,SW:00000000,JOY:11111,L
CD:Hello,RESET:1,POWER:0,EXTERNAL:0
LED:00000000,SW:00000000,JOY:11101,LCD:Hello,
RESET:1,POWER:0,EXTERNAL:0
```

Code responsible for translating the text into an approachable form:

```
//change all \r\n or \r or \n to commas
$log = preg_replace('/[\r\n]|\r|\n/', ',' $log);
//change multiple commas to a single one
$log = preg_replace('/\,+/', ',' $log);
$log_split = array_reverse(preg_split('/(LED:|SW:|
JOY:|LCD:|RESET:|POWER:|EXTERNAL:|BOX:|[\r\n
n])/', $log));
```

The use of regex has three main purposes here: cleanup of the log text (from unnecessary line breaks, carriage returns and commas), identification of log parts and division into blocks/arrays according to their content [23]. The position BOX is appended to the log as the input from the LCD pattern example.

Next step is the implementation of array manipulation in order to isolate only the required parts of the log for comparison. For example, stepping to the same parameter value (e.g. LED) in the next line is executed as incrementation of the array index by 7 (as there are seven elements in each line). That way, for testing LED response as a reaction for JOY input, only the highlighted sequence will be searched for in the log, ignoring other parameters:

```
LED:11100000,SW:00000000,JOY:1111
1,LCD:Hello,RESET:1,POWER:0,EXTERNAL:0
LED:01100000,SW:00000000,JOY:11111,
LCD:Hello,RESET:1,POWER:0,EXTERNAL:0
LED:00100000,SW:00000000,JOY:11111,
LCD:Hello,RESET:1,POWER:0,EXTERNAL:0
LED:00000000,SW:00000000,JOY:11101,LCD:Hello,
RESET:1,POWER:0,EXTERNAL:0
```

In the administration panel, the teacher can define blocks of such patterns, defining monitored inputs and outputs, hence allowing the user to freely test all functions of his program in any configuration, as many times as he wants. The introduced algorithm is highly efficient – redundant and insignificant parts of the user's performance are ignored and the checking procedure is finished after the first occurrence of required action-reaction scheme.

Due to the parallel nature of operations in the FPGA technology the teacher has to define a parameter defining the expected response time. If it is shorter than the processing of a web request, the response will be shown in the same line as its trigger. Therefore, the course creator defines if the algorithm should begin in the trigger line or in the next one. As a result, the platform becomes adjustable for parallel and serial operating systems (or systems with varying response time for different operations).

## 6.5. LCD Checking

The LCD pattern text is appended to the log and processed as such. The user is required to fill in the text that is expected to appear on the LCD, and the algorithm checks if that succeeded. That approach creates the possibility of applying custom text for each user

making the teaching process personal and more interactive (e.g. displaying each student's name on the LCD).

In order to prevent cheating, double verification of the LCD exercises is supported:

Algorithmic comparison of user input with the displayed text.

The solution is saved to the Moodle database, so that the teacher may check if it meets the exercise passing criteria.

The introduction of the LCD module opens way for further development of this interactive platform. It would be possible to use a predefined LCD text pattern to fully automate the checking procedure, yet the exercises would not be personalized that way. Another idea is to integrate the LCD text pattern with the Moodle user personal information (e.g. name, username or email).

## 7. Evaluation and Discussion on Results

System integration of many hardware and software modules in embedded systems makes testing and verification the key success factors in embedded solutions [24]. Therefore, testing and verification methodology reflects as a big challenge for embedded engineering education.

Evaluation and assessment of engineering education is an important point closing the improvement loop of education process. Here, a dilemma is what and how to measure – achieved knowledge level, usability of acquired knowledge, soft capabilities (team work, project management) as well as capability for innovations. Some approaches for education quality evaluation and assessment are proposed in [25], [26] and [27].

The E2LP has been evaluated at 8 universities in running study programs. Four of them are project partners and the other four universities outside the project have also adopted this learning platform. Results in the first two years of usage have been evaluated using the established evaluation tools showing visible improvements of study efficiency. Development and evaluation results are published at conferences and in the journal as well as summarized in a book of Springer special edition. Promotions have been organized at two fairs and in two externally organized workshops.

The established E2LP consortium prepared a framework for promotion and exploitation of the developed learning platform for embedded engineering. A preparation of a follow-up project is in progress addressing necessary updates and extensions for a broader usage of the E2LP, from introduction courses at high schools up to expert courses for lifelong engineering education.

The E2LP project involved the development, implementation and evaluation of an advanced learning platform for computers and embedded systems engineering education. Beyond the development of hardware and software, the project also included the development of an inventory of 65 experiments and lab assignments for students at three levels: exercises, problems and projects.

This chapter presents the preliminary student's practical validation of developed E2LP Remote Laboratory, which was performed at Warsaw University of Technology (WUT) at Mechatronics Faculty during the evaluation stage of the E2LP project. The main purpose of performed evaluation was showing to students system capabilities and engaging them in contribution in testing the developed RL platform as an additional value to study programs in WUT.

A study was completed under "Intelligent Measurement Devices" – a new course in the Electronic Measurement Systems specialization on engineering degree.

During this course students gain comprehensive skills: knowledge about the intelligent sensors, measurements devices and systems operation rules, competence in signal processing and the methodology of novel apparatus construction.

One of the main purpose of the evaluation and the E2LP project was the enrich aforementioned skills with understanding the different digital logic circuits and their operation, implementation of Boolean functions using digital logic circuits, understand the Xilinx ISE software environment and tools as well as understand VHDL description of digital logic circuits.

To get the summative feedback from students towards presented system, the quantitative on-line analysis was conducted, which was prepared by other E2LP project partner Ben-Gurion University of the Negev, based on Computer System Usability Questionnaire (CSUQ) [28]. It includes many aspects that refer to the usage RL platform and its and user acceptance. The questionnaire results are presented and discussed by Kloda *et al.* [29].

Our E2LP Remote Laboratory is innovative learning platform, which easy customizes to any course needs and doesn't require any cost for teachers, namely they don't need any specialize software and hardware. Since the students were beginners in VHDL language and Xilinx environments we prepared separate set of easy exercises, which were in line with the curriculum of the subject.

Regarding the e-learning platform for FPGA, the users confirm, that proposed solution are powerful and efficiently improved by using RL. In this sense, students declare they somewhat agree with the idea that remote work is possible without the need to work with the real board.

Considering the aspects related to the user graphic interface, users proof that it is easy to use and its readability increase significantly. Moreover students stress that they are able to quick learning.

The biggest encountered problem was connected with using Xilinx ISE software, which was source of error messages and poor programming experience. The low mark might be a reason of very low student's initial knowledge level of FPGA systems.

## 8. Conclusions

This paper has discussed all the features provided by E2LP RL for its implementation and deployment in embedded systems engineering education along with feedback from the universities that had deployed it in their learning curricula

Results presented in the paper confirms that introduction of RL into curriculum and new learning model is challenging in the education of engineers in embedded systems. Student, who has never had any practice with Xilinx ISE environment and any FPGA board configuration needs really precise procedure what to do in current exercise.

Proposed solutions based on integrated together Remote Laboratory components and e-learning Moodle Platform enable student to acquire desired knowledge about digital systems and significantly support learning process. During the evaluation it occurred that remote operations through real-time experiments stimulate the students curiosity and productivity.

In summary, we believe that the evaluation methodology and tools developed in this research were not just an important ingredient in the E2LP project, but could also contribute a meaningful layer to the literature and practice of engineering education, especially in the context of developing and evaluating new technology-based curricula.

## ACKNOWLEDGEMENTS

E2LP Remote Laboratory development were performed in the Industrial Research Institute for Automation and Measurements PIAP. E2LP Remote Laboratory evaluation were made in the Institute of Metrology and Biomedical Engineering, Warsaw University of Technology.

## AUTHORS

**Rafał Kloda\*** – Industrial Research Institute for Automation and Measurements PIAP, al. Jerozolimskie 202, 02-486, Warsaw, Poland, rkloda@piap.pl.

**Jan Piwiński** – Industrial Research Institute for Automation and Measurements PIAP, al. Jerozolimskie 202, 02-486, Warsaw, Poland, jpiwinski@piap.pl.

**Kacper Kurzejamski** – Institute of Metrology and Biomedical Engineering, Warsaw University of Technology, Św. A. Boboli 8, 02-525 Warsaw, Poland, kacperk@op.pl.

\*Corresponding author

## REFERENCES

- [1] Ch. A. Mattmann, N. Medvidović, S. Malek, G. Edwards, S. Banerjee, "A Middleware Platform for Providing Mobile and Embedded Computing Instruction to Software Engineering Students", *IEEE Transactions on Education*, vol. 55, no. 3, August 2012, 425. DOI: 10.1109/TE.2012.2182998.
- [2] B. Benson, A. Arfaee, Ch. Kim, R. Kastner, R. K. Gupta, "Integrating Embedded Computing Systems Into High School and Early Undergraduate Education", *IEEE Transactions on Education*, vol. 54, no. 2, May 2011, 197. DOI: 10.1109/TE.2010.2078819.

- [3] J. C. Cunha, J. P. Amaro, L. Marques, "A joint academy-industry initiative for the development of an engineering program", *1<sup>st</sup> Int. Conf. of the Portuguese Society for Engineering Education*, 2013.
- [4] M. Pokkiyarath, R. Raman, K. Achuthan, B. Jayaraman, "Preparing global engineers: USA-India academia & industry led approach", *IEEE*, 2014. DOI: 10.1109/FIE.2014.7044385.
- [5] D. Ktoridou, N. Eteoleous, "Engineering education: time to reform the fragmented, content-overloaded curricula context?", *IEEE Global Engineering Education Conference EDUCON*, 2014, 377–380. DOI: 10.1109/EDUCON.2014.6826121.
- [6] G. Karsai, F. Massacci, L. J. Osterweil, I. Schieferdecker, "Evolving embedded systems", *IEEE Computer*, May 2010, 34–40. DOI: 10.1109/MC.2010.135.
- [7] G. MacBride, E. L. Hayward, G. Hayward, et al., "Engineering the future: embedded engineering permanently across the school-university interface", *IEEE Transactions on Education*, vol. 53, no. 1, Feb. 2010, 120–127. DOI: 10.1109/TE.2009.2025368.
- [8] R. Bruce, D. Brock, S. Reiser, "Teaching programming using embedded systems", *Proceedings of IEEE Southeastcon*, 2013. DOI: 10.1109/SEC-ON.2013.6567401.
- [9] M. K. Banavar, D. Rajan, A. Strom, et al., "Embedding Android signal processing apps in high school math class – an RET project", *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*. DOI: 10.1109/FIE.2014.7044266.
- [10] E2LP project website, URL <http://www.e2lp.org>
- [11] I. Kastelan, J. R. Lopez Benito, E. Artetxe Gonzalez, J. Piwinski, M. Barak, M. Temerinac, "E2LP: A unified embedded engineering learning platform", *Microprocessors and Microsystems*, vol. 38, no. 8, Part B, November 2014, 933–946. DOI: 10.1016/j.micpro.2014.09.003.
- [12] Piwiński J., Kłoda R., "E2LP Remote Laboratory: e-learning service for embedded systems education", *Advances in Intelligent Systems and Computing, Embedded Engineering Education*, vol. 421, Springer 2015, ISSN 2194-5357.
- [13] E2LP Remote Laboratory, e-learning portal for E2LP, URL <http://e2lp.piap.pl>
- [14] <https://moodle.org/>
- [15] A. Sangiovanni-Vincentelli, G. Martin, "Platform-based design and software design for embedded systems", *IEEE Design & Test of Computers*, vol. 18, no. 6, Nov-Dec 2001, 23–33.
- [16] L. de la Torre, R. Heradio, C. A. Jara, et al., "Providing Collaborative Support to Virtual and Remote Laboratories", *IEEE Transactions on Learning Technologies*, vol. 6, no. 4, Oct.-Dec. 2013. DOI: 10.1109/TLT.2013.20.
- [17] J. Froyd, P.Wankat, K. Smith, "Five major shifts in 100 years of engineering education". *Proc. IEEE*, vol. 100, no. Special Centennial Issue, May 2012, 1344–1360. DOI: 10.1109/JPROC.2012.2190167.
- [18] J. García Zubía, G. R. Alves (eds.), *Using Remote Labs in Education. Two Little Ducks in Remote Experimentation*. Prize for Best Research UD – Grupo Santander. University of Deusto, 2011.
- [19] Distance-Learning Remote Laboratories using LabVIEW; Publish Date: Sep 06, 2006 <http://www.ni.com/white-paper/3301/en/>
- [20] N. Ackovska, S. Ristov, "OER Approach for Specific Student Groups in Hardware-Based Courses", *IEEE Transactions on Education*, vol. 57, no. 4, Nov. 2014. DOI: 10.1109/TE.2014.2327007.
- [21] J. Moore, M. Churchward, *Moodle 1.9 Extension Development: Customize and Extend Moodle by Using Its Robust Plugin Systems*. Birmingham: Packt Publishing, 2010.
- [22] R. Higgins, P. Hartley, A. Skelton, "The Conscientious Consumer: Reconsidering the Role of Assessment Feedback in Student Learning", *Studies in Higher Education*, vol. 27, no. 1, 2002, 53–64.
- [23] J. Goyvaerts, S. Levithan, *Regular Expressions Cookbook*, Beijing: O'Reilly, 2009.
- [24] D. Marijan, V. Zlokolica, N. Teslic, et al., "Automatic functional TV set failure detection system", *IEEE Transactions on Consumer Electronics*, vol. 56, 2010, 125–133. DOI: 10.1109/TCE.2010.5439135.
- [25] C. Borri, E. Guberti, J. C. Quadrado, "Quality assurance of engineering education worldwide", *IEEE International Conference on Interactive Collaborative Learning*, 2014, 346–351.
- [26] P. K. Raju, C. S. Sankar, G. Halpin, G. Halpin, J. Good, "Evaluation of an engineering education courseware across different campuses", *30<sup>th</sup> ASEE/IEEE Frontiers in Education Conference*, 2000, T4B-11.
- [27] U. Jayasinghe, A. Dharmaratne, A. Atukorale, "Education system vs. traditional education system", *12<sup>th</sup> International Conference on remote engineering and virtual instrumentation*, 2015, 131–135.
- [28] J. R. Lewis, *IBM Computer Usability Satisfaction Questionnaires: Psycho-metric Evaluation and Instructions for Use*, *International Journal of Human-Computer Interaction*, vol. 7, no.1, 1995, 57–78.
- [29] Kłoda R., Piwiński J., Szewczyk R., "E2LP Remote Laboratory: introduction course and evaluation at Warsaw University of Technology", *Advances in Intelligent Systems and Computing, Embedded Engineering Education*, vol. 421, Springer 2015, ISSN 2194-5357.