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Ubiquitous learning based on mobile devices and industrial prototypes

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Abstract— **Background: In technical subjects, the "hands-on" aspect is important because the students cannot assimilate some concepts until they practice with real industrial systems. They need to have the demonstration that what they are performing is real and works in order to create a true mental image of the subject concepts, which translates as an increase in professional skills.**

Application Design: In this work, it is described a step forward in integrating mobile devices and real physical laboratories in a ubiquitous learning approach. Contribution: The latest experiences with mobile devices showed that it is possible to get near real "hands-on" by combining specially designed equipment and flexible virtual scale models running on the mobile device, without requiring physical laboratories or classic remote labs. This approach can be applied to many technical subjects that face the same issues.

Findings: Based on the evaluation results, the proposed u-lab architecture provided strong evidence of the benefits achieved. The proposal presents interesting advantages from the economic and professor productivity point of view, obtaining better academic achievements. The resulting platform should facilitate educational activities which use mobile devices. This approach can be applied to many technical subjects that suffer economic restrictions.

This opens up new scenarios for mobile device-based learning without excessive additional costs.

Index Terms— **Engineering studies, Industrial Informatics, mobile devices, problem-based learning, u-learning.**

I. INTRODUCTION

In university education, it is important to reinforce practical learning "hands on", since students will learn by doing and knowledge will be consolidated more and for a longer time.

In this paper, it is described an innovative methodology integrating mobile devices and real hardware laboratories in a full-learning approach. The main objective is to meet the students' need for hands-on practice and for guidance in their autonomous work while dealing with current economic constraints. This approach can be applied to a wide spectrum of technical subjects and areas that face the same issues [1].

The proposed methodology has been applied to the subject of Industrial Informatics (II) that provides an overview of the applications of computer science in industry. Initially, the course introduces the general idea of industrial computer system development by means of example projects and the analysis of different types of platforms. Later, the level of abstraction decreases, and the students focus on real embedded industrial systems, studying specific aspects of microprocessor architectures and their peripherals.

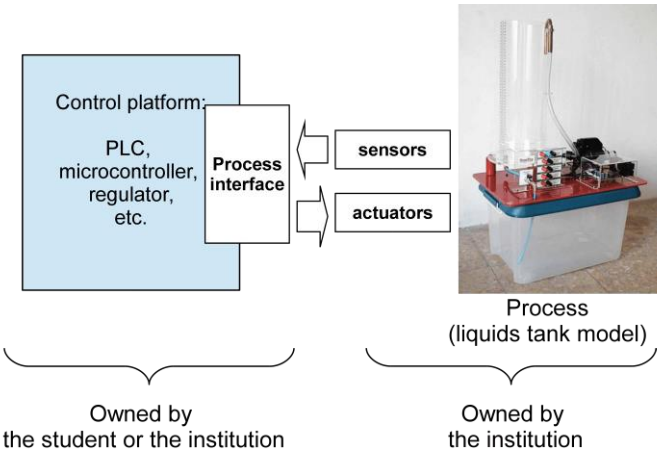

Fig. 1. Case study application

II subject implements Problem Based Learning (PBL) [2], examining the specification, design and development of an information technology (IT) project to apply control techniques over an industrial process. The learning activities are conducted following the case study application shown in Fig. 1. In order to undertake the project, students have to apply the knowledge acquired from the lectures and lab sessions and integrate them into their own "mini-project" [3].

Laboratory practice is a fundamental part of the teaching process, as some students cannot assimilate some concepts until they practice on real systems. They need to have a practical demonstration of what they are doing is real. The use of real physical scale models was the approach applied in the first year of establishment of the subject.

In the particular case of II, up to 70 students participate in the practical sessions simultaneously in the same laboratory (see Fig.2), which is highly stressful for the lecturers. The use of case studies of real physical scale models is not a realistic option, as they are expensive, maintenance costs are high, and such models suffer from a lack of flexibility with regard to their adaptation to new scenarios.

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As mobile devices are becoming an essential part of everyday life, and considering that anything that appears on the screen seems to immediately catch the student attention, these devices can represent excellent tools to guide their learning. Furthermore, smartphones and tablets are powerful enough to perform simulations of physical models such as water tank, elevator, or robot arm processes.

Fig. 2. Practical session laboratory

To avoid dependency on the physical processes, a new approach based on mobile devices was established. The main idea is that the student is the owner of key parts of the target system where the application is developed. Thanks to a specially designed “wireless signal bridge (WSB)”, the programmed system by the student controls a virtual process running on a mobile device.

Although, smartphones can have some drawbacks such as student distraction using applications as social networks, etc., while it can reveal social differences because some students will carry better devices compared to others. On the other hand, other advantages that can be pointed out are: development of digital competence, promoting critical thinking, increase motivation and participation, allow monitoring and evaluation of teaching and learning processes.

The rest of this paper is organized as follows. The related research is discussed in section II, the proposed methodology is described in section III, and section IV presents the proposed architecture with the case study, and section V discusses the evaluation of the approach and presents the results obtained. Finally, the conclusions are summarized in section VI.

II. PREVIOUS WORK

II subject deals with the specification, design and development of IT systems for the control of industrial processes, applying a PBL methodology [2]. All the learning activities are based on a case study. Reference skills for Industrial Informatics are based on the educational goals proposed by the Accreditation Board for Engineering and Technology [4] and the skill model representation proposed in [5], as it takes into account aspects such as hands-on, simulators and remote laboratories, which are key technologies for this study [6][7].

Traditional teaching methods used to develop the desired skills with real prototypes. This method is mainly applicable to small groups because they are expensive in terms of teacher effort, laboratory infrastructure and technical maintenance. In the course presented in this paper, the work was carried out with groups of around 70 students. To successfully use PBL methodology, it was necessary to considerably reduce the use of specific laboratory equipment.

To achieve these goals, a series of data acquisition system simulators have been developed, such as SimSeny [8].This PC software tool eliminates the need for real data acquisition cards. Using Simseny, students are free to practice from anywhere with data acquisition systems.

Simulators have been successfully used as learning tools on different engineering courses. They provide the considerable advantage of enabling students to improve their work outside the classroom. However, students with small abstraction capacity are not able to perceive the relationship between the simulated systems and the equivalent real ones [2]. Previous experience [3] has shown that, in these technical subjects, “hands-on” sessions are crucial to enable students to create a mental image of the concepts of the course, and simulators tend to hinder this objective.

An approach for providing “hands-on” experience was the application of remote laboratories [9]. Remote labs have been widely used [5][6][10][11] to provide location-agnostic laboratory activities focused on conceptual understanding. The current popularity of remote labs is due to their ability to provide real and affordable experimental data via shared instrument devices, increasing the number of times and places in which a student can perform experiments [13]. However, there are also issues such as lack of flexibility and the feeling of students that both simulated and remote labs are the same [11][14].

A step forward in this area is the enhancement of the teaching process with the introduction of mobile devices [15]. In a previous study [9], smartphones have been used for the review of theoretical material and the resolution of practical problems. The challenge was that the tutorials had to achieve rapid student learning to enable them to repeat the practical activities successfully [16]. In this case learning is more effective if the information is presented in different but complementary formats [17].

The main drawback found of the discussed papers is a reduction of true “hands-on” experience, which cannot be supplied perfectly. On the other hand, the methodology presented in this paper shows that it is possible to take a step forward and achieve true “hands-on” experience using a hybrid combination of real hardware and flexible virtual scale models running on mobile devices.

III. METHODOLOGY

As has been discussed in the previous work, traditional approaches [11][13][18] require students to perform face-to-face experiments in laboratories with the need for often expensive and maintenance-intensive equipment, although students can practice with real equipment [12]. However, this drawback is overcome with the proposed methodology. The approach aimed to provide students with an experience that was a step closer to the original u-learning principle of learning anytime and anywhere. This proposal was possible because applying the method, no limitations were found regarding the availability of laboratory models.

Moreover, the proposed PBL based approach included the setting of "mini-projects" [9], with the objective of encouraging the students to make an effort in the practical aspects, fostering abilities such as teamwork and the capacity to adapt to new challenges, among other skills.

To this end, the university provides each group of students with the basic laboratory material: computer, data acquisition card, and the necessary software. From then on, in addition to implementing the mini-projects, each group of students will be able to use the existing hardware components in the laboratory. That is, the hardware to connect to the data acquisition card. If there is some very specific material, each group will acquire it on their own. At the end, each group will be the owner of the material.

Examples of mini-projects carried out are the control of greenhouse, living room illumination, electric motor speed, a traffic lights system and an elevator control, among others. Fig. 3 shows the water tank mini-project undertaken by a group of students.

One of the advantages of this approach was its support for Just-In-Time Learning (JIT-Learning) scenarios. Students could access knowledge and train to improve their skills at the specific moment that this was required, in contrast with the classic way in which concepts are acquired with the expectancy of eventually being used. Activities involving highly specialized tasks, characteristic of technical subjects, can benefit from this approach.

As stated before, for the hands-on practice in the laboratory, low cost data-acquisition cards and microcontroller-based systems are used to control scale models available in the laboratory. To avoid dependency on the physical processes, a new approach based on mobile devices was established.

Fig. 3. Mini-project undertaken by a group of students

A diagram of the approach using the developed demonstrator can be seen in Fig. 4. It consists of an industrial process modelled on a mobile (Fig. 4 right), the controller of that industrial process (Fig. 4 left) and a wireless interface system between the controller and the simulated industrial process (Fig. 4 center). The didactic idea is that the student is the owner of key parts of the target system where the application is developed. Thanks to a specially designed "wireless signal bridge (WSB)", the system programmed or developed by the student controls a virtual scale model running on a mobile device.

This provided a true hands-on experience, without needing students to be present in the laboratory, as it is not required having available a real process.

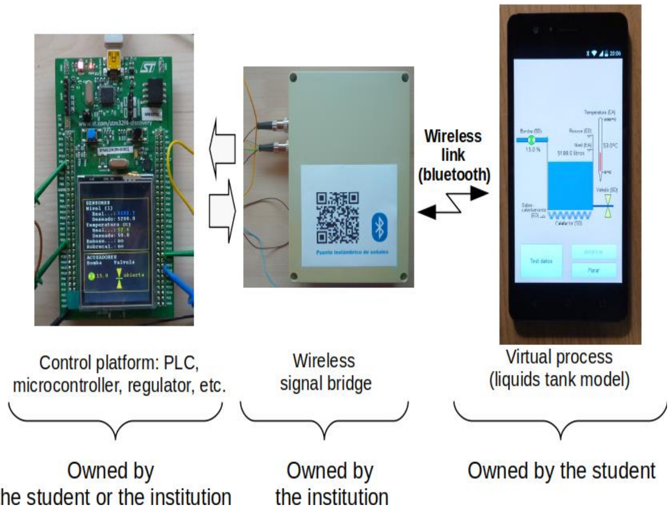

Fig. 4. Diagrammatic representation of the approach using the demonstrator developed

With the introduction of this "ubiquitous laboratory" (u-lab) and the mixture of the other pedagogical methods, the required levels of competence are considered to be achieved.

IV. PROPOSED IT IMPLEMENTATION

A. *Architecture*

A technological architecture was created by the authors of this paper to support the present methodology, as shown in Fig. 5

This architecture defines two domains, the u-lab and the learning cloud [18][19]. The focus of this paper is on the u-lab domain. In this system, the student works on a real device that is connected to a virtual scale model through the WSB. The cloud domain provides the resources to improve the learning experience, providing scale models, tutorials, videos and instructor assistance. The mobile device is responsible for bringing the two domains together using its Internet capabilities.

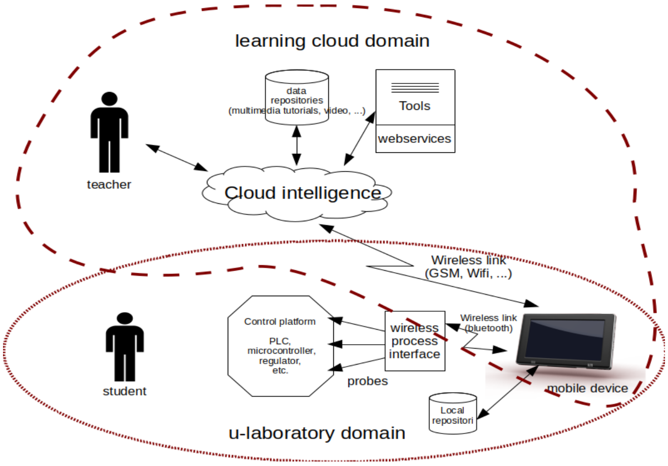

Fig. 5. Block diagram of the technological architecture

This architecture combines mobile devices, cloud computing and Internet connectivity, enabling students to overcome their lack of expertise, maximizing target skills and minimizing instructor dependency.

An obstacle of this methodology is the availability of hardware elements capable of transferring electrical data signals from the control system and the virtual scale model to the mobile device. To solve this problem, it was developed specific hardware that brings together both elements using wireless connectivity.

B. Mobile device implementation

The mobile device is the tool used both to access the teaching material and for the virtualization of a real industrial process while connected to a real physical device. The mobile device is connected to the physical device by means of the WSB. In this case, the mobile device runs CPU-intensive software that collects information from the target system being monitored and modifies the behavior of the monitored system by sending signals.

The mobile application considers which concepts the application displays and the way that the whole experience works following [20]. To implement the mobile application, it was selected the Google Android OS for the initial prototype, the C/C++ programming language, the Qt framework and additional libraries such as Zbar, (bar code reader), Poppler (pdf rendering) and gSoap (SOAP webservices for C/C++). The Android platform was chosen because of its openness, both in terms of development environments and licensing, compared to iOS. In any case, the choice of the Qt development environment would allow it to be built for Qt for iOS.

These components were integrated to achieve the solution shown in Fig. 6, where the logical modules are represented. These modules are:

- For any network technology, a virtual serial link or a set of TCP/IP connections that transfers information between the real system and a local representation of the state of the process. This link is bidirectional, i.e. the mobile device is also capable of modifying the state of the monitored system that is generating the signals.
- An internal representation of the process state that is updated with the information gathered from the link and the information generated by the simulation model. The representation of magnitudes is independent of the acquisition hardware. We use units such as meters, revolutions-per-minute, Celsius degrees, etc.
- A simulation model and the physics and/or electrical behavior equations, incorporating sub-modules for graphical representation on the mobile device.
- A logical signal connections module that relates the simulated model signals with the signals stored in the image.
- A rule-based test engine. This engine enables the running of tests on the model and collects data about the behavior of the real system, for example, functional testing or assessment monitoring.

The next section will describe the wirless bridge linking the real process and the smartphone.

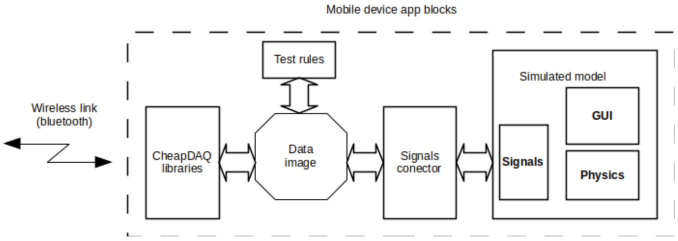

Fig. 6. Logical modules

C. Wireless signal bridge (WSB)

A key piece of the system is the WSB [21] , a wireless link between the students' target device (data acquisition hardware, PLCs, microcontrollers, etc.) and the mobile device. This link is responsible for sensing physical and electrical signals, generating electrical signals and collecting data. This component must be cheap, transparent to the system and highly reconfigurable to suit different needs. Moreover, it needs to be reconfigured from the mobile device according to the industrial process being monitored and the type of test being carried out. Fig. 7 provides a visual representation of the process. The main parts of this component are:

- A signal sampler and generator wich outputs are physically connected to the monitored or tested device and samples and generates electrical signals at fixed rates and connects it.
- A virtual serial communications port (serial link) module that handles the transfer of signal information between the sampler/generator and the mobile device. This connectivity is equivalent to legacy serial commnication pot by working on top of Bluetooth (Serial Port Profile - SPP) or WiFi connectivity.

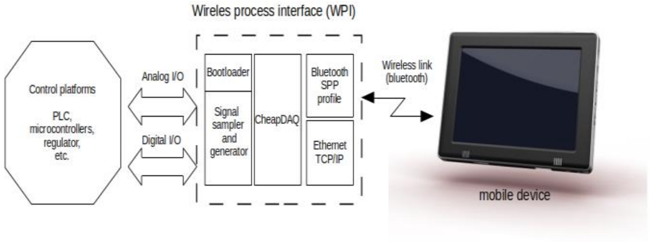

Fig. 7. Visual representation of the process

Initially, this functionality was implemented on an Arduino derivative, but in the latest implementations it was decided to use an ESP32-WROOM module, providing both Bluetooth and WiFi connectivity. Both implementations were done usig C language programming and consists on a simple infinite loop generating the values requested throug the serial link and sampling continuously the digital and analog inputs and send them to the mobile device without any optimization (suchas sending only changes) to keep a given sample rate independently of the number of changes. Bluetooth connectivity is utilized because, compared to WIFI, it is a protocol able to guarantee real-time behavior but with limited throughput. The developed approach allows real-time for fullduplex operation up to 40 ksamples/s and uses a limited amount of digital input/output pins (GPIO pins), analog-to-digital converters (ADC pins), and digital-to-analog converters (DAC pins) to generate/sample these signals. Fig. 8 shows the physical set-up.

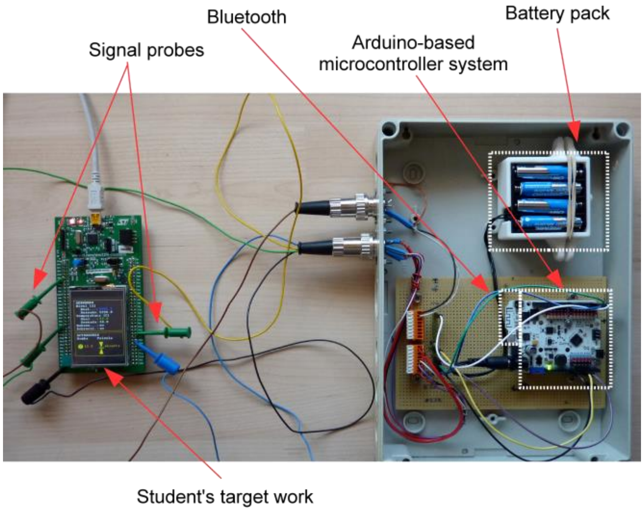

Fig. 8. Physical set-up

In essence, the WSB accepts commands from the network link based on the CheapDAQ project [22]. Data representation is independent of the platform; for example, an analog read/write is treated as a value in volts that is independent of the A/D converter and the reference voltage.

To achieve a very high degree of flexibility and adaptability, the WSB incorporates a boot-loader that enables the firmware to be updated based on the required type of monitoring application. The mobile device is responsible for reprogramming this component over-the-air on a per-task basis benefiting of the built-in capabilities of over-the-air updates (OTA) of the ESP32 platform.

D. *Cloud services*

In the cloud domain, this architecture can provide the teaching resources which will assist the student in the u-lab work. Likewise, the cloud is responsible for the provision of the software for the scale models for both the mobile device and the WSB. As a result, the software can easily be adapted to new scale models or software versions.

TABLE I
SOFTWARE COMPONENTS USED IN THE CLOUD-DEPLOYED VIRTUAL MACHINE

Component	**Description**
Linux Ubuntu server 16.04	Operating system for the virtual machine
Qt	Multiplatform development libraries for C++, HMI, etc.
Libqxt	Extension for Qt. In this case, web service extension.
Code Red development tools for ARM Cortex-M	Based on GCC compiler for ARM Cortex-M. Limited.
git-core	GIT server

Whereas the mobile device is the central part of this method, the cloud provides valuable extra functionality and services. In this u-learning approach, cloud connectivity provides the documentation, multimedia tutorials, collaborative activities and assessments.

Taking into consideration the very specific tools required, was decided to configure a Linux Ubuntu virtual machine deployed in the Amazon Web Services cloud with all the necessary software shown in TABLE I, providing the necessary tools as a REST (Representation State Transfer) service.

E. *Test bed: liquid storage tank project*

A test case system used to develop the methodology of the subject was built around the automated control of a liquid storage tank. This system includes analog and digital sensors (temperature, level, overflow, overheating, etc.) and analog and digital actuators (heater, pump, valve, etc.). Fig. 9 shows the scale model available in the laboratory, and Fig. 10 shows an image of the virtual scale model of the tank running on an Android compatible device.

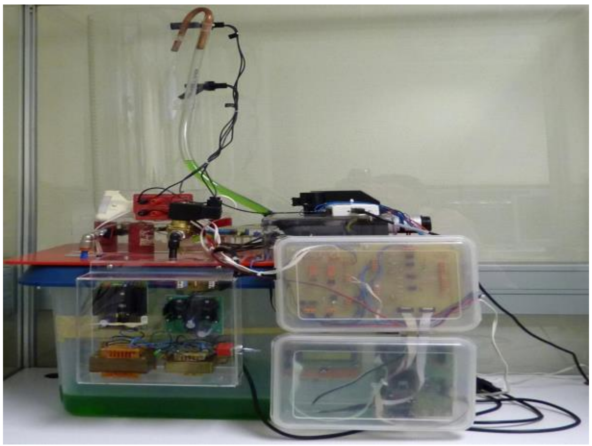

Fig. 9. Laboratory scale model

The students had to develop a control system using a STM32 Discovery microcontroller board. Such a board costs around 20 euros, so is encouraged the students to buy one for the u-lab practice.

Students develop an application that should control the tank scale model of Fig. 9, but using the u-lab approach, the scale model is only needed for demo purposes when the students present their work.

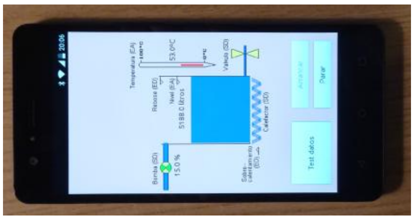

Fig. 10. virtual scale model of the tank

V. EXPERIMENTAL EVALUATION AND RESULTS

To perform an evaluation of the approach presented in this paper, was carried out a pilot experiment during three academic courses. A pilot group was formed with a total of seventy randomly selected students. These students worked with the prototype platform. The final grades of the students in the pilot group were compared with those of the rest of the students (140 students). The abilities of the pilot group were also evaluated and compared. To compare the new proposal and the traditional approach, groups come from a homogeneous population regarding the necessary initial knowledge to attend the course. At the beginning of the course, all the students were assessed using a prerequisites test. The experiences obtained were used to verify if the student sample for this experiment was statistically representative of the student population. A two-sided Student's t-test was performed on the data collected from the initial examination. The null hypothesis that the means of both populations are equal was supported by the test with a confidence for the pre-requisites test of p = 0.81183 for the first academic year, of p = 0.80824 for the second academic year, and of p = 0.82916 for the third academic year.

To obtain the final marks, the overall class grading is calculated using the following weights: problem-solving exam weight is 40%, mini-project development weight is 30%, public presentation weight is 10% and practical evaluation weight is 20%. Problems marks were obtained from the problem-solving exam, whereas practice marks were obtained from mini-project development, practical evaluation and public presentation.

The results obtained, reflect that the mean of the scores of the students using the new methodology is higher than the rest of students. Student’s t-test and the null hypothesis were used to establish the statistical difference between groups, with the results showing that the differences in marks were significant. This is evidence that the proposed platform provides better learning results than more traditional approaches (see TABLE II).

TABLE II
AVERAGE MARKS FOR TEST STUDENTS GROUP AND THE REST OF STUDENTS

	Pilot group		**Rest of students**	
	Average first, second and third year			
	Mean	Std. deviation	Mean	Std. deviation
Problems marks	7.2	2.8	6.3	2.4
Practice marks	8.7	2.5	6.7	2.2

In addition, in the third year, a skills assessment test was carried out in order to evaluate the time required to detect and correct defects in a real malfunctioning system. The tests were carried out using an e-learning platform system owned by the university, consisting of practical questions to measure student skills aimed at obtaining a realistic view and detecting possible biases. The idea is to evaluate if the proposed platform reduces the diagnostic time and helps students to repair the manufacturing process. In this experiment, some malfunctions were introduced into the real system hardware and/or source code.

From a total of 160 students, only four students (10%) in the pilot group (40 students) were unable to solve the maintenance problem in a limited time of one hour. For the rest of students, 26 (21%) were unable to solve the issues in the limited time.

Given the results of this experiment, it was considered that the pilot students were better skilled, as students without professional experience achieved similar results to those of the experts.

To obtain qualitative information on student satisfaction (and opinions on the course), it was conducted a Google Drive-based survey following Likert [23]. The survey was designed in such a way that it is simple and easy to answer. The survey was anonymous, but was conducted separately in order to distinguish between pilot groups and the rest of the students.

To ensure reliable results, students filled out the survey during two academic years, giving us the opportunity to better compare data between different years and determine the overlap between the different academic courses. Each year, three groups answered the survey, each group consisting of around 70 students. A total sample of about 400 students gives us sufficient confidence to consider these values reliable. Students gave us their opinion at the end of the course and before obtaining their qualifications; consequently, they had a more objective well-formed opinion on the use of this approach.

The overall assessment made by students in relation to the application of the proposed methodology and architecture is highly satisfactory, being of significant help to the students to achieve the target skills. Some 95% of students believe that the new proposal facilitated their learning process, which shows they prefer this approach compared to a more traditional and less interactive teaching method.

Moreover, the use of new mobile technologies introduces a motivational aspect for the students, and 93% of the students were highly motivated by the use of the proposed hands-on methodology with their smartphones or tablets. Furthermore, u-labs allow students to progress faster in learning contents and acquiring professional skills.

It can be concluded that the proposed methodology is advantageous and helpful for the students, and the students themselves also confirm that 97% of them would recommend it to other students in future courses.

Regarding the time invested by the staff, it cannot state a reduction in the teaching staff, but it can appreciate a higher satisfaction in the lab maintenance personnel associated with this project due to a reduction in the needs of real models.

VI. CONCLUSIONS

In this paper, it has been proposed a new approach for the effective deployment of u-learning laboratories in higher education, offering new possibilities for creating high quality educational experiences. It was applied over the course of three academic years in order to assess and improve its operation and use.

A complete platform was created in order to make mobile devices the key elements in the creation of ubiquitous laboratories, thereby obtaining advantages compared to the use of classic remote labs.

The application of the methodology described here had to overcome a number of challenges. Even though most of the work focused on resolving technical challenges, the resulting platform should facilitate educational activities which use mobile devices. This opens up new scenarios for mobile device-based learning without excessive additional costs. Moreover, students can use the tools during their spare time while at university, at home, and elsewhere.

In the experiments, the proposed u-lab architecture provided satisfactory results, and demonstrated the advantages and suitability of the overall methodology from the point of view of the students. This approach presents attractive economic advantages, while also leading to superior academic achievement. Furthermore, the approach can be deployed in a wide range of technical subjects.

Given these positive results, it is intended to continue with this line of research, incorporating new tools and enhancements, such as new virtual prototypes. In any case, it is necessary now to evaluate the savings or not in terms of the staff involved in this approach.

REFERENCES

[1] Möller, D., Haas, R., Vakilzadian H. (2013). Ubiquitous learning: Teaching modeling and simulation with technology. Proceedings of the 2013 Grand Challenges on Modeling and Simulation Conference, 45 (10), 125-132.

[2] Magin, D. J., Kanapathipillai, S. (2000). Engineering students' understanding of the role of experimentation. European J. Eng. Education, 25(4), 351–358.

[3] Hassan, H., Dominguez, C., Martínez, J.M., Perles, A., Albaladejo, J., Capella, J.V. (2008). Integrated Multicourse Project-based Learning in Electronic Engineering. International Journal of Engineering Education, 24:581 – 591

[4] ABET (2023). Criteria for Accrediting Engineering Programs, 2022 – 2023. Accessed 16 February 2023.

[5] Ma, J., Nickerson, J.V. (2006). Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review. ACM Computing Surveys, 38(3).

[6] Faulconer, E. K., & Gruss, A. B. (2018). A review to weigh the pros and cons of online, remote, and distance science laboratory experiences. International Review of Research in Open and Distributed Learning, 19(2).

[7] Chamunorwa, Tinashe & Modran, Horia & Ursutiu, Doru & Samoila, Cornel & Hedeşiu, Horia. (2022). Cloud-Based, Expandable Reconfigurable Remote Laboratory for Electronic Engineering Experiments. Electronics. 11. 3292. 10.3390/electronics11203292.

[8] Perles, A., Albaladejo, J., Capella, J.V., Martínez, J.M., Hassan, H., Dominguez, C. (2008). Design and Application of a Data Acquisition Card Simulator for Electronic Engineering Studies. International Journal of Engineering Education, 24, 825 – 832.

[9] Hassan, H., Martínez, J.M., Perles, A., Capella, J.V., Dominguez, C., Albaladejo, J. (2013). Smartphone-Based Industrial Informatics Projects and Laboratories. IEEE Transactions on Industrial Informatics, 9(1), 557-566.

[10] Zumsande, J., Bosselmann, S., Dagen, M., & Ortmaier, T. (2023). Design and Development of a Remote Lab for Hands-On Education in Mechatronics and Control Engineering. In repo.uni-hannover.de. Accessed 16 February 2023

[11] Nedic, Z., Machotka, J., Nafalski, A. (2003). Remote laboratories versus virtual and real laboratories. In Proceedings of the 2003 33rd Annual Frontiers in Education Conference. Boulder, CO. T3E.1-T3E.6

[12] Altalbe, Ali. (2019). Performance Impact of Simulation-Based Virtual Laboratory on Engineering Students: A Case Study of Australia Virtual System. IEEE Access, vol 7. 1-1. 10.1109/ACCESS.2019.2957726.

[13] Ruchtera, M., Klarb, B., Geigerc, W. (2016). Comparing the effects of mobile computers and traditional approaches in environmental education. Computers & Education, 54, (4), 1054–1067.

[14] Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers & Education, 87, 218-237.

[15] Gashoot, M., Eve, B., & Mohamed, T. (2023). Implementing Technology for Teaching: The Use of a Mobile/Tablet Approach for Enhancing Students' Learning (Design Interaction) Technology-Enhanced Learning (TEL). Journal of Education, 203(1), 230-241.

[16] Ritzhaupt, A. D., Gomes, N. D., Barron, A.E. (2008). The effects of time-compressed audio and verbal redundancy on learner performance and satisfaction. Comput. Human Behavior, 24(5), 2434–2445.

[17] Matsuo, K., Barolli, L., Xhafa, F., Koyama, A., Durresi, A. (2017). New functions for stimulating learners' motivation in a web-based e-learning system. Int. J. Distance Edu. Technol., 6(4), 34–49.

[18] Hernandez-de-Menendez, M., Escobar Díaz, C. A., & Morales-Menendez, R. (2020). Educational experiences with Generation Z. International Journal on Interactive Design and Manufacturing (IJIDeM), 14, 847-859.

[19] Vaquero LM, Rodero-Merino L, Caceres J, Lindner M (2015). A break in the clouds: towards a cloud definition. ACM SIGCOMM Computer Communication Review, 39:50-55

[20] Churchill D, Hedberg J (2008). Learning Object Design Considerations for Small-Screen Handheld Devices. Computers & Education, 50:881-893

[21] Capella, J. V., Perles, A., Martínez, J. M.; Hassan, H., Domínguez, C., Albaladejo, J. (2012). Ubiquitous E-Maintenance Proposal Based on the Integration of Mobile Devices and Cloud Computing. Advanced Science Letters. 18, 121-131.

[22] CheapDAQ: A project for building a cheap and open Data Acquisition Card (2019). http://www.disca.upv.es/aperles/CheapDAQ/CheapDAQ.html Accessed 16 February 2023

[23] Likert, R. (1932). A technique for the measurement of attitudes. Archives of psychology, 22(140), 1-55.

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