Anexo V. Modelo para la presentación de la Memoria final (PIE y AIE)

MEMORIA FINAL DEL PROYECTO

Curso 2017-2018

II Convocatoria de Proyectos de Innovación Educativa (PIE) y Actividades de Innovación Educativa (AIE)

Memoria final del Proyecto
Curso 2017-2018

FICHA GENERAL

Nombre del Proyecto/Actividad de Innovación Educativa:	
Desarrollos Avanzados Multi-Objetivo d Laboratorios Remotos para Actividades Educativas DAMO-LRAE	
Nombre del GID, en caso de Proyecto de Innovación Educativa (PIE)	
GID2016-17 G-TAEI	
¿Ha recibido subvención en la convocatoria?	
Si	
Nombre y DNI del Coordinador/a	
Nombre y Apellidos	DNI
Manuel Alonso Castro Gil	36025191S
Extensión	
6476	
Correo electrónico	
mcastro@ieec.uned.es	
Facultad/Escuela	
Ingenieros Industriales	
Departamento	
Dpto. de Ingeniería Eléctrica, Electrónica, Control, Telemática y Química Aplicada a la Ingeniería	
Asignatura/s en la/s que la se ha trabajado (indique entre paréntesis si la asignatura /s pertenece al primer o segundo semestre)	
Nombre de la asignatura	Facultad/ Escuela
1. Fundamentos de Ingeniería Electrónica I	Ingenieros Industriales (Primer cuatrimestre)
2. Fundamentos de Ingeniería Electrónica II	Ingenieros Industriales (Segundo cuatrimestre)
3. Diseño de Circuitos eléctricos asistidos por ordenador	Ingenieros Industriales (Primer cuatrimestre)
4. Computer modeling and simulation of electronic circuits	Ingenieros Industriales (Segundo cuatrimestre)

LÍNEA TEMÁTICA

Señale con una cruz la línea/s que corresponda

Línea I Diseño de procedimientos para mejorar el apoyo y el seguimiento de los estudiantes.	X
Línea II Diseño o desarrollo de métodos de evaluación de los resultados de aprendizaje y de las competencias específicas y genéricas adquiridas por los estudiantes en diferentes asignaturas.	
Línea III Diseño de metodología de producción de recursos didácticos en diferentes formatos (texto, audiovisual, etc.) para diferentes canales (aula virtual, canal UNED, etc.)	
Línea IV Propuestas de intervención para evitar y minimizar el abandono universitario en los primeros cursos de las titulaciones oficiales de Grado y Máster de la UNED.	
Línea V Incorporación a las asignaturas de Grado y Máster de los Objetivos del Desarrollo Sostenible (ODS) de Naciones Unidas y los valores que promueven.	
Línea VI Incorporación de nuevas tendencias didácticas a la metodología docente, especialmente en asignaturas de Trabajo Fin de Grado (TFG), Trabajos de Fin de Máster (TFM) y Prácticas, y que puedan generalizarse a diferentes titulaciones.	

Relación de miembros que han participado

Sólo se indicarán los miembros que hayan participado satisfactoriamente. Se insertarán o eliminarán tantas filas como se precisen.

Nº	Nombre completo	NIF	Facultad	Departamento
1.	Castro Gil, Manuel Alonso	36025191S	ETSIndustriales	DIEECTQAI
2.	San Cristóbal Ruiz, Elio	50196688Q	ETSIndustriales	DIEECTQAI
3.	Díaz Orueta, Gabriel	02520935C	ETSIndustriales	DIEECTQAI
4.	Pérez Molina, Clara	52367413R	ETSIndustriales	DIEECTQAI
5.	Martín Gutiérrez, Sergio	49000802S	ETSIndustriales	DIEECTQAI
6.	Nevado Reviriego, Antonio	51067986M	ETSIndustriales	DIEECTQAI
7.	Gil Ortego, Rosario	50417961Y	ETSIndustriales	DIEECTQAI
8.	López-Rey García-Rojas, África	03851582W	ETSIndustriales	DIEECTQAI
9.	Albert Gómez, Maria Jose	50417961Y	Educación	Teoría de la Educación y Pedagogía Social
10.	Elena Ruiz Larrocha	46875443V	ETSInformatica	DISSI
11.	Roberto Hernández Berlinches	05266644N	ETSInformatica	DSCC
12.	Rafael Pastor Vargas	52371733C	ETSInformatica	DSCC

Relación colaboradores

Se presentará una relación única por Proyecto/Actividad Innovación Educativa.

Nombre del Proyecto/Actividad Innovación Educativa:				
Nombre del Coordinador/a:				
Breve descripción de las actividades realizadas por los colaboradores				
Nº	Nombre completo	NIF	e-mail	Empresa/Organismo/Institución
1.	Blazquez Merino, Manuel	33506307E	mblazquez@ieec.uned.es	I.E.S. Ramiro de Maeztu
2.	Garcia Loro, Felix	02547269L	fgarcialoro@ieec.uned.es	Centro Asociado UNED Madrid
3.	Macho Aroca, Alejandro	47399651D	amacho@ieec.uned.es	Fever Labs INC.
4.	Baizán Álvarez, Pablo	53545324J	pbaizan@ieec.uned.es	Tecnobit
5.	Plaza Merino, Pedro	02662350P	pplaza@ieec.uned.es	Siemens Rail Automation
6.	Carro Fernandez, German	34895795B	gcarro@ieec.uned.es	Centro Asociado UNED Coruña
7.	Losada de Dios, Pablo	11799584D	plosada@ieec.uned.es	UNED

En Madrid, a 14 de Enero de 2019

Firma del Coordinador	Firma del Decano/Director de la Facultad/Escuela
Manuel Alonso Castro Gil	Jose Carpio Ibañez

MEMORIA DEL TRABAJO

Por favor, cumplimente cada uno de los apartados y sub-apartados que se muestran a continuación. Utilice tantas páginas como sean necesarias

1. RESUMEN.

(Debe contener los objetivos, metodología, resultado y conclusiones, con el fin de su posterior publicación en la página web del Instituto Universitario de Educación a Distancia) máximo 15 ó 20 líneas

El proyecto DAMO-LRAE (Desarrollos Avanzados Multi-Objetivo de Laboratorios Remotos para Actividades Educativas) se ha orientado para la realización de nuevos entornos educativos avanzados para sistemas complejos de Ingeniería, basados en este caso en IoT, eHealth y FPAA.
Se han realizado y se han puesto las bases para los siguientes tres objetivos:

- Creación de recursos educativos para STEM en los niveles de pre-ingeniería e ingeniería, así como Formación para la Vida, para fomentar la vocación de ingeniería y optimizar el aprendizaje de conceptos en electricidad y electrónica
- Desarrollo de laboratorios remotos para FPAA, e-Health e IoT.
- Creación y desarrollo de prácticas online en asignaturas y MOOCs.

De estas tres líneas de trabajo se han publicado los resultados más destacados (o se publicarán en breve) en cuatro artículos en cuatro diferentes congresos de máxima relevancia internacional,

- Plaza Merino, P., Sancristobal, E., Carro, G., Castro, M., Blazquez, M. y Garcia-Loro, F. Multiplatform Educational Robotics Course to Introduce Children in Robotics. FIE 2018, ASEE/IEEE Frontiers in Education Conference – Fostering Innovation Through Diversity, (Anual), págs. 1-9 (9 págs. en USB). Organizador: ASEE/IEEE, ISBN: 978-1-5386-1173-9, 3-6 de Octubre de 2018, San Jose, CA (USA).
- Baizan, P., Macho, A., Blazquez, M., Garcia-Loro, F., Perez, C., Diaz, G., Sancristobal, E., Gil., R. y Castro, M. IoT Remote Laboratory based on ARM Device - Extension of VISIR Remote Laboratories to Include Internet of Thing Support. Aprobado y se presentará en el congreso REV 2019 del 3 al 6 de Febrero de 2019 en Bangalore (India).
- Macho, A., Baizán, P., Blázquez, M., García-Loro, F., Sancristobal, E., Diaz, G., Gil., R., Pérez, C. y Castro, M. Work in progress: Proof of concept: Remote Laboratory Raspberry Pi + FPAA. Aprobado y se presentará en el congreso EDUNINE 2019 del 17 al 20 de Marzo de 2019 en Lima (Perú).
- Blázquez-Merino, M., Macho-Aroca, A., Baizán-Álvarez, P., Garcia-Loro, F., San Cristobal, E., Díaz, G. y Castro, M. Structured MOOC designed to optimize Electricity learning at Secondary School. IEEE Global Engineering Education Conference (EDUCON 2018) – "Emerging Trends and Challenges of Engineering Education", (Anual). págs. 229-238 (10). Organizador: IEEE-ES, Universidad de la Laguna, ISBN: 978-1-5386-2957-4, 17-20 de Abril de 2018, Santa Cruz de Tenerife (España).

2. OBJETIVOS DEL PROYECTO

Grado de cumplimiento de los objetivos propuestos

Diferenciando por las líneas de proyecto, los objetivos han sido:

* Línea educativa para estudiantes (incluyendo mujeres) de Educación Secundaria dentro del área de STEM:

1. Se han proporcionado herramientas didácticas y objetos educativos para optimizar el aprendizaje de temas relacionados con la Ingeniería eléctrica y electrónica. Para ello se han desarrollado diversos cursos MOOCs disponibles gratuitamente (en castellano y en inglés) así comos e han realizado mesas redondas y seminarios en congresos para promocionar contenidos y actividades para jovenes y mujer en ingeniería.
2. Con todo lo anterior se han fomentado vocaciones en Ingeniería entre los alumnos y alumnas de esta etapa educativa.

Estas acciones realizadas se unen con los objetivos de la tercera línea,
* Línea de creación y desarrollo de prácticas online en asignaturas y MOOCs.

Línea de desarrollo y diseño de nuevos laboratorios remotos:
* IoT y e-Health:
Se ha desarrollado la estructura de un laboratorio remoto de IoT, puesto que existen numerosos laboratorios de electrónica, ninguno de los actuales está dedicado a las tecnologías IoT de forma que los alumnos puedan adquirir unas competencias prácticas en las tecnologías de IoT. Estas prácticas incluyen numerosas áreas de conocimiento: física, química, electrónica, programación, comunicaciones, seguridad electrónica.
Para el desarrollo se ha partido de las investigaciones y trabajos previos realizados en los grupos de investigación e innovación educativa del departamento, en especial las que se han llevado a cabo en torno al laboratorio remoto de prácticas VISIR. Por ello el desarrollo del nuevo laboratorio de IoT es compatible con VISIR y además está basado en él.
* FPAA:
El desarrollo de esta línea se basa en el estudio de la reconfiguración dinámica en dispositivos electrónicos y su aplicación en diferentes ámbitos, principalmente en el campo de la educación, para su posterior transferencia de los conocimientos adquiridos por los alumnos a la industria. El laboratorio remoto diseñado puede ser utilizado de forma presencial, para conocer y comprender los conceptos en los que se basa la tecnología de los FPAA y como esta tecnología puede ayudar a comprender otros conceptos de electrónica analógica de forma más sencilla, más segura y de una manera más eficiente.

Otro de los objetivos que se ha tenido en cuenta es la adaptación del el proceso de publicaciones a los sistemas actuales de Acceso Abierto y publicación rápida, (Open Access), explorando esta nueva via de diseminación internacional.

3. DESCRIPCIÓN DE LA EXPERIENCIA DE INNOVACIÓN.

Metodología y el plan de trabajo seguidos, con una breve descripción de las tareas, actividades y/o iniciativas llevadas a cabo. A modo de ejemplo:

- *Diseño y planificación del trabajo*
- *Instrumentos aplicados (encuestas, cuestionarios, otros, pueden incluirse anexos)*
- *Número de estudiantes que han participado con procedimientos de selección y asignación a grupos, en el caso de haber trabajo de grupo*
- *Número de profesores tutores que han participado*
- *Desarrollo de las actividades realizadas*

También se deben especificar las acciones del plan de trabajo previstas que no se han llevado a cabo y justificar por qué.

Las tareas realizadas han sido:
- Estudio de actividades en cursos de electrónica general y desarrollo de objetos educativos y cursos MOOCs abiertos y disponibles para todo tipo de alumnos.
- Diseño y desarrollo de laboratorio remoto sobre tecnología IoT.

- Diseño y desarrollo de laboratorio remoto sobre tecnología FPAA.
- Diseño y desarrollo de nuevas actividades educativas, preparación como objetos educativos reutilizables y MOOCs para el laboratorio remoto VISIR.

- Análisis y estudio de la puesta en marcha de metodologías, entornos, laboratorios remotos y tecnologías para el estudio de los conceptos de electricidad y electrónica en alumnos de educación secundaria.
    - Se han analizado y publicado los resultados de los alumnos de Educación Secundaria en materias técnicas tras el uso de metodologías y herramientas (laboratorios remotos) que complementan su educación tecnológica.

Para el desarrollo del presente proyecto de investigación se partirá como ya se ha mencionado de investigaciones previas desarrolladas especialmente en torno a VISIR y con el que los nuevos desarrollos son compatibles.

Se ha desarrollado durante 2018 el proyecto de innovación educativa e investigación para el desarrollo de nuevos recursos educativos, dentro de un entorno multi-objetivo, y con tecnologías avanzadas, que permitan la utlización de laboratorios remotos para la docencia, investigación e innovación educativa en Internet de las Cosas (IoT), Área de Salud (e-Health) y Dispositivos Analógicos Programables (FPAA). Estos laboratorios coordinados e integrados permitirán a los estudiantes que los utilicen interactuar, con los componentes e instrumentación más avanzados que nos podemos encontrar en un laboratorio de prácticas de última generación.

De esta forma, los estudiantes pueden practicar y obtener los mismos resultados que los de ese mismo trabajo realizado en un laboratorio de prácticas convencional. Pero, en este caso, en vez de interactuar de forma física en el propio laboratorio, se realiza de forma remota mediante un navegador web, pero con la misma experiencia, conocimiento y adquiriendo las mismas competencias que en una práctica presencial. Y mejorada, al utilizarse técnicas de inmersión y multimedia avanzadas, y poder tener en su ordenador y navegador todo slos materiales, vídeos, prácticas, etc., materiales creados al efecto para mejorar esa experiencia práctica.

Se han desarrollado (y se complementarán en los siguientes trabajos de Doctorado) un conjunto de prácticas, donde los estudiantes pueden interactuar con diferentes sensores y actuadores (ambientales, eventos, agricultura inteligente, gases y salud). Para ello, los estudiantes tienen acceso a diferentes entornos de sistemas embebidos con capacidad para ser programados de manera que puedan trabajar con los diferentes sensores, comunicarse entre sí mediante diferentes canales y topologías, de forma que lleguen a formar una red de sensores inteligentes.

Una de las líneas del proyecto y actividades desarrolladas ha sido enfocada a la creación de recursos educativos y ha incluido trabajos de observación, análisis, estudio y obtención de conclusiones del trabajo de alumnos de Enseñanza secundaria con dos finalidades:
1. Proporcionar a estos estudiantes, herramientas didácticas que optimicen el aprendizaje de temas relacionados con la Ingeniería eléctrica y electrónica.
2. Fomentar vocaciones en Ingeniería entre los alumnos y alumnas de esta etapa educativa.

En el siguiente apartado de resultados se incluyen CUATRO articulos (dos de ellos ya publicados y otro a publicarse entre febrero y marzo de 2019) para poder evaluar los resultados obtenidos en este proyecto durante 2018.

4. RESULTADOS OBTENIDOS

Describir los resultados obtenidos haciendo referencia a:

- *Análisis realizados*

- *Descripción de los principales resultados obtenidos aportando, para ello, tablas de datos, gráficos y todos aquellos elementos de apoyo que se consideren oportunos*

A continuación se incluyen los siguientes artículos publicados (o a punto de publicarse) para remarcar los resultados obtenidos.

El primer artículo remarca el uso de técnicas de robótica en este caso para acercar a los estudiantes jóvenes a las áreas de ingeniería y STEM en general.

- Plaza Merino, P., Sancristobal, E., Carro, G., Castro, M., Blazquez, M. y Garcia-Loro, F. Multiplatform Educational Robotics Course to Introduce Children in Robotics. FIE 2018, ASEE/IEEE Frontiers in Education Conference – Fostering Innovation Through Diversity, (Anual), págs. 1-9 (9 págs. en USB). Organizador: ASEE/IEEE, ISBN: 978-1-5386-1173-9, 3-6 de Octubre de 2018, San Jose, CA (USA).

El segundo artículo remarca el uso educativo de actividades de enseñanza de electrónica general para acercar a los estudiantes jóvenes a las áreas de ingeniería y STEM en general, así como los entornos desarrollados

- Blazquez-Merino, M., Macho-Aroca, A., Baizán-Álvarez, P., Garcia-Loro, F., San Cristobal, E., Díaz, G. y Castro, M. Structured MOOC designed to optimize Electricity learning at Secondary School. IEEE Global Engineering Education Conference (EDUCON 2018) – "Emerging Trends and Challenges of Engineering Education", (Anual). págs. 229-238 (10). Organizador: IEEE-ES, Universidad de la Laguna, ISBN: 978-1-5386-2957-4, 17-20 de Abril de 2018, Santa Cruz de Tenerife (España).

Y los dos últimos artículos remarcan el desarrollo de los laboratorios de IoT y FPAAs y los resultados obtenidos hasta el momento en el proyecto.

- Baizan, P., Macho, A., Blazquez, M., Garcia-Loro, F., Perez, C., Diaz, G., Sancristobal, E., Gil., R. y Castro, M. IoT Remote Laboratory based on ARM Device - Extension of VISIR Remote Laboratories to Include Internet of Thing Support. Aprobado y se presentará en el congreso REV 2019 del 3 al 6 de Febrero de 2019 en Bangalore (India).
- Macho, A., Baizan, P., Blazquez, M., Garcia-Loro, F., Sancristobal, E., Diaz, G., Gil., R., Perez, C. y Castro, M. Work in progress: Proof of concept: Remote Laboratory Raspberry Pi + FPAA. Aprobado y se presentará en el congreso EDUNINE 2019 del 17 al 20 de Marzo de 2019 en Lima (Peru).

Como ampliación se pueden consultar igualmente otros dos artículos publicados.

- Macho, A., Garica Teruel, M., Baizan, P., Blazquez, M., Garcia-Loro, F., Sancristobal, Diaz, G., Gil, R. y Castro, M. Dynamic Configuration in FPAA and its Use in Education. FIE 2017, ASEE/IEEE Frontiers in Education Conference – Educating Our Future, Honoring Our Past, (Anual), págs. 1-7 (7 págs. en USB). Organizador: ASEE/IEEE, ISBN: 978-1-5090-5920-1, 18-21 de Octubre de 2017, Indianapolis, IN (USA).
- Blazquez, M., Macho, A., Baizan, P., Garcia, F., San Cristobal, E., Diaz, G., Castro, M., y Plaza, P. Experiencia Didáctica en la Escuela Secundaria con el Laboratorio Remoto VISIR. TAEE 2018. XIII Congreso sobre Tecnologías, Aprendizaje y Enseñanza de la Electrónica, (Bianual). págs. 299-308 (10). Organizador: Universidad de La Laguna. ISBN: 978-84-09-03113-9, 20 al 22 de Junio de 2018, Tenerife (España).

Multiplatform educational robotics course to introduce children in robotics

Pedro Plaza
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
pplaza@plazarobotica.es

German Carro
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
germancf@ieee.org

Manuel Blazquez
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
manuel.blazquez.merino@gmail.com

Elio Sancristobal
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
elio@ieec.uned.es

Manuel Castro
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
mcastro@ieec.uned.es

Félix García-Loro
Departamento de Ingeniería Eléctrica, Electrónica y Control (DIEEC) (UNED)
Madrid, España
fgarcialoro@ieec.uned.es

Abstract*—Robotics and computational thought are ideal tools for developing science, technology, engineering and mathematics (STEM) pedagogy. Throughout this paper a modular and adaptive course is presented, the main objective of which is to make known simple and economic tools of educational robotics. This course is aimed at those who want to discover the possibilities of educational robotics in the context of the introduction to robotics. Today, robotics training tools are raised with the aim of promoting innovation and motivation of students during the learning process. Robots are becoming more and more common in our daily lives; therefore, it is important to integrate robots into all levels of our society. The course is designed to work with the Scratch, Crumble and Arduino tools as STEM enhancers. Using Scratch, interactive stories, games and animations can be programmed. Scratch helps young people to acquire and improve skills such as think creatively, think systematically, and work collaboratively. Scratch is a project of MIT Media Lab's Lifelong Kindergarten Group. It is offered free of charge. On the other hand, Crumble is an easy-to-use programmable controller. Its programming interface uses a block programming language based on Scratch that makes it easy for children from 10 years old to use it. In addition, the hardware elements associated with Crumble are very intuitive and easy to connect. Last, but not least, Arduino is an open source electronic platform based on hardware and software that is easy to use. It is a platform that incorporates a simple microcontroller and an interface development environment to create the applications to be downloaded on the board. The course offers a three-tiered journey through three levels with each of the three tools. It consists of a total of 9 modules. This course has a very practical approach. A project-based pedagogical methodology is used. Experiments are promoted, where trial and error are part of learning and self-discovery. The student learns to have more autonomy and responsibility. Knowledge is acquired in different disciplines. It develops: motor skills (scale mobility in the hands), group skills, allowing people to socialize, creative abilities, and learning in a fun way. The operational details, materials used and examples of activities for some modules are also presented with the expectation that all teachers will be able to adapt these activities in their class. In addition, results are included from several groups of students who have already completed some modules. Despite not having a large number of students, the experience provided results that may be useful for other teachers to promote a course with similar or equal content for more results. The results of this work show that it is important to combine theory and practice to include fun tasks intertwined with the challenges of applying theory to problem solving.

Keywords—education; programming; robotics; STEM

I. Introduction

Robotics and computational thinking are ideal tools for developing science, technology, engineering and mathematics (STEM) pedagogy. This is because robotics integrates with areas of knowledge such as mechanics, electricity, electronics and computer science. In addition, robotics has been one of the main drivers of the modernization and continuous improvement of most processes for several decades now [1].

But what is robotics? The creator of the term "robotics" was Isaac Asimov in its 1941 history. Although, as Asimov himself later acknowledged in Gold, he thought he was using an existing word. "The Robot Chronicles." One such story is the well-known book "I, Robot". The image of the robot that appears in his work is that of a well-designed machine with a guaranteed safety that acts in accordance with the three laws of robotics.

From 1941 to the present day, robotics has become a benchmark for science and technology. Today, robotics is a key part of modernizing and improving most processes. This is due to the ease with which robots can be integrated into industrial processes [2]. The author in [3] presents the development of an active ankle-foot orthosis (AFO) to improve walking ability. Another example of robotic implementation is the robot with light, elastic legs that uses surface tension to stay on the surface of the water described in [4].

As noted, robotics is being included as a powerful tool to encourage students to access science, technology, engineering and mathematics (STEM) subjects. STEM education has great potential and its popularity is growing day by day [5]. Primary education is confronted with the development of STEM thinking and STEM-friendly attitudes in early learners. Reference [6] describes design, implementation and evaluation as a solution to address both problems. Reference [7] provides vision and guidance for the future on many interesting aspects: innovative teaching methods and tools (including assessment), community aspects, aspects of curriculum design and aspects of

978-1-5386-1174-6/18/$31.00 ©2018 IEEE

instructional design that consider the costs of UMI (ubiquitous computing, mobile computing and the Internet of Things) to improve STEM education. Educational technology is a powerful tool that is increasing its presence day by day. Some examples are those provided by [8] as part of the eMadrid network.

However, the introduction of robotics as a learning process is not a trivial matter. Robotics combines areas of knowledge such as mechanics, electricity, electronics and computing. Robots are machines capable of making decisions and adapting to different situations. They are usually built with elements such as sensors, actuators and process units [2].

Throughout this paper we present a modular and adaptive course, whose main objective is to introduce simple and economical tools of educational robotics. This course is aimed at those who want to discover the possibilities of educational robotics in the context of the introduction to robotics. Today, robotics training tools are designed to promote innovation and motivation of students during the learning process. Robots are becoming increasingly common in our daily lives; therefore, it is important to integrate robots into all levels of our society.

The tools chosen for the proposed course are Scratch, Crumble and Arduino. Scratch is presented as the simplest and most user-friendly tool for programming and robotics. Authors in [9] presents the use of Scratch - a widely used tool - as a tool to guide students in the acquisition of robotics skills. This paper shows Scratch as a first step in introducing students to robotics. The reference [10] shows the opportunities that Scratch offers for use in the training of future designers of the worlds offered by computing. Thus, it aims to turn consumers of computing resources into explorers and designers of the worlds offered by computing. In research such as that shown in [11] the authors examine predictive analysis of users' written communication through commentary in an open online social networking forum at Scratch.mit.edu. Reference [12] details a comparative study to investigate any differences in the transition of students' motivation to learn programming using Scratch and App Inventor for Android in K-12 educational environments.

Crumble is the tool of choice, as the programming interface is visual, Scratch-based, and it makes programming tasks easier for students as they delve into the hardware elements that are introduced with this tool.

Despite being an emerging tool, the use of Crumble is beginning to spread as a tool that promotes STEM knowledge learning. Due to its reduced cost and simplicity of use, it is not only limited to use in classrooms or private educational centers, but also allows for its use at home [13].

Last but not least, Arduino is used. This tool is the most complex of the three, but it is also the tool that allows more development. In the field of digital design, Arduino-based environments are used as the main platform in courses on microcontrollers and advanced digital design techniques. Thanks to the use of Arduino students showed better design skills and motivation compared to students in past courses [14]. Arduino based developments, in part due to their low cost, ease of use, flexibility and wide adoption in both consumer and industrial applications are being considered in education. The reference [15] shows as an example the transformation of automotive laboratories using Arduino shields. The authors in [16] show the new possibilities in education provided by the Bring Your Own Device (BOYD) policies adopted at different stages of learning. This is easy to implement with devices such as Arduino, Arduino shields and visual software (Visual Basic and Scratch) for educational purposes. A very important component of engineering is that the knowledge acquired in the classroom can be applied in practice. In the reference [17] the authors review concepts such as the application of practical teaching laboratories to the technological areas related to the project. They also include in their study the use of the Arduino and Android platforms. Arduino features support for tools such as LabVIEW for students participating in Virtual Measurement and Instrumentation programming courses [18]. There are also developments such as the haptic controller for the Arduino based educational environment. This platform allows students to implement haptic algorithms in multiple mechatronic devices [19].

This paper consists of four sections. Section II describes the course from the point of view of the tools used and the levels of difficulty involved. Section III details an example of educational material that can be used for the development of the course. Section IV includes the results obtained from the deployment of the first module using Scratch and a basic difficulty level. The last section contains the conclusions of the material presented.

II. COURSE DESCRIPTION

The context of this course is the introduction to robotics for boys and girls. Given the context of the course and the target audience, no prior knowledge or specific skills are required. This course is designed to be started by children of 6 years of age and depending on the development of skills and the acquisition of competencies, students can program through the different modules that make up the course.

This course is based on three tools widely used in teaching. The tools are characterized by two main parameters: the degree of simplicity of their use and the degree of complexity of the applications that can be made with them.

On the other hand, the course consists of three levels of difficulty. A first level is very simple and has as its main objective to be a contact of the students with the tool in question. This is followed by an intermediate level, and finally a level of greater complexity with which it is intended that students can develop complex applications in the field of the tool used and in the framework of educational robotics.

Figure 1 shows the set of matrix modules placed by type of tool used and level of difficulty.

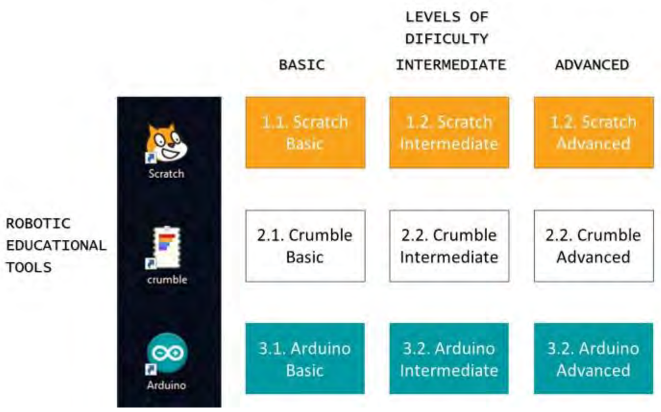

Fig. 1. Course matrix.

For all the above reasons, the course has been designed as a set of three difficulty modules with each of the three tools. From there a total of nine modules are obtained for the complete development of the course.

Each module is designed to be deployed in one-hour sessions on a weekly basis. Therefore, the deployment of each module can be balanced with the school terms. For example, if the school year begins in October and ends in December, a module can be planned to be delivered in four one-hour sessions for each of the months of October, November and December.

A. Robotic educatianl tools and resources

The first tool used in the course is Scratch. Scratch was developed by the Education Division of MIT (Massachusetts Institute of Technology). The mission of the Massachusetts Institute of Technology is to advance knowledge and educate students in science, technology and other scholarship areas that will best serve the nation and the world in the 21st century. Interactive stories, games and animations can be programmed with Scratch [20].

Scratch is provided free of charge, is very easy to use and is perfectly valid for ages 6 and up.

The main advantages of Scratch are:

- Block-based visual programming language. This facilitates access for children who have never programmed before, as well as for children who are not proficient in reading comprehension.
- Allows image editing and use of predefined images.
- It has a command categorization system. This allows children to quickly and easily find the command they need to use at any given time.

The disadvantages of this tool are the following:

- Only the peripherals of the computer can be used: the screen, the speakers, the microphone, the keyboard and the mouse.
- It does not allow the interaction of programs on one computer with programs on another computer.

The second tool used in the course is Crumble. Crumble is an electronic board to which up to two motors, lights, switches and sensors can be connected to control its operation. It connects to the PC via USB and can be programmed using the free software. They are manufactured by Redfern Electronics and some accessories are available that are compatible with the Crumble [21] card.

Crumble software is provided free of charge and the controller is priced at £10. It is very easy to use but incorporates hardware and mechanical components that limit the minimum age of the users. It is perfectly valid for ages 8 and up.

The Crumble controller is a card that is capable of handling motors, analog and digital sensors, Sparkles and servos.

The main advantages of Crumble are:

- Block-based visual programming language. The programming language is based on Scratch.
- Like Scratch, it has a command categorization system,
- Allows interaction of the controller board with different types of electrical and electronic devices.
- Allows the use of static and mobile robotic platforms. This feature is of utmost importance, as it promotes motivation and helps to gain students' attention.

The disadvantages of this tool are the following:

- The number of electrical and electronic devices with which the controller board can interact is limited. In addition, no more than six elements can be connected simultaneously, limiting the applications that can be developed with Crumble.
- The interaction of the programs of one controller with the programs of another controller is very limited due to the low number of general purpose input/output ports.

The third tool used in the course is Arduino. Arduino was launched by Massimo Banzi in 2005 as a modest tool for Banzi students at the Instituto de Diseño de Interacción Ivrea (IDII). Arduino is an easy-to-use hardware and software based open source electronic platform [22]. It is a platform that incorporates a simple microcontroller and an interface development environment to create the applications to be downloaded to the board. The use of Arduino projects covers a wide range of applications, from robotics to automatic control irrigation systems.

The Arduino software is provided free of charge the controller has a price of 20 €. It is very simple to use but requires textual programming. It also incorporates hardware and mechanical components that limit the minimum age of users. It is perfectly valid for ages 12 and up.

Arduino is a card that is capable of handling both analog and digital signals. It integrates a variety of communication protocols such as serial communication, SPI (Serial Peripheral Interface), I2C (Inter-Integrated Circuit) and others. Including Arduino compatible shields, the controller can be used for any type of application, from motor control to the implementation of a robotic remote laboratory.

The main advantages of Arduino are:

- Allows interaction of the controller board with any type of electrical or electronic device.
- Allows the connection of a large number of electrical and electronic devices simultaneously.
- Allows connection of multiple controllers via wired or wireless communication.
- Allows the use of static and mobile robotic platforms.
- It is possible to implement any type of robotic application.

The disadvantages of this tool are the following:

- Textual programming language. Students will experience difficulties with the language syntax. In addition, the commands used must be known by heart or they will have to resort to examples or the reference guide.
- Given the wide variety of possibilities offered by Arduino, the complexity of the applications requires a great deal of time and it is necessary to define a stricter work methodology than with the previous tools.

B. Levels of dificulty

Three levels of difficulty have been defined for this course: basic, intermediate and advanced. The basic level aims to provide students with a first contact with the tool. It is also intended that students begin to know the different elements with which the tool can interact when implementing different applications. At this level, the applications developed will be very similar for each of the three tools. Secondly, the intermediate level already starts from the premise that students have acquired the skills of a basic use of the tool. Therefore, at this level, more in-depth use of the tool will be deepened, and more complex applications will be developed. At this level, the applications developed may have a degree of similarity, but they will have connotations specific to the tool used. Finally, through the Advanced level, students will work with more complex and tool-oriented applications they are using.

C. Course metrics and indicators

To assess whether a student has acquired the necessary skills and abilities, different metrics and indicators are proposed that should be used to know if a student is ready to progress to the next module. Two types of measurement tools are proposed: firstly, the analysis of the instructor throughout the sessions, and secondly, the use of control surveys at the beginning and end of each module.

The age of the students should be considered when making the transition from one module to another. This is important, especially because of the recommended minimum age for each of the tools.

It is also important to know the concerns of students. A student may complete the intermediate Scratch module and the natural transition would be to the advanced Scratch module. But if the student is interested in starting the Crumble module, it would be advisable to take this opinion into account when choosing the next module to be taken by the student.

D. Student progress

Given the structure of the course, it is possible to make many transitions between modules. Figure 2 shows different possible transitions. First, you could take a tour from basic advanced Arduino Scratch to all levels of difficulty and all the tools. This path is represented by Figure 2 as blue arrows marked with identifier 1. It is also possible, if the student's age is equal to or greater than the recommended age for each of the tools, for a student to attend the basic levels of each tool first, then the intermediate levels and finish the advanced levels of each of the tools. advanced Arduino Scratch to all levels of difficulty and all the tools. This path is represented by Figure 2 as green arrows marked with identifier 2.

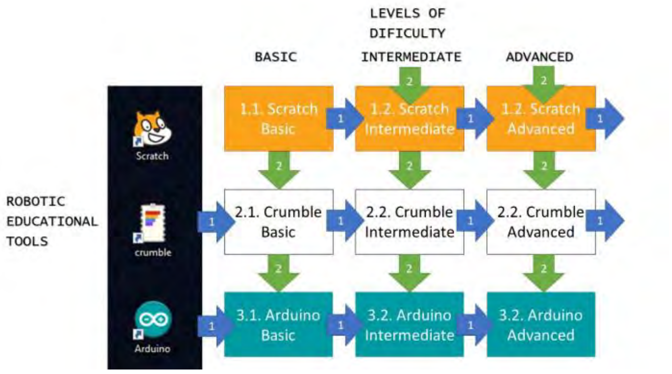

Fig. 2. Module transitions.

In addition, it is not a prerequisite to start at the basic level of Scratch. If a student has previous experience with programming and robotics or has an age and knowledge that tools like Scratch and Crumble are too trivial for him or her, this student could start with the basic Arduino module.

III. Example of Material

This section describes a cross-platform material oriented to the basic level. That is, the same content is used to be deployed with Scratch, Crumble and Arduino. The idea is to develop a material with very similar objectives, but with an implementation adapted to each of the tools. Throughout the basic level, three elements of real life will be dealt with, with which the students may be familiar. The first element is a traffic sign, the second element is a garage access barrier, and lastly, it will work a follower lines - navigation of mobile platforms using sensors. Each of the modules is divided into four parts. A first part to familiarize the students with the corresponding tool. A second part for them to work on the implementation of the traffic signal. A third part for students to develop the garage access barrier. And a last part for the line follower to be implemented by the students.

A. *Scratch basic level*

In the first part of this module, students are shown the structure of the development interface and its different elements. The panels that make up the development interface, command categorization, some basic commands, and the display panel are explained. At this point, we move on to activities in which the students have more participation. First, you work on programming without a computer. Students must define invented commands, define a list of them, and finally, execute that set of instructions. Then they must start programming with Scratch. The first challenge is to program the Scratch cat to move from left to right. The next exercise aims to get the Sprite to paint the background as it advances. Using the program generated so far, students must modify the program so that the Sprite draws a triangle and a square. To end this part, students must define a word, share it with others, and create a story with all the words. With that story defined, students must do a program with Scratch.

In the second part we work on implementation of a traffic signal with Scratch. The first step is to create a traffic sign with Sprites. To do this, students will use the Sprites as traffic signal lights. Then they will create a junction with two traffic signs, and then they will create a junction with four traffic lights. At this point, students are challenged to create a circuit with two traffic signs. Subsequently, students must use Sprites to create the lights for the pedestrian crossing portion. Finally, the final objective is to implement a traffic signal to control the crossing of vehicles and pedestrians.

In the third part, we work on the implementation of a garage access barrier. To do this, students must use a Sprite to implement the barrier. They must also include a color sensor in the programming so that the barrier knows when a vehicle is waiting, passing, or no vehicle is present. In addition, the garage barrier must include a traffic light signal, to inform you when it can pass, when caution is required because the barrier is opening or closing and, finally, to inform you when it cannot pass because the barrier is closed.

In the last part, students should use a Sprite containing color detectors so that a black line can be detected on a white background. They must also modify the background to create a circular-shaped circuit. Once these two elements and the Sprite program are developed, students must modify their programs to make sure that their virtual robot follows lines can move as quickly as possible without leaving the circuit. The next step is to use a rectangular shaped circuit. Finally, the Sprite will be used to circulate in more complex circuits that the students themselves must create.

B. *Crumble basic level*

The first part of this module shows students the Crumble hardware. The controller board is described and the hardware elements to be used along the module are described. These hardware items are such as the battery holder, the electrical connection cables, the USB cable for programming the controller card, the Sparkle, the ultrasonic sensor, the motors and the line detection sensor. The following describes the structure of the development interface and its different elements. The panels that make up the development interface, the categorization of commands and some basic commands are explained. At this point, we move on to activities in which the students have more participation. The first challenge is for them to program the controller so that the Sparkle looks a color of their choice. The following exercise is intended to make the Sparkle blink with a one-second power-on period and a one-second power-off period. To finish this part, students should program the controller so that the Sparkle displays a succession of colors of their choice.

In the second part, we work on the implementation of a traffic signal with Scratch. The first step is to create the sequence of aspects to be displayed by the Sparkle. Students will use the following sequence: two seconds red, two seconds yellow and two seconds green. They will then modify their program so that the sequence runs cyclically. In a next step, students should modify their schedule for the yellow aspect, instead of being a fixed aspect, or an intermittent aspect. At this point, students are challenged to create the lights on the pedestrian crossing side, i.e. fixed red, fixed green and flashing green. Finally, the final objective is to implement a traffic signal to control the crossing of vehicles and pedestrians.

In the third part, we work on the implementation of a garage access barrier. To do this, students must use a servo to implement the barrier. They must also include an ultrasonic sensor so that the barrier knows when a vehicle is waiting, passing, or no vehicle is present. In addition, the garage barrier must include a traffic light signal, to inform you when it can pass, when caution is required because the barrier is opening or closing and, finally, to inform you when it cannot pass because the barrier is closed.

In the last part, students must use a wheeled robot containing line detectors so that a black line on a white background can be detected. A white surface and black insulating tape will be used to draw the different circuits. The first basic circuit will be a circular one Once a program is developed that makes the robot follow the circular circuit, students must modify their programs to make sure that their robot follows lines can move as quickly as possible without leaving the circuit. The next step is to use a rectangular shaped circuit. Finally, it will use more complex circuitry that the students themselves must create.

C. *Arduino basic level*

In the first part of this module, students are shown the Arduino hardware. The controller board is described and the hardware elements to be used along the module are described. These hardware items are such as the electrical connection cables, the USB cable for programming the controller card, the LEDs (Light Emitter Diode), the ultrasonic sensor, the motors and the line detection sensor. The following describes the structure of the development interface and its different elements. It explains the structure of Arduino programs, the general syntax of the language, how the ports are configured, and how the ports on the card are written and read. Also included are explanations on how to choose the COM programming port and which card to choose before programming. Finally, it details how a program would load on the Arduino card. At this point, we move on to activities in which the students have more participation. The first challenge is to program the controller so that the LED integrated in the board looks fixed. The following exercise is intended to make the LED blink with a one second power-on period and a one second power-off period. To finish this part, students must integrate an external LED into the board and use the program created previously.

In the second part, we work on the implementation of a traffic signal with Arduino. The first step is to connect an LED for every aspect of the traffic signal. Second, students must program the sequence of aspects to be displayed by the LEDs. Students will use the following sequence: two seconds red, two seconds yellow and two seconds green. In a next step, students should modify their schedule for the yellow aspect, instead of being a fixed aspect, or an intermittent aspect. At this point, students are challenged to create the lights on the pedestrian crossing side, i.e. fixed red, fixed green and flashing green. Finally, the final objective is to implement a traffic signal to control the crossing of vehicles and pedestrians.

In the third part, we work on the implementation of a garage access barrier. To do this, students must use a servo to implement the barrier. They must also include an ultrasonic sensor so that the barrier knows when a vehicle is waiting, passing, or no vehicle is present. In addition, the garage barrier must include a traffic light signal, to inform you when it can pass, when caution is required because the barrier is opening or closing and, finally, to inform you when it cannot pass because the barrier is closed.

In the last part, students must use a wheeled robot containing line detectors so that a black line on a white background can be detected. A white surface and black insulating tape will be used to draw the different circuits. The first basic circuit will be a circular one Once a program is developed that makes the robot follow the circular circuit, students must modify their programs to make sure that their robot follows lines can move as quickly as possible without leaving the circuit. The next step is to use a rectangular shaped circuit. Finally, it will use more complex circuitry that the students themselves must create.

IV. Resutls from Experience

This section contains all the details of the experience carried out with the deployment of the basic Scratch module to a group of children without any previous programming or robotic experience.

A. Course location and resources used

The course took place in the center of La Estera, in the town of Camarma de Esteruelas. Camarma de Esteruelas is located in the eastern part of the Community of Madrid. La Estera is an independent socio-cultural center, self-funded by neighbors and a non-profit organization.

The classroom is made up of tables that form an island. On one side of the island the visual learning material is projected. On the other hand, the instructor manages the computer that contains the audiovisual material, presents the session and interacts with the children.

Students have personal computers (PCs), each of which is used in pairs. These PCs run Lubuntu as an operating system. Lubuntu is a lightweight version of the Ubuntu distribution that is characterized by optimizing the resources of computers that do not have a lot of RAM (Random-Access Memory) or the speed of its microprocessor is not very high. This operating system was chosen because of its compatibility with Scratch, Crumble and Arduino programming environments. In addition, Lubuntu can be used free of charge and free software can be installed for educational purposes.

B. Student profiles

The student group consisted of eight students aged 6 to 11. Four students were under the age of 8. The rest of the students were between 9 and 11 years old.

One of the students is a girl (10 years old) and the other thirteen are boys. Table I summarizes the grades students have. In addition, Table I includes the correspondence between the Spanish educational level and the ISCED (International Standard Classification of Education) level.

TABLE I. Students' Grades

Spanish educational grade	**ISCED level**	**Number of students**
Primary Education	1	14

Before starting the module, a pre-test was conducted to obtain the concerns about their attendance at the module. They were also asked about their previous knowledge about programming, robotics and the use of the Scratch tool.

Table II compiles the responses to the other questions related to previous knowledge about programming, robotics and the use of the Scratch tool. Most of the students had not programming, robotics and Scratch experience.

TABLE II. Pre-test responses

Question	**Student's level (1 – None; 5 – High)**				
	1	**2**	**3**	**4**	**5**
Programming experience	14	0	0	0	0
Programming knowledge	14	0	0	0	0
Robotics knowledge	14	0	0	0	0
Scratch experience	12	1	1	0	0
Scratch knowledge	12	1	1	0	0

C. Course results

In the first part, most of the students had their first contact with Scratch. This part is eminently theoretical but combined with the participation promoted by the instructor. As the instructor explained the theoretical concepts, the participants could experiment to a greater or lesser extent. All participants completed the first activity. The rest of the activities required additional clarification and assistance from the instructor. Table III summarizes information regarding the activities that were completed by the students.

TABLE III. FIRST PART ACTIVITIES AND STUDENTS WHICH COMPLETED

Activity title	Completed without help	Completed with some help	Completed with help
Scratch envorionment	14 (100 %)	0 (0 %)	0 (0 %)
Programming without computer	0 (0 %)	2 (14 %)	12 (86 %)
Basic programming	14 (100 %)	0 (0 %)	0 (0 %)
Programming a simple story	4 (29 %)	10 (71 %)	0 (0 %)

Table IV summarizes information regarding the activities that were completed by the students along the second part. During the first activities, the students needed help from the instructor to achieve the objectives they had set for themselves. However, the students completed the last two activities without having to be assisted by the instructor.

TABLE IV. SECOND PART ACTIVITIES AND STUDENTS WHICH COMPLETED

Activity title	Completed without help	Completed with some help	Completed with help
Working on Sprites	0 (0 %)	2 (14 %)	12 (86 %)
Basic traffic signal lights (I)	0 (0 %)	4 (29 %)	10 (71 %)
Basic traffic signal lights (II)	14 (100 %)	0 (0 %)	0 (0 %)
Complete traffic signal lights	14 (100 %)	0 (0 %)	0 (0 %)

In the third part, again needed support from the instructor during the first activities. As with the second part of the module, in this third part the students completed the last activities independently. Table V summarizes information regarding the activities that were completed by the students.

TABLE V. THIRD PART ACTIVITIES AND STUDENTS WHICH COMPLETED

Activity title	Completed without help	Completed with some help	Completed with help
Basic garage barrier	2 (14 %)	12 (86 %)	0 (0 %)
Garage barrier with detection	4 (29 %)	10 (71 %)	0 (0 %)
Garage barrier with lights	14 (100 %)	0 (0 %)	0 (0 %)
Complete garage barrier	14 (100 %)	0 (0 %)	0 (0 %)

Table VI summarizes information regarding the activities that were completed by the students during the fourth part. As can be seen from the results obtained, all the students showed greater independence in solving the challenges they had been faced with.

TABLE VI. FOURTH PART ACTIVITIES AND STUDENTS WHICH COMPLETED

Activity title	Completed without help	Completed with some help	Completed with help
Color detector	10 (71 %)	2 (14 %)	2 (14 %)
Circuit	12 (86 %)	2 (14 %)	0 (0 %)
Increasing speed	12 (86 %)	2 (14 %)	0 (0 %)
Complex circuits	14 (100 %)	0 (0 %)	0 (0 %)

Additionally, at the end of module, a post-test was conducted to obtain the opinion about the student's outcomes from the module. Firstly, a battery of question was asked with aim of getting the students' opinion about the module. Table VII compiles the students' opinion about the module.

TABLE VII. STUDENTS' OPINION ABOUT THE MODULE

Module topic	Number of students			
	Most liked	Less liked	Easiest	Hardest
Programming	3	2	10	3
Creating histories	0	12	3	6
Making real life aplications	11	0	1	5
Theory	0	0	0	0
Nothing	0	0	0	0

All questions related to verify that the students had acquired the knowledge that was intended to be transmitted throughout the course were answered correctly by all students.

On the other hand, Table VIII compiles the responses to the other questions related to acquired knowledge about programming, robotics and the use of the Scratch tool. Most of students increased their perception about programming, robotics and Scratch knowledge. Furthermore, most of students showed an increase in their curiosity about robotics.

TABLE VIII. POST-TEST RESPONSES

Question	Student's level (1 – Nothing; 5 – Many)				
	1	2	3	4	5
Programming knowledge	0	0	2	7	5
Robotics knowledge	0	0	3	3	8
Robotics interest	0	1	3	2	8
Scratch knowledge	0	0	2	7	5

At the end of the module we could see how all the students increased their motivation to program and create simple projects. At the beginning of the module, all the students had knowledge of new technologies such as computers, tablets and smartphones. Despite this, the use they made of it was a basic user use this knowledge was limited to Internet queries, games or basic functionalities. During the course, they scaled up their skills such as systems thinking, programming mentality, active learning, math, science, judgment and decision making, good communication, technological design, complex problem solving and persistence.

D. Discusion

As it can be seen from the results shown in the previous sections, a pedagogical strategy that combines theory and practice contributes to a level of attention that helps students acquire knowledge and become involved in the learning process.

As it can be seen from the results shown, Scratch is an ideal tool for introducing students to robotics. Scratch is distributed free of charge, can be used in its online or offline versions for Windows, MAC OS and Linux operating systems, and is a tool that does not require large resources from the device where it runs.

Throughout the activities, most of the students completed the proposed activities without the help of the instructor. Some of the students completed the activities with the support of the instructor. In some cases, other students were providing support to others. The need for help was not related to the age of the students or to gender.

The students enjoyed their activities and learned a lot from the experience. In addition, they improve their STEM-related skills.

V. CONCLUSIONS

As shown throughout this paper, the combination of STEM pedagogy with educational robotics presents promising opportunities for the development of skills and competencies needed by future professionals. Despite this, the introduction to educational robotics is not an easy task. But thanks to the great variety of tools such as the proposals, it is possible to contribute with cost-effective solutions that provide great flexibility to deploy varied knowledge in a way that is attractive to students.

First, it is demonstrated how a course can be planned that takes advantage of common contents to be developed with different types of platforms. Each of the above tools has many features that fit different age ranges of students. In this way, Scratch is a pure software tool that makes it easy for students to access areas of knowledge related to computer science. It is also very useful for the development of skills such as creative thinking, systematic thinking and collaborative work. Crumble, on the other hand, is a tool that enhances everything you've acquired with Scratch and makes it easier for students to access basic electrical and electronic systems. Last but not least, Arduino is a great choice when it comes to implementing virtually any type of application.

This work also includes an example of educational material for the basic levels proposed for each of the tools. For the cases in which a student must repeat a module, an educational material could be developed based on similar lines to those proposed in the example (lights, sensors, moving elements) but with other different applications. This would continue to attract attention and motivate students to help them acquire the skills and abilities they have not been able to develop adequately.

The experience discussed at the end of the paper demonstrates the potential of the course and the Scratch tool as the start of the proposed course. We still need to continue working with the proposed materials, develop more educational materials and analyze the results of more students in order to complete the proposal presented.

Finally, the results will be integrated in an open hardware platform which promotes innovation and motivation for students during the learning process [23]. The platform which is being developed presents wirelessly connections such as Bluetooth and WiFi as enhancements [24]. This research continues the development described in [25]. The doctoral thesis is being carried out in the Engineering Industrial School of UNED (Spanish University for Distance Education) and the Electrical and Computer Engineering Department (DIEEC).

ACKNOWLEDGMENT

The authors acknowledge support from the Engineering Industrial School of UNED, the Doctorate School of UNED, and the “Techno-Museum: Dis-covering the ICTs for Humanity” (IEEE Foundation Grant #2011-118LMF) and partial support from the eMadrid project (Investigación y Desarrollo de Tecnologías Educativas en la Comunidad de Madrid) - S2013/ICE-2715, the Internet of Things for European Small and Medium Enterprises (IoT4SMEs) project, the Erasmus+ Strategic Partnership (no. 2016-1-IT01-KA202-005561), mEquity (Improving Higher Education Quality in Jordan using Mobile Technologies for Better Integration of Dis-advantaged Groups to Socio-economic Diversity), Erasmus+ Capacity Building in Higher Education 2015 (grant no. 561727-EPP-1-2015-1-BG-EPPKA2-CBHE-JP), the Platform Integration of Laboratories based on the Architecture of visiR (PILAR) project, and the Erasmus+ Strategic Partnership (grant no. 2016-1-ES01-KA203-025327). And to the Education Innovation Project (PIE) of UNED, “Desarrollos Avanzados Multi-Objetivo de Laboratorios Remotos para Actividades Educativas – DAMO-LRAE”, from the Academic and Quality Vicerectorate and the IUED (Instituto Universitario de Educación a Distancia) of the UNED as well as to the project 2018-IEQ18 from the Industrial Engineering Technical School of UNED.

The authors are also thankful to El Circulo, Incomaz, Plaza Robótica, Alejandro Muñoz Montero and César Muñoz Montero due to their collaboration.

REFERENCES

[1] G. Carro, S. Martin, E. Sancristobal, F. Mur and M. Castro, "Robotics, the New Industrial Revolution," in IEEE Technology and Society Magazine, vol. 31, no. 2, pp. 51-58, Summer 2012. DOI: 10.1109/MTS.2012.2196595

[2] Plaza P, Sancristobal E, Carro G, Castro M, Blázquez M “From 4 Wheeled Remote Robot to Serious Collaborative Remote Laboratory”. Int Rob Auto J 3(4): 00065. DOI: 10.15406/iratj.2017.03.00065

[3] Mazumder, O., Kundu, A., Lenka, P., et al.: ‘Robotic AFO to enhance walking capacity: initial development’, Electronics Letters, vol. 52, no. 22, pp. 1840-1841, 10 27 2016. DOI: 10.1049/el.2016.3056

[4] Zhou, S., Zhang, W., Zou, Y., et al.: ‘Piezoelectric driven insect-inspired robot with flapping wings capable of skating on the water’, Electronics

Letters, vol. 53, no. 9, pp. 579-580, 4 27 2017. DOI: 10.1049/el.2017.0186

[5] Pickering, T. A., Yuen, T. T., and Wang, T.: ‘STEM conversations in social media: Implications on STEM education’, 2016 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Bangkok, 2016, pp. 296-302. DOI: 10.1109/TALE.2016.7851810

[6] Kintsakis, D., and Rangoussi, M.: ‘An early introduction to STEM education: Teaching computer programming principles to 5th graders through an e-learning platform: A game-based approach’, IEEE Global Engineering Education Conference (EDUCON), Athens, 2017, pp. 17-23. DOI: 10.1109/EDUCON.2017.7942816

[7] Mavroudi, A., Economides, A. A., Fragkou, O., et al.: ‘Motivating students with Mobiles, Ubiquitous applications and the Internet of Things for STEM (MUMI4STEM)’, IEEE Global Engineering Education Conference (EDUCON), Athens, 2017, pp. 37-38. DOI: 10.1109/EDUCON.2017.7942820

[8] Delgado Kloos, C., Rodríguez, P., Velázquez-Iturbide, A., et al.: ‘Digital education in the classroom’, IEEE Global Engineering Education Conference (EDUCON), Athens, 2017, pp. 31-32. DOI: 10.1109/EDUCON.2017.7942818

[9] P. Plaza, E. Sancristobal, G. Carro, M. Castro, M. Blazquez, J. Muñoz and M. Alvarez. “Scratch as Educational Tool to Introduce Robotics”. In: Auer M., Guralnick D., Simonics I. (eds) Teaching and Learning in a Digital World. ICL 2017. Advances in Intelligent Systems and Computing, vol 715. Springer, Cham. DOI: 10.1007/978-3-319-73210-7_1

[10] K. Brennan, "Learning Computing through Creating and Connecting," in Computer, vol. 46, no. 9, pp. 52-59, September 2013. DOI: 10.1109/MC.2013.229

[11] N. F. Velasquez et al., "Novice Programmers Talking about Projects: What Automated Text Analysis Reveals about Online Scratch Users' Comments," 2014 47th Hawaii International Conference on System Sciences, Waikoloa, HI, 2014, pp. 1635-1644. DOI: 10.1109/HICSS.2014.209

[12] S. A. Nikou and A. A. Economides, "Transition in student motivation during a scratch and an app inventor course," 2014 IEEE Global Engineering Education Conference (EDUCON), Istanbul, 2014, pp. 1042-1045. DOI: 10.1109/EDUCON.2014.6826234

[13] P. Plaza, E. Sancristobal, G. Carro and M. Castro, "Home-made robotic education, a new way to explore," 2017 IEEE Global Engineering Education Conference (EDUCON), Athens, 2017, pp. 132-136. DOI: 10.1109/EDUCON.2017.7942837

[14] J. C. Martínez-Santos, O. Acevedo-Patino and S. H. Contreras-Ortiz, "Influence of Arduino on the Development of Advanced Microcontrollers Courses," in IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, vol. 12, no. 4, pp. 208-217, Nov. 2017. DOI: 10.1109/RITA.2017.2776444

[15] Y. Lin, J. Conners and S. Livengood, "Assessing the use of open source microcontroller board for teaching engine sensing and communication in automotive laboratory," 2017 IEEE Frontiers in Education Conference (FIE), Indianapolis, IN, 2017, pp. 1-5. DOI: 10.1109/FIE.2017.8190738

[16] A. Garrigós, D. Marroquí, J. M. Blanes, R. Gutiérrez, I. Blanquer and M. Cantó, "Designing Arduino electronic shields: Experiences from secondary and university courses," 2017 IEEE Global Engineering Education Conference (EDUCON), Athens, 2017, pp. 934-937. DOI: 10.1109/EDUCON.2017.7942960

[17] L. Boaroli, A. D. Spacek, C. L. Izidoro, J. Mota Neto, E. Maestrelli and O. H. Ando Junior, "Data Monitoring and Hardware Control for App Android by Bluetooth Communication for Laboratory Teaching in Electrical Engineering Courses," in IEEE Latin America Transactions, vol. 15, no. 1, pp. 31-39, Jan. 2017. DOI: 10.1109/TLA.2017.7827885

[18] D. Călinoiu, R. Ionel, M. Lascu and A. Cioablă, "Arduino and LabVIEW in educational remote monitoring applications," 2014 IEEE Frontiers in Education Conference (FIE) Proceedings, Madrid, 2014, pp. 1-5. DOI: 10.1109/FIE.2014.7044027

[19] J. J. Gil, I. Diaz, X. Justo and P. Ciäurriz, "Educational haptic controller based on Arduino platform," 2014 XI Tecnologias Aplicadas a la Ensenanza de la Electronica (Technologies Applied to Electronics Teaching) (TAEE), Bilbao, 2014, pp. 1-7. doi: 10.1109/TAEE.2014.6900140

[20] Scratch [Online]. Disponible en: https://scratch.mit.edu/, visited on 6 April 2018.

[21] Redfern electronics [Online]. Disponible en: http://redfernelectronics.co.uk/, visited on 6 April 2018.

[22] Arduino [Online]. Disponible en: https://www.arduino.cc/, visited on 6 April 2018.

[23] P. Plaza, E. Sancristobal, G. Carro, M. Castro and C. Pérez, "Collaborative robotic educational tool based on programmable logic and Arduino," 2016 Technologies Applied to Electronics Teaching (TAEE), Seville, 2016, pp. 1-8. DOI: 10.1109/TAEE.2016.7528380

[24] P. Plaza, E. Sancristobal, G. Carro and M. Castro, "A Wireless robotic educational platform approach," 2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV), Madrid, Spain, 2016, pp. 145-152. DOI: 10.1109/REV.2016.7444455

[25] P. Plaza, E. Sancristobal, G. Carro and M. Castro, "Robotic Educational Tool to engage students on Engineering," 2016 IEEE Frontiers in Education Conference (FIE), Eire, PA, 2016, pp. 1-4. DOI: 10.1109/FIE.2016.7757417

Structured MOOC designed to optimize Electricity learning at Secondary School

Blazquez-Merino, Manuel (mblazquez@ieec.uned.es), Macho-Aroca, Alejandro (amacho@ieec.uned.es), Baizán-Álvarez, Pablo (pbaizan@ieec.uned.es), Garcia-Loro, Félix (fgarcialoro@ieec.uned.es), San Cristobal, Elio (elio@ieec.uned.es), Diez, Gabriel (gdiaz@ieec.uned.es), Castro, Manuel (mcastro@ieec.uned.es)

Electronics, Electric and Control Engineering Department
UNED - Universidad Nacional de Educación a Distancia
Madrid, Spain

The contents, hereby introduced, show a methodology to teach electricity to Secondary school students. As secondary teachers, one of the highest worries is to recognize the level of significance in learning in our students. Significance means permanent learning and thus, the assimilation of a solid basis conducts to make easier to understand knowledge in higher levels as our students are growing up. As a consequence of these worries, a structured massive open online course has been developed to optimize the assimilation of basic concepts, magnitudes and skills in relation with Electricity contents. The works in relation with the quantification of learning is written in this paper as well in order to show how good our students are learning and what the most important difficulties they find.

Keywords—MOOC; electricity; remote lab; VISIR; secondary school

I. INTRODUCTION

Learning the theory of electricity is not easy and neither is teaching the concepts and electrical magnitudes to secondary education students. Physics and electricity books contain a great wealth of content, but in many cases students waste their time in understanding and even imagining electrical phenomena [11]. Secondary school students are very accustomed to learning via the visual learning style, and only in the subject of mathematics they progress according to their capacity for abstraction [13]. For this reason, the technology teacher, despite having educational resources and access to advanced educational technology, struggles to have his students understand electrical phenomena. Learning becomes the mere application of formulas and laws that students replicate from the examples that the teacher shows in class. It is important to understand that learning methodology of new contents determines cognitive development and establishes strategies to achieve a solid conceptual basis[12]. The course, here introduced, has been designed according these premises.

II. CONFLUENCE OF EDUCATIONAL RESOURCES

In the context of the research study carried out in the Electrical, Electronic and Control Engineering Department of the Spanish Open University (UNED), it has been thought that many of the problems to understand electrical theory in undergraduate students could be reduced if the learning of electricity was optimized in the previous courses of the secondary stage. To achieve this goal, a MOOC (Massive Open Online Course) has been designed for students between 12 and 14 years old.

The MOOC has to include a specific methodology beneficial to this age group, and after deep reflections, we have decided to create a methodology based upon Bloom's taxonomy. It should be added that this choice has not been easy because Bloom's taxonomy [1, 10] is specified as a means of evaluation for students of higher education and there is an inadequate body of literature speaking to its application in the first courses of secondary education. However, we have thought, as an hypothesis, that this could be perfectly applied in Secondary School students. Bloom and Anderson argue that learning has two learning states, one lower and one higher. The lower state is related to the acquisition of data while the higher state allows using this data to devise approaches with which to apply knowledge to create new scenarios. Both states are implemented by the activation of lower order (LOTS) and higher order (HOTS) thinking skills, respectively. So we support the idea that at adolescent ages it is possible to activate HOTS if LOTS are properly worked and consolidated. In this way, if a student might develop his/her creative and reflective skills, meaningful learning achievement of about electricity concepts is possible and as a consequence, learning is translated into permanent knowledge. In the figure 1, Bloom-Anderson's approach is represented as two main states, each of them containing the kind of thinking activities to be practiced in the way for students to develop their own capabilities. Precisely, this scheme, later developed in section III, will be the guide in the elaboration of the didactic materials included in the MOOC.

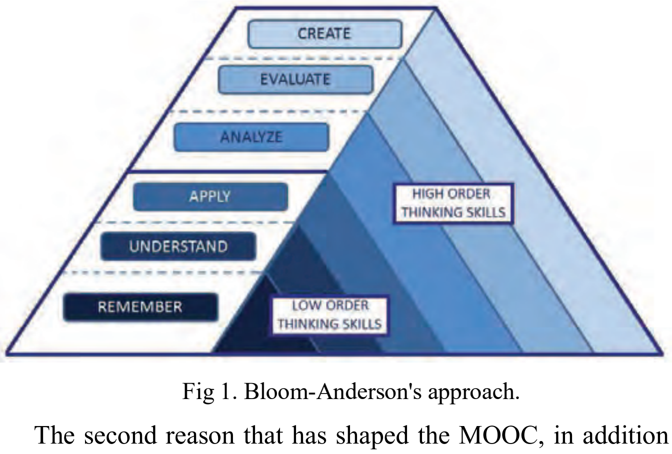

Fig 1. Bloom-Anderson's approach.

The second reason that has shaped the MOOC, in addition to the design of a specific methodology, has been the incorporation of technological resources that allow the students to move from an initial conceptualization to practice-based learning.

For this reason, VISIR remote laboratory [3,4] has been chosen as the main technical resource to build circuits and implement measurements. One might think that it could be enough to use virtual simulation applications and in a way, these are the resources that have been used so far. However, it has been decided to use a remote laboratory for several reasons. The first one is related with the easiness of the remote lab to be used what offers a very fast learning curve. This means that is plausible to invest some time with the making of the first measures but the making of the second and successive measures are reduced to the minimum [6,7]. Other of the reason of the selection of VISIR remote lab is related with the minimal cost of its implementation and use for the educational center, enhanced with the possibility for the students to practice by their own at home once they are granted with an user name and password. This allows students to use the remote 365 days a year and 24 hours a day [2,5]. The third reason to select VISIR is related to the operation of the tool from a computer. On the one hand, students handle a graphical user interface with the necessary controls to carry out an assembly in the same way as if wires and components were to be connected to a breadboard, considering the reality factor since measurements are made on real components[8,9]. This means that unlike virtual laboratories, VISIR transfers to students the concept of measurement error in the same way as if it was assembled in a real laboratory.

III. MOOC DIDACTIC MATERIALS AND RESOURCES

IES Electric Measures MOOC, as introduced in this communication, is available with the URL: http://62.204.201.27/moodle/login/index.php. In order to optimize the working time, some videos have been recorded and distributed throughout the MOOC. In figure 2, an aspect of the first steps in the MOOC and a partial view of one of the videos are shown.

Firstly, three videos have been located in the introductory section, "*Recognizing your measures practices course*". Students have to watch the videos before downloading the practice documents. With these videos, students become familiarized with the concepts of remote lab, and specifically with the use of VISIR, how to access to the lab and what methodology is applied in the course.

After completing the first section, students will then be able to access to the documents that have been carefully designed with the objective to optimize learning of electricity concepts and magnitudes. The resources have been divided into three levels (L1, L2 and L3), with each level containing the so-called Bloom-Anderson's taxonomy six stages. The first three stages haven been designed to facilitate the development of students' low order thinking skills (LOTS) and are:

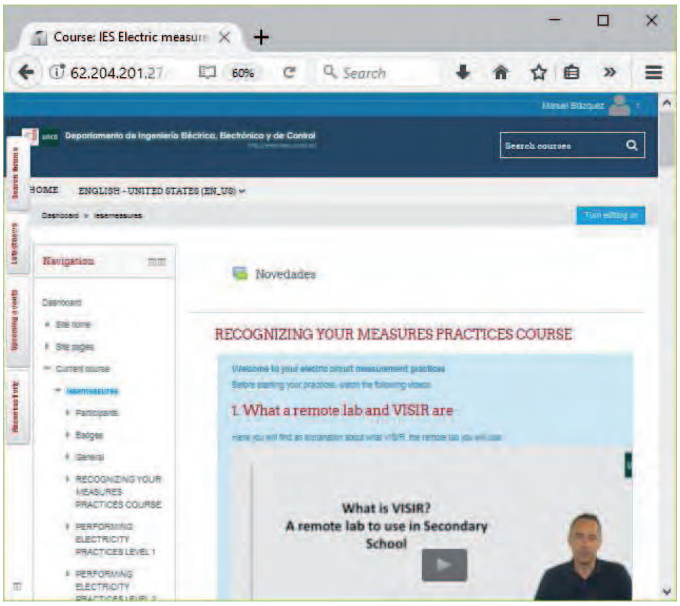

Fig 2. Aspect of the welcome page to the MOOC with the first access to videos.

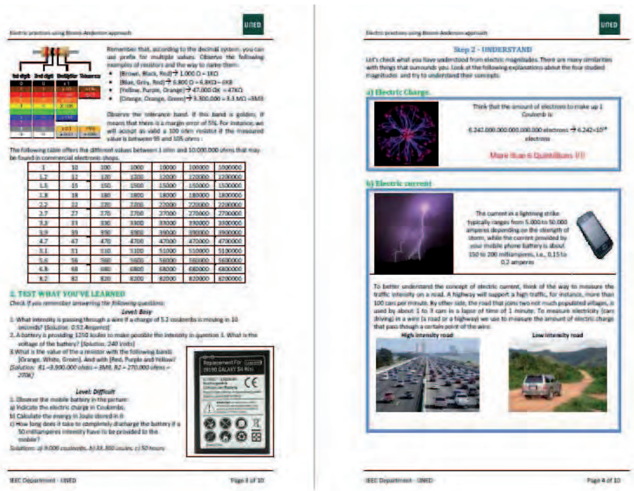

Fig 3. Aspect of one of the sections in the students' practices documentation

- Stage 1: Remember, which reviews some concepts that students should know to establish a starting point for the contents,
- Stage 2: Understand, through which students will be able to contextualize the studied concepts,
- Stage 3: Apply, to qualify students to understand the practical usefulness of concepts, being the remote laboratory the resource used for it.

The strategy of the course, as indicated in previous sections is the consolidation of LOTS in order to activate students' high order thinking skills (HOTS) and in this way HOTS stages development are explained as follows:

- Stage 4: Analyze, through which students will exercise the recognition of the results obtained in the measures, being able to decide for themselves whether the obtained measurements are of the expected order of magnitude and in which the analysis of errors by comparison with expected values will be put into practice.

- Stage 5: Evaluate, in which students will be able to determine the validity of the obtained results, and
- Stage 6: Create, in which students will be challenged change the scenario of practices, and perform as designers themselves. This stage determines if the student has achieved significant learning.

As indicated above, the course consists of three levels, designed for students to gradually access to increasingly complex topics and knowledge. More specifically, students in Level 1 will study the concepts of electricity, electrical magnitudes, and electrical components of a circuit and will deepen their understanding and recognition of electrical resistors. In level 2, students will practice with the series and parallel circuits and the concept of equivalent resistance. In the figure 4, an snapshot of the documentation at this level is represented in which students will follow the instructions to connect series and parallel circuits as part of the *Stage 3. Apply* and the study of the obtained values by the *Stage 4. Analyze* and *Stage 4. Evaluate*.

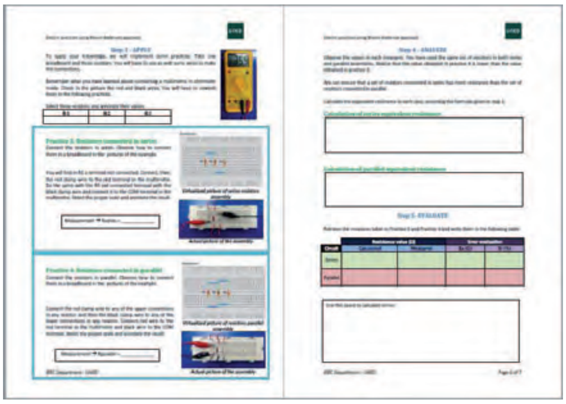

Fig 4. View of the documentation: Apply, Analyze and Evaluate in Level 2.

Finally, in level 3, students will practice with the compound circuit concept and they will be provided with useful strategies for solving this type of circuits. Additionally, each of the levels has a video that helps the students to understand the electric theory and assist them with the execution of the practices. In the figure 5, stages 4, 5 and 6 of Level 3 is represented.

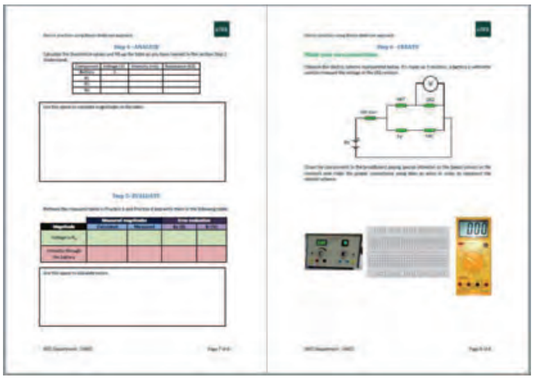

Fig 5. View of the documentation: Analyze, Evaluate and Create in Level 3.

IV. EVALUATION CRITERIA AND DISTRIBUTIONS

Electric Measures MOOC implementation has been carried out for a period of three weeks in which eight sessions have been distributed. In total, 147 students, 12 to 14 years old, have participated in the research. The age of the students corresponds to the first two courses of secondary compulsory education stage according to Spanish education organization and European Education laws.

A process of assessment has been implemented and the data collected from the students activities have been assessed and analyzed according to some standards of evaluation based on 16 indicators described as follows in Table 1.

TABLE I. LEARNING ASSESSMENT INDICATORS IN LEVEL 1 PER TASK

Task	***Description of the activity***
1	Ability to apply the concepts and electrical magnitudes to the solution of a real everyday problem
2	Practice 1. Measure of the resistance of a resistor and understanding of the concept of tolerance
3	Understanding of the concept of absolute and relative error in measures to the calculation of percentages changing the context.
4	Practice 2. Measure of multiple resistances and calculation of absolute and relative error
5	Analysis of values retrieved from practice 2
6	Conducting a research study on the origin of errors in measurement processes

TABLE II. LEARNING ASSESSMENT INDICATORS IN LEVEL 2

Task	***Description of the activity***
1	Practices 3 and 4. Connection of several resistor in series and parallel and measurement of equivalent electric resistance in each case.
2	Calculation of equivalent electric resistance from a series circuit made up the resistors used in practice 3.
3	Calculation of equivalent electric resistance from a parallel circuit made up the resistors used in practice 4
4	Retrievement of theoretical and measured values in order to calculate absolute and relative errors
5	Representation of the scheme of a series and a parallel circuit and calculation of theoretical resistors values given measured values and relative errors.

TABLE III. LEARNING ASSESSMENT INDICATORS IN LEVEL 3

Task	***Description of the activity***
1	Calculation of the electric magnitudes in a given circuit
2	Connection of a compound circuit according to a given electric scheme made up a battery and three resistors and completion of practices 5 and 6. Voltage measurement in a resistor of the compound circuit (Practice 5) and electric current measurement through a certain branch of the compound circuit (Practice 6)
3	Calculation of voltages and electric intensities in a specific resistor.

Task	*Description of the activity*
4	Retrievement of theoretical and measured values in order to calculate absolute and relative errors
5	Drawing of the set of connections of a compound circuit made up 5 resistors with a power supply, a multimeter and a breadboard.

In addition, an attribute has been assigned to each indicator in order to define it as activity of LOTS or HOTS achievement as described in Table IV.

TABLE IV. LOTS-HOTS ACHIEVEMENT INDICATORS

	Type of activity	
LEVEL	***LOTS***	***HOTS***
1	1- 2	3-4-5-6
2	1	2-3-4-5
3	1-2	3-4-5

In the research study, 144 students, have been divided into two groups. The first group of 72 students have used the VISIR remote laboratory to carry out the activities of electrical measurements. The remaining 72 students have formed the control group that performed the experiments and measurements using actual instrumentation in class. the gender distribution is shown in the following table V.

TABLE V. DISTRIBUTION OF GROUPS IN THE RESEARCH

		STUDENTS		***TOTAL***
GROUP	***TYPE OF LAB***	***BOYS***	***GIRLS***	
REFERENCE GROUP	VISIR REMOTE LAB	41	31	72
CONTROL GROUP	ACTUAL LAB	39	31	70
	TOTAL	80	62	142

V. ANALYSIS OF LEARNING OUTCOMES IN THE OBJECTIVE ASSESSMENT

According to the previous data, and once the students have finished practices, all them have delivered the documentation. This means that in total each of the students of the first year have delivered Level 1 and Level 2 activities notebooks while the students of second year have delivered Level 1, Level 2 and Level 3 activities notebooks. The correction of the activities have been submitted to the criteria of degree of precision in numerical answers and level of correction in descriptive activities according to the information given in Tables I to III. The qualifications of each activity have been determined in a value between 1 and 10, being 1 the value assigned to an activity not performed or totally incorrect and 10 to an activity executed to perfection.

So then, after correction of activities, students' scores have been calculated by averages. Table VI shows total averages and standard deviations according to type of lab.

For students of 1st year, as it can be observed in the previous table, average scores are similar in both groups. It cannot be accepted as a conclusion that one lab is better than the other, since scores differ at a minimum grade.

TABLE VI. STUDENTS' SCORES PER LEVEL FOR 1ST YEAR ACCORDING TO THE TYPE OF LAB

	TYPE OF LAB		
Avg	***Actual***	***VISIR***	***TOTAL***
L1	5.11	5.10	5.11
L2	5.67	5.25	5.46
Lab	5.39	5.18	5.28

	TYPE OF LAB	
TD	***Actual***	***VISIR***
L1	1.80	2.21
L2	2.19	2.33
Lab	1.77	1.95

(1) Students' scores in a scale of 10 points. Avg = Avarage score, TD=Typical deviation

However, things are changing when referring to students of 2nd year. In this case, the differences turn higher between VISIR group and the control group. Having into consideration that the students have been randomly selected to belong to each group, VISIR students have obtained up to 23.5% better marks than their classmates from control group.

TABLE VII. STUDENTS' SCORES PER LEVEL FOR 2ST YEAR ACCORDING TO THE TYPE OF LAB

	TYPE OF LAB		
Avg	***Actual***	***VISIR***	***TOTAL***
L1	5.40	6.91	5.88
L2	5.40	6.49	5.71
L3	4.71	5.77	4.88
Lab	5.17	6.39	5.49

	TYPE OF LAB	
TD	***Actual***	***VISIR***
L1	2.06	2.73
L2	2.81	3.33
L3	2.43	2.89
Lab	2.05	2.78

(1) Students' scores in a scale of 10 points. Avg = Avarage score, TD=Typical deviation

At a first instance, 1st year students' similar cases can be explained because of the factor of the novelty to use a lab resources and components, in many cases for the first time. For them have been difficult to manage resistors and to deal with a multimetre so in the actual lab than in VISIR remote lab. However, considering that students from the 2nd year have never made electricity practices and have never seen how a remote lab works, it's a significant the difference. So, in this case, we cannot avoid the fact that the students that have performed their practices with VISIR remote lab, have achieved better grades what can be translated into better learning.

But if more detailed data is observed, as shown in Table VII, looking at the distribution of students who has not answered to each of the activities, null activities are more related with theoretical questions than with the completion of practices 1 and 2. This can be also thought, observing averages of the activities.

TABLE VIII. STUDENTS' SCORES PER ACTIVITY IN LEVEL 1 IN FIRST YEAR

Activity	***Type of activity***	***Percentage of null answers***	***Students' average score (1)***
1.1	Theoretical question	72%	2.29
1.2	Measurement Practice 1	1%	8.67
1.3	Theoretical question	70%	3.61
1.4	Measurement Practice 2	0%	8.00
1.5	Theoretical question	50%	4.86
1.6	Theoretical question	62%	3.21

(1) Students' average score in a scale of 10 points

We understand then that the focus of poor outcomes is focused on the resolution of theoretical problems rather than the use of a laboratory with technical resources to carry out the practices. In order to check if this hypothesis is correct, the same activities have been made by students of 2nd year. In this case, all the scores have been improved, even the amount of null answers. This is observed in table VIII.

TABLE IX. STUDENTS' SCORES PER ACTIVITY IN LEVEL 2 IN FIRST YEAR

Activity	*Type of activity*	*Amount of null answers*	*Students' average score (1)*
1.1	Theoretical question	28%	5.28
1.2	Measurement Practice 1	7%	8.22
1.3	Theoretical question	62%	4.24
1.4	Measurement Practice 2	7%	7.48
1.5	Theoretical question	24%	6.83
1.6	Theoretical question	31%	4.72

(1) Students' average score in a scale of 10 points

Differences are really notorious between the outcomes of the students of 1st and 2nd year, but only in the way to face theoretical questions. These differences don't exist when comparing the performance in the making of measurement practices. This means that the students of second year have better assimilated the theoretical aspects and have taken more advantage of the use of the labs. However, this will be later seen in the next section by means of a deep analysis of the impact of Bloom-Anderson's Taxonomy.

Once determined the origin of the averages, it's important to observe how students are performing the practices. In this way, scores from the evaluation of the practices have been retrieved in order to be compared with a normal distribution of scores N(μ,σ), where μ is the average of the students' scores, and σ is the standard deviation of the students'. For us, one of the objectives of the research is to compare students' performance in relation with the type of laboratory used while practicing.

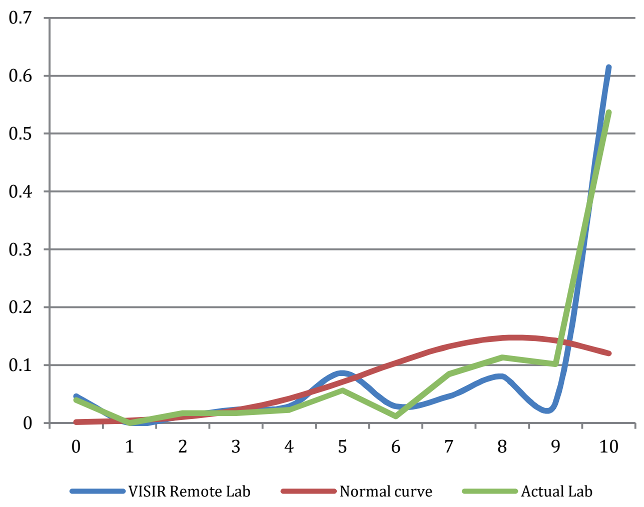

Fig 6. Comparison of students' practices performance in 1st year - All practices

In the figure 6, most of students have perfectly performed the practices. We have to remember that Practice 1 consists in the firsts steps to use a multimetre, Practice 2 makes the students to measure several resistors and in Practices 3 and 4 the students have to build a series circuit and a parallel circuit respectively and measure the equivalent resistance.

Although at the beginning, we had assumed that practice 1 would be the simplest and practices 3 and 4 the most difficult, in figures 7 to 9 it can be seen that the latter have been those that have paradoxically better performed. We consider that this behavior is due to the fact that the students have become accustomed to the use of measuring devices and have learned to interpret an electrical diagram and as a result have been able to correctly perform the assembly and subsequent measurement. As a matter of quantification, the percentage of students who have perfectly finished the practices have been: Practice 1 (65%), Practice 2 (37%) and Practices 3-4 (73%),

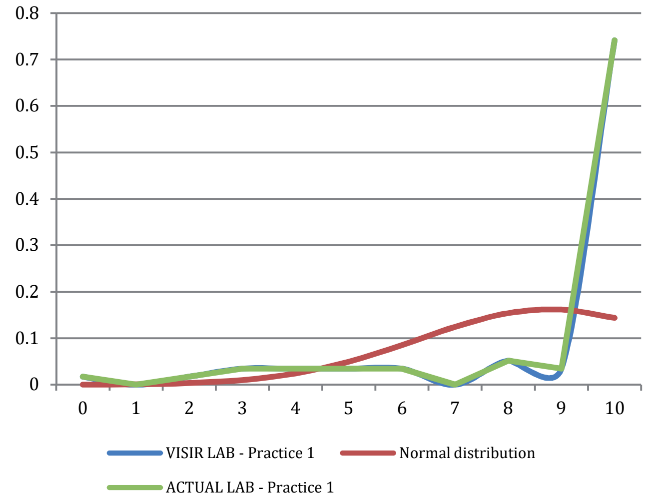

Fig 7. Comparison of 1st year students' Practice 1 performance

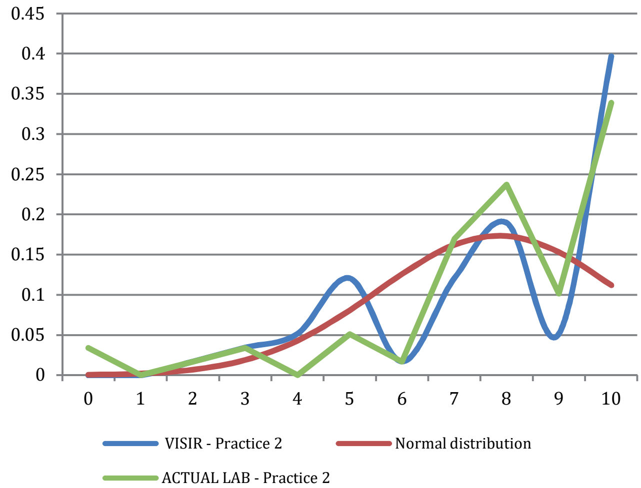

Fig 8. Comparison of 1st year students' Practice 2 performance

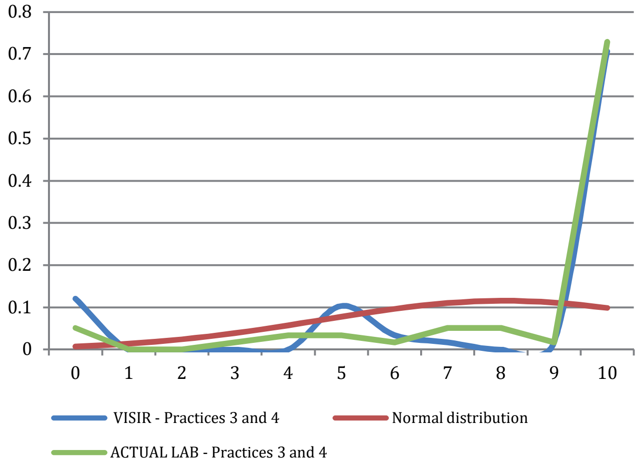

Fig 9. Comparison of 1st year students' practices 3- 4 performance

About students of 2nd year, they have performed the practices in the three levels, the same first four practices than the students of 1st year but also practices 5 and 6. These two latter practices, 5 and 6, consists of the assembly of a compound circuit made up three resistors and the measurement of the voltage in one of them and the intensity in the power supply as it can be observed in the figure 10.

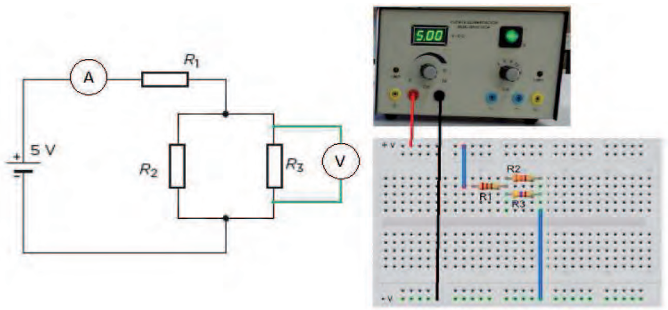

Fig 10. Electric circuit related to practices 5 and 6

In this case, the scores obtained by students only according to the grades obtained in the evaluation of the practices have been represented in figures 11 and 12, where actual lab and remote lab scores have respectively been included.

By the observation of graphs in figures 11 and 12, a similar performance is detected in both types of labs, actual and remote, although, average grades have been higher in VISIR remote lab than in actual lab.

So, up to this point, we have seen in general terms a slightly better performance from students that are using VISIR remote lab than those who have used actual lab resources. However, we've seen that independently of the kind of lab used, and knowing that none of the students have ever used a electricity laboratory, theoretical aspects and practical performances have be considered as the core elements in the improvement of learning of any discipline of science and particularly in electricity.

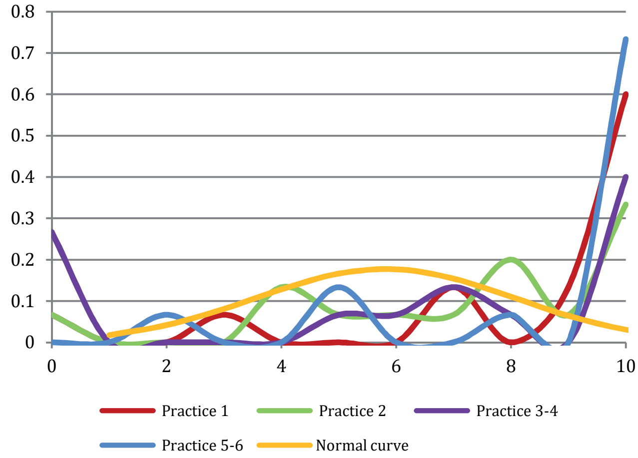

Fig 11. Actual Lab performance of students of 2nd year - All practices compared with normal distribution

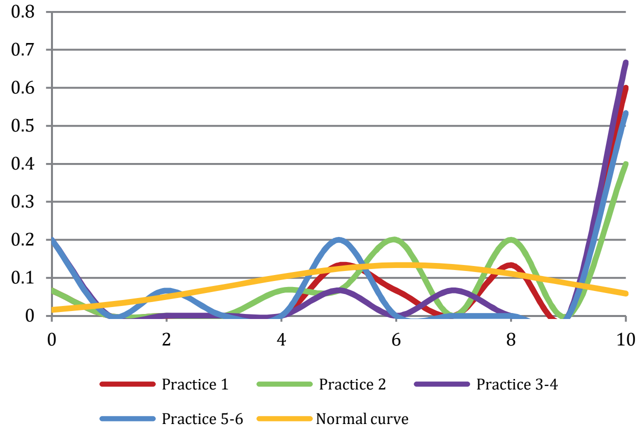

Fig 12. VISIR Remote Lab performance of students of 2nd year - All practices compared with normal distribution

In the next section, a innovative study has been carried out, having into account that we are not going to consider theoretical or practical activities as the division of task to improve learning. In this study, we have determine the task involved in the resource of two kinds: those that contribute to assimilate the simpler skills (LOTS) and those that make students to improve more complex skills, such as reflective thinking by means of analytical activities and creative thinking by means of a kind of tasks that impulse to students to be able to apply solutions studied for a certain problem to other context like a change of scenario (HOTS).

VI. BLOOM-ANDERSON'S TAXONOMY IMPACT IN THE IMPROVEMENT OF SKILLS

According to the last approach shown in the previous section, the activities that make up the different levels of the course (Level 1, 2 and 3) will be divided into two types of tasks, LOTS and HOTS.

The hypothesis that we propose through this study is to be able to validate the affirmation that if the LOTS are consolidated, students will have greater options to develop reflective and creative thinking through HOTS tasks. On the other hand, we understand that the opposite approach is equally valid, that is, if the knowledge to develop the simplest skills is not properly assimilated, it will not be possible to fully develop the most complex skills.

The tasks in the different levels in this course have been tagged as LOTS and HOTS according to a carefully design of activities. In the table X, the number of activities associated with the type of thinking skills, low or high, is listed. Check that the description of these activities is available is tables I, II and III.

Scores from each student and activity have been organized under this approach and two kinds of studies have been carried out in order to determine the relation proposed between LOTS and HOTS. The first approach has consisted of the calculation of the Pearson correlation coefficient. The second approach is a consequence of this first one. Given correlation coefficient shows the degree of interdependence between both variables, but Pearson correlation coefficient doesn`t express causality, a dots cloud has been represented in order to find an explanation to the hypothesis above proposed.

TABLE X. LEARNING ASSESSMENT INDICATORS IN LEVEL I

	Type of Thinking Skills	*Activities*
LEVEL 1	LOW ORDER	1-2
	HIGH ORDER	3-4-5-6
LEVEL 2	LOW ORDER	1
	HIGH ORDER	2-3-4-5
LEVEL 3	LOW ORDER	1-2
	HIGH ORDER	3-4-5

Pearson's correlation coefficient is an index of easy execution and interpretation and it will show the kind of linearity or proportionality between two variables, that in our case will be LOTS and HOTS scores. The coefficient will oscillate between 0, that means no mutual relation between variables and 1, that means a perfect correlation between them.

This perfect correlation case is perfect positive when exactly as one of both increases, the other increases as well. This happens when the relation between the two variables is functionally accurate and it is frequent to occur in the physical sciences where the phenomena is conformed to known laws. For example, the relation between space and time for a vehicle moving at a constant speed.

In this case, we are trying to find out what is the relation between how low order thinking skills have been assimilated (LOTS as the first variable) and how students have been able to develop their ability to analyze a proposed electric problem and have shown a certain degree of activity by means of the reflective and creative thinking as part of their high order thinking skills (HOTS as the second variable).

Among the students of 1st year, the correlation coefficient has been obtained in a general way, it's said, applying a correlation coefficient calculation to the averages, grouping activities by their kind of thinking skill. Solutions to the coefficient calculations are shown in the following Tables XI to XIII.

TABLE XI. CORRELATION COEFFICIENTS IN THE 1ST YEAR STUDENTS' GRADES

		Grades Average	*Correlation coefficient*
FULL COURSE	LOTS	6.16	*0.497*
	HOTS	4.44	
LEVEL 1	LOTS	5.11	0.306
	HOTS	4.42	
LEVEL 2	LOTS	8.28	0.403
	HOTS	4.47	

At first glance, figures do not seem to show a high interrelation between both variables. A certain relationship is observed but certainly weak. Let's then observe what is the particular position of the values of the variables from each of the participating students.

Thus, clouds of dots have been represented, in figures 13 to 15. Each dot means that a student has been assessed with two grades :LOTS grade represented in X-coordinate and HOTS grade in Y-coordinate So, (LOTS, HOTS) coordinate is used to draw a dot.

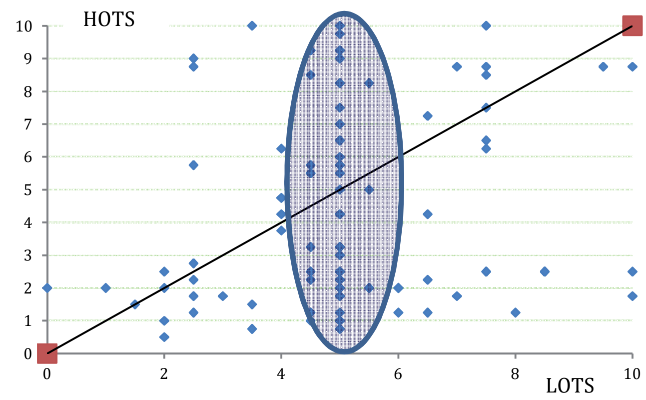

Fig 13. Dot cloud of average grades obtained by students of 1st year in Level 1 activities

In figure 13 and 14 a diagonal line has been represented to delimitate the path for a perfect correlation. In the case of figure 13, about the half of dots are located in the lower region under the diagonal while the other half is located in the upper region. This shows a great dispersion but it's interesting to observe how the majority of dots are located on a central vertical line about the grade LOTS = 5.

The lack of linearity is observe by means of this phenomenon. Most of students have obtained a mid grade in low skills (5) and some of these have achieved better results than expected by the hypothesis. By the contrary there are many students than have failed in the assessments of their high order thinking skills.

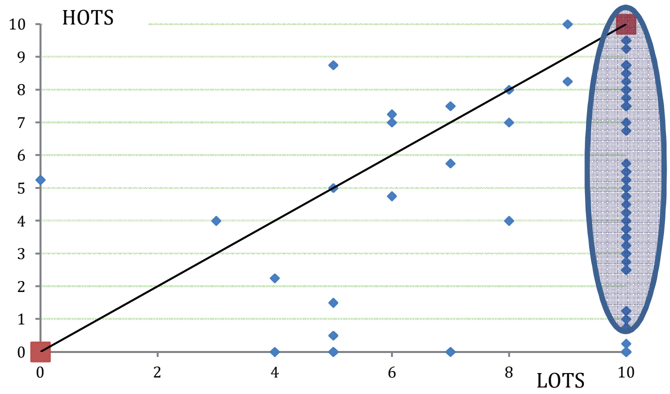

Fig 14. Dots cloud of average grades obtained by students of 1st year in Level 2 activities

The same phenomenon happens with the assessment of the skills in Level 2 represented in Figure 14. Instead of accumulating points in the vertical line corresponding to the mark of 5, this accumulation happens at the mark of 10. This means that at this level (L2), the students in general, have shown high abilities in their LOTS, but on the contrary there is no dependence that supposes to have improved in their HOTS, since these high order thinking skills have been evaluated in a very varied way.

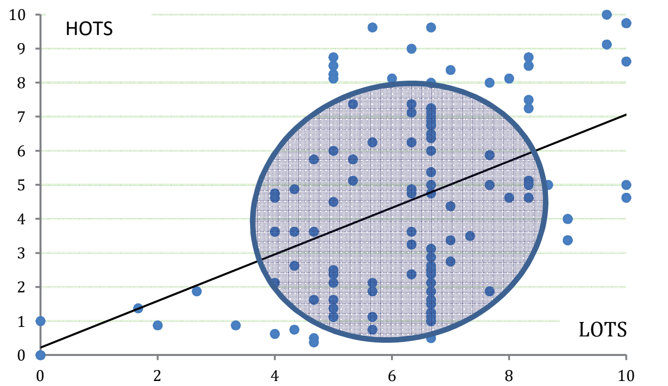

Fig 15. Dots cloud of average grades obtained by students of 1st year in the assessment of all the activities

Finally, figure 15 is showing the general grades of students. The dots are concentrated inside an oval also represented in the graph. The oval is almost a circle, with almost no eccentricity what may be understood as a high dispersion of dots. A positive diagonal was expected in the case of the variables to be very related, but the oval shows very low relation between LOTS and HOTS.

About the numbers obtained by the students of 2nd year, numbers and graphs are very different. After calculating the Pearson correlation coefficients in Level 1 activities, Level 2 activities and Level 3 activities, an increase in all the coefficients can be recognized. In fact, it can be said that the relationship between the qualification of the LOTS and that of the HOTS is high. These coefficients can be seen in the Table XII.

TABLE XII. CORRELATION COEFFICIENTS IN THE 1ST YEAR STUDENTS' GRADES

		Grades Average	*Correlation coefficient*
FULL COURSE	LOTS	6.25	0.862
	HOTS	5.18	
LEVEL 1	LOTS	6.61	0.759
	HOTS	5.51	
LEVEL 2	LOTS	6.83	0.861
	HOTS	5.43	
LEVEL 3	LOTS	5.62	0.505
	HOTS	3.53	

In order to check the relation, in the following figures 16 to 19, dots clouds have been represented in the same way than these of 1st year students.

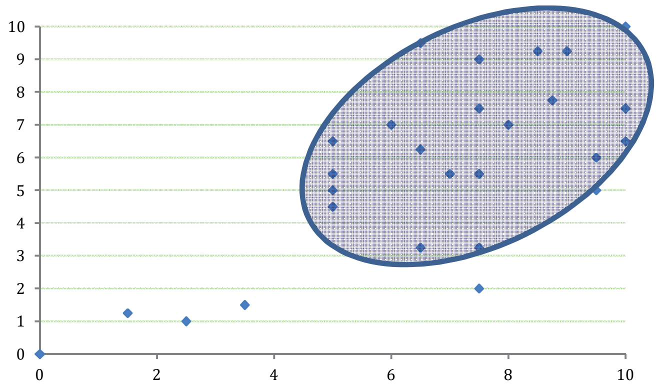

Fig 16. Dots cloud of average grades obtained by students of 2nd year in Level 1 activities

In the making of Level 1 activities, the dots representing the grades of students appear in the right top corner of the graph, what is understood as a high relation between LOTS and HOTS by its accumulation in a short area, but the position of dots also offer a certain causality degree.

In figure 17, the accumulation of dots appear in a vertical line in the right top corner of the graph. The interpretation of this situation consists of a good assimilation of LOTS and a variable degree of development but in a high degree as well, being all the height of the dots between 5 and 10 points. However this situation is not similar to activities of Level 3 in figure 18, where several dots clusters appear in the graph in different situations, one in the mid part of the graph, showing high relation but poor grading and another cluster in the right part but reproducing no relation by the variability of the vertical situation of the dots.

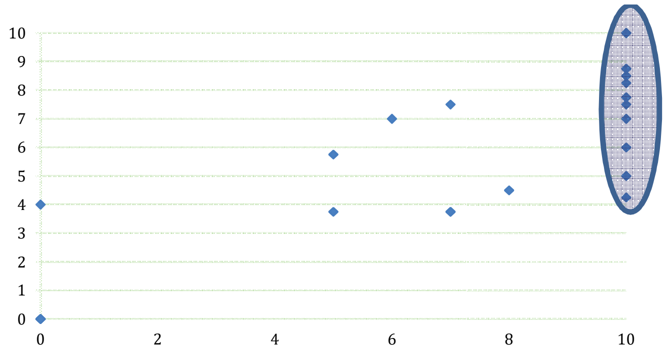

Fig 17. Dots cloud of average grades obtained by students of 2nd year in Level 2 activities

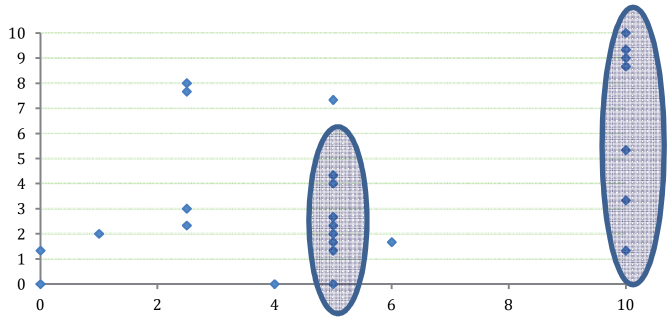

Fig 18. Dots cloud of average grades obtained by students of 2nd year in Level 3 activities

It can be concluded that students have improved HOTS from LOTS in Level 1 activities, have made a good work in Level 2 accumulating high LOTS and HOTS grades, and very variable with no relation in Level 3 activities.

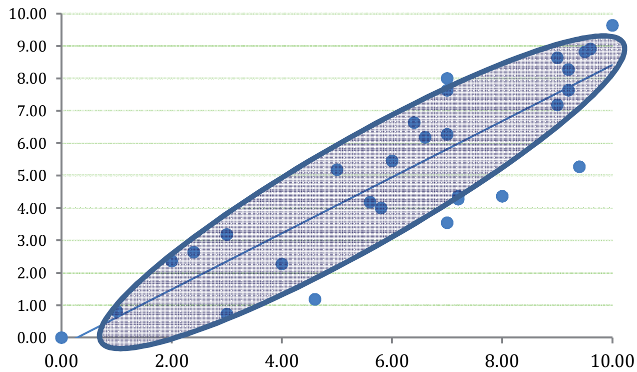

Fig 19. Dots cloud of average grades obtained by students of 2nd year in all the activities

To finish this section, figure 19 shows the representation of dots from each of the students, considering their general grading averages. In this case, a high correlation is observed. This has been marked by means of the ellipse superposed in the graph inside which most of dots are concentrated. The ellipse has an axis very close to the main diagonal, what is interpreted has a high correlation. Because of the narrow shape of the ellipse, we interpret that the consolidation of LOTS is the main factor to improve their HOTS.

VII. Subjective Perception of Students.

In order to let the students to evaluate the experience in the realization of the course, two questionnaires have been carried out, one (Q1) before starting the activities and another (Q2) when they have been completed. In them, the students have answered the same questions, with which it has been possible to determine not only their evaluation in different areas, knowledge and skills, but also the evolution of their perception of improvement, what makes us to call to the measurement of evolution as objective assessment. To quantify answers, students have selected their preferences from a scale from 1 to 4, being the number 1 very poor/unsatisfied and 4 very high/very satisfied.

The questionnaires have been divided into 5 sections, being composed each with 5 questions. Section 1 is about general issues and interest and use of technology, section 2 about knowledge of electricity, section 3 about expectations and motivation with practices, section 4 about contents and methodology of materials and resources and finally, section 5 about laboratory experience. In the following table XIII, some of the most significant answers have been shown in order to observe the level of evolution that students think they have experimented. This level of evolution has been titled as percentage of improvement (P.I).

TABLE XIII. Correlation coefficients in the 1st year students' grades

Question	*Average mark in Q1*	*Average mark in Q2*	*P.I. (%)*
I know to distinguish electric devices in a electric scheme, such as batteries, resistors, switches, etc.	2.69	3.28	22.2
I would know to relate a color with its corresponding numerical value in the resistors color code	2.22	3.44	55.0
. I know how to use a multimetre and how to connect it into a circuit in order to measure voltage, electrical current or electrical resistance	1.89	3.15	66.7
I consider very important the making of electric measures practices to better understand Electricity	3.17	3.36	6.0
I think it is important to understand the process of how to do electrical measures the teacher to guide me in the steps to follow.	3.42	3.46	1.2
Only for students of remote lab group - I think that after using the remote laboratory, my knowledge and understanding about electric components and circuits have improved	3.15	3.67	16.3
Only for students of actual lab group - I think that after using the remote laboratory, my knowledge and understanding about electric components and circuits have improved	3.36	3.25	-3.4
Only for students of remote lab group - I consider important the remote laboratory to be adequate to my needs	3.05	3.20	4.9
Only for students of actual lab group - I consider important the remote laboratory to be adequate to my needs	3.09	2.88	-7.0

From all of the questions, the most significant are those related to the perception of students to electricity knowledge. In this way, the knowledge of electrical magnitudes, how to read resistance values from color codes in resistors, how to manage a multimetre. We are expecting that students' perception of improvement to be positive what means that they acknowledge their own learning because the students will be able to replicate any kind of problem using the obtained knowledge.

By other side, we are interested in other type of questions such as the valuation of the resources and materials they have been using. Finally, it's important for us to know about the evolution of perceptions of learning by students depending on the type of lab used, in order to help to validate VISIR remote lab as a type of lab easy to use and good to improve students' learning.

VIII. CONCLUSIONS

The research has been carried out in the context of secondary school and specifically in several groups of students in the period to teach Electricity classes. It has brought various advantages since the use of a remote lab to make practices has reduced the cost of the operations and maintenance in the department.

Initially, we, teachers of the department of Technology, were not sure about the convenience of the use of such a resource and whether it could be a good tool for students' use at a first instance, and if so, if a remote lab like VISIR could make the process of learning to be improved. So we decided to implement the practices of electricity by means of using VISIR remote. We thought that the best option to declare VISIR as a good learning resource would be the making of the practices with VISIR by the half of the students and with normal lab instrumentation by the other half.

With the aim to improve learning we have designed a MOOC and specific didactic materials to be used by all the students, so the only variable to compare would be the type of lab each student would use. Learning outcomes presented in this paper after the assessment of the activities included in the course, have indicated that students using VISIR obtained similar results in youngest students, what may be interpreted as VISIR to be a valuable resource just for the department. But by other side, there have been slightly better results in VISIR groups than those groups of students who perform the normal laboratory instrumentation in older students from more advanced courses. This makes us to think about VISIR as a good resource to improve learning, preferably for older and more experimented students.

Given these reasons that suggest success and advantages of the remote VISIR laboratory, the Department of Technology sees a magnificent opportunity to introduce this technical resource into the classrooms.

ACKNOWLEDGES

The authors acknowledge the support of the "Escuela de Doctorado de la UNED", eMadrid project (Investigación y Desarrollo de Tecnologías Educativas en la Comunidad de Madrid) - S2013/ICE-2715, VISIR+ project (Educational Modules for Electric and Electronic Circuits Theory and Practice following an Enquiry-based Teaching and Learning Methodology supported by VISIR) Erasmus+ Capacity Building in Higher Education 2015 nº 561735-EPP-1-2015-1-PT-EPPKA2-CBHE-JP and PILAR project (Platform Integration of Laboratories based on the Architecture of visiR), Erasmus+ Strategic Partnership nº 2016-1-ES01-KA203-025327.

REFERENCES

[1] Anderson, L.(2001) "Taxonomy of educational objectives," in Encyclopedia of Educational Theory and Philosophy Anonymous Sage Publications, 01, pp. 789-791

[2] Angulo, I. et al.. (2010) "El proyecto VISIR en la universidad de Deusto: laboratorio remoto para electrónica básica". Conference proceedings TAEE 2010 - ISBN: 978-84-96737-69-3

[3] Gustavsson, Ingvar (2001) "Laboratory experiments in distance learning". Proceedings of the ICEE 2001 Conference August 6 - 10, 2001. Oslo/Bergen, Norway. Available at: http://www.ineer.org/. Last visit: February 27th, 2017.

[4] Gustavsson, I.and e. al, (2007) "The VISIR Project - An Open Source Software Initiative for Distributed Online Laboratories," in Remote Engineering & Virtual Instrumentation (REV '07), June 2007

[5] Tawfik, Mohamed et al (2011) "VISIR Deployment in Undergraduate Engineering Practices. Global Online Laboratory". Consortium Remote Laboratories Workshop (GOLC), 2011. 978-1-4577-1944-8. GOLC Workshop in the 41st ASEE/IEEE Frontiers in Education Conference (FIE 2011).

[6] García-Zubía, Javier et al (2010) "Easily Integrable platform for the deployment of a remote laboratory for microcontrollers". EDUCON 2010 – Annual Global Engineering Education Conference - The Future of Global Learning in Engineering Education. IEEE Education Society. EDUCON 2010 Conference Book. ISBN: 978-84-96737-70-9

[7] Pastor Vargas, Rafael. (2006) "Especificación formal de laboratorios virtuales y remotos: Aplicación a la Ingeniería de Control". Doctoral Thesis presente at Escuela Técnica Superior de Ingeniería Informática de la Universidad Nacional de Educación a Distancia. UNED, 2006

[8] Chen, Xuemin; Zhang, Yongpeng; Kehinde, Lawrence and Olowokere, David (2010) "Developing virtual and remote undergraduate laboratory for engineering students", 40th ASEE/IEEE Frontiers in Education Conference Proceedings. January 13th, 2010, Arlington, VA.

[9] Deniz, Dervis Z., Bulancak, Atilla and Özcan, Gökhan (2003) "A novel approach to remote laboratories". 32nd ASEE/IEEE Frontiers in Education Conference Proceedings. November 6 - 9, 2002, Boston, MA

[10] Bloom, B. S., M. D. Englehart, E. J. Furst, W.H. Hill, and D. R. Krathwohl. 1956. Taxonomy of educational objectives: The classification of educational goals. New York:David McKay Company.

[11] Bruner, J. (1966). Studies in cognitive growth: A collaboration at the Center for Cognitive Studies. New York: Wiley & Sons.

[12] Piaget, J. (1990). The child's conception of the world. New York: Littlefield Adams.

[13] Tyler, R. 1949. Basic principles of curriculum and instruction. Chicago: University of Chicago Press.

IoT Remote Laboratory based on ARM Device

Extension of VISIR Remote Laboratories to Include IoT Support

Pablo Baizan

Spanish University for Distance Education (UNED)
pbaizan@ieec.uned.es

Alejandro Macho

Spanish University for Distance Education (UNED)
amacho@ieec.uned.es

Manuel Blazquez

Spanish University for Distance Education (UNED)
mblazquez@ieec.uned.es

Felix Garcia-Loro

Spanish University for Distance Education (UNED)
fgarcialoro@ieec.uned.es

Clara Perez

Spanish University for Distance Education (UNED)
clarapm@ieec.uned.es

Gabriel Diaz

Spanish University for Distance Education (UNED)
gdiaz@ieec.uned.es

Elio Sancristobal

Spanish University for Distance Education (UNED)
elio@ieec.uned.es

Rosario Gil

Spanish University for Distance Education (UNED)
rgil@ieec.uned.es

Manuel Castro

Spanish University for Distance Education (UNED)
mcastro@ieec.uned.es

adfa, p. 1, 2011.
© Springer-Verlag Berlin Heidelberg 2011

Abstract. This paper presents an extension of the VISIR Remote Laboratory to support the IoT Technologies. By means of this new extension, the users of the remote laboratory can experiment by programming an ARM device (a raspberry Pi) and interact with sensors and actuators. Furthermore, all the characteristics of VISIR are still preserved. Therefore, the user can wire in the breadboard their circuits including sensors and actuators and interact with the instrumentation. On the other hand, a Raspberry Pi OS (Raspbian) complete remote desktop is available as an instrument more of VISIR.

Keywords: VISIR, Remote Laboratory, Internet of Things, Raspberry pi, ARM, IoT, Python, Virtual Instrumentation, VirtualBox.

1 Introduction

The Internet of Things (IoT) is an emerging technology, which is increasingly present in many sectors, such as industry automation, home appliances, mobile devices, agriculture, medicine, security, etc. Although these are some examples of sectors where IoT is present, new applications for this technology appear every day (as a rule, everything that can be actuated, sensing and/or integrated on the Internet). The rise of this technology implies an increase in the demand of qualified professionals. Therefore, the educational institutions must incorporate in their areas of knowledge a learning of the technologies of IoT, if they do not want to remain obsolete.

For students to gain the skills of a professional in an efficient manner, it is necessary to consolidate knowledge by practicing. To this end, educational institutions must have a practice laboratory with the necessary instrumentation and equipment. Due to the high cost of this equipment and instrumentation, in many cases, the institutions cannot acquire as many as they are needed. This implies that students must share equipment and instrumentation during the practice session. On the other hand, these practice sessions are usually carried out in the buildings of the educational institution at a certain timetable, forcing the students to move and adapt to the timetables.

Thanks to the advances in Internet technologies (where IoT is included), a new type of laboratory, the Remote Laboratory, has appeared. In these, all the instrumentation and equipment are connected to the Internet, presenting many advantages, among the main ones are:

1. Availability of 24 hours and 365 days, the laboratory is not limited to the hours of the institution.
2. Accessible from a device with an Internet connection, avoiding travel to the institution.
3. Better support for people with disabilities or sick, thanks to the possibility of connection when and where they want (whenever they have compatible device and with Internet connection).

4. Lower costs, more efficient use of resources, opportunity to share access and resources with other institutions.
5. Scalable, it is easy to increase the number of practices, equipment, instrumentation and laboratories.
6. Robust, the laboratory is always connected, if a fault occurs the experiment can be transferred to another remote laboratory automatically.

This scenario has increased the interest in the use of a remote laboratory as an alternative to on-site laboratories by educational institutions (especially those related to science, engineering and Technology). An interesting remote laboratory project related to electronic engineering is the Virtual Instruments System In Reality VISIR [1]. The VISIR remote laboratory project began as a research project at the Blekinge Institute of Technology, Sweden by Gustavsson and others [1] in 1999. Today, VISIR has the support of a consortium of universities in Sweden, Spain, Portugal, Austria, Georgia and India. VISIR is one of the most popular analog electronic remote laboratories and possibly also one of the most replicated. There are numerous research projects on new educational technologies and remote electronic labs based on VISIR [2, 3, 4, 5]. These characteristics make the VISIR a project base ideal for the development of a laboratory of remote IoT.

Many batch projects are based on the embedded arm, such as [6, 7, 8], these devices being the most used for the development of batch technologies. Of the ARM devices analyzed for the development of the remote laboratory of IoT, highlights the Raspberry PI for various reasons:

1. Many IoT projects include raspberry PI, such as [6, 9, 10].
2. The raspberry PI has been developed to promote the teaching of electronic and informatics. So, it includes a very good learning support [8].
3. There are a lot of examples of open source code applications and increasing every day.
4. The raspberry pi includes numerous interconnectivity ports, such as USB, Ethernet, I2C, SPI, GPIOS, and the last versions WIFI and Bluetooth.
5. It is a low-cost environment, which makes it easy to replicate. Also, on the market there are many development and expansion boards also low-cost.

This paper describes research around an IoT ARM embedded devices remote laboratory based on VISIR. Section II provides a general description of VISIR remote laboratory. Section III describes the requirements and problems to be faced when implementing an extension IoT for VISIR. The Section IV analyzes the architecture used to implement the remote laboratory of IoT.

2 VISIR, Features and Architecture

This section provides a brief description of the characteristics and architecture of

VISIR, which is important because it is important for a better understanding of the following sections. VISIR is a remote laboratory for wiring and measuring electronics circuits, the user designs an electronic circuit by web browser on a virtual breadboard, sends the circuit to the server and once verified, it is built by a relay switching matrix board (RSM) and the measurements are returned to the user. The instrumentation is based on National Instrument (NI) PCI eXtensions for Instrumentation (PXI), this include an embedded PC controller board and following instrument boards: Digital multi-meter (DMM), DC power supply (PS), Digital oscilloscope (DO) and Analog function generator (FGENA). The instrumentations are connected to RSM and this communicates with the controller by USB.

The RSM is a stack of "PCI/104" sized boards, the circuits are built by opening and closing relays with the received circuit design. The instrumentation and the electronic components necessary for the construction of the circuit are connected to one of the 10 nodes available (A-I) of the RSM (Fig. 1 and 2) by means of relays of the components and instruments boards.

Fig. 1. RSM Available Nodes

The RSM form at least three instrument boards and can include up to sixteen components boards (see Fig.2). The component boards contain 10 sockets connected to a Double-Pole Single-Throw (DPST) relays (4 of these sockets can be connected instead to 2 Single-Pole Single-Throw (SPST) relays).

Fig. 2. VISIR Instruments and RSM boards assembly

The DO and DMM channels can be connected to any node depending on the design, instead, the channels FGENA, + 6V, + 25, -25V and AUX are connected to A, X1, x2, x3 and X4 nodes respectively (Fig 3).

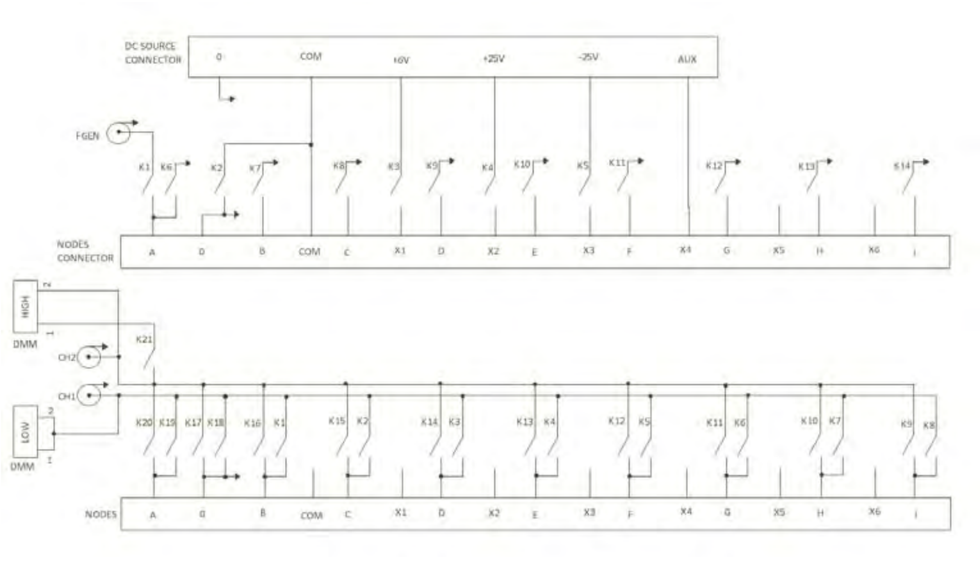

Fig. 3. VISIR Instrumentation Board schematic

VISIR include an open source software under the GPL license. In the current version its architecture (Fig 4) consists of four independent components, which are:

1. Experiment client.

2. Measurement server.
3. Equipment server.
4. Remote Laboratory Management Systems (RLMS)

2.1 Experiment client

The Experiment client is a JavaScript embedded code into html5 user interface that simulate an analog electronic experiment laboratory. The user wires the circuit on a simulated breadboard by clicking and dragging the components and wires, as shown in Fig. 5. Once the circuit has been designed, the user can select the virtual instrument with which to measure and configure it. The interfaces simulate real instruments that the user could handle in an on-site laboratory (Fig.5) these are the following:

1. A HP 33120A Analog Function Generator.
2. A Fluke 23 Digital Multimeter.
3. An Agilent 54622A Digital Oscilloscope.
4. A E3631A DC power supply.

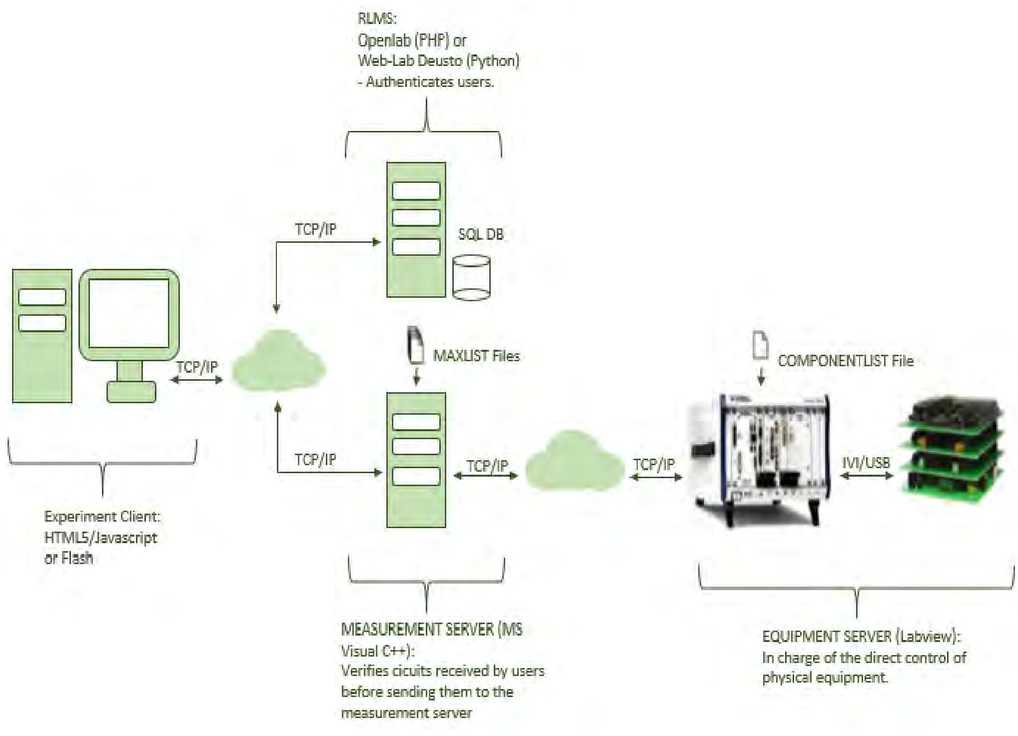

Fig. 4. VISIR Architecture

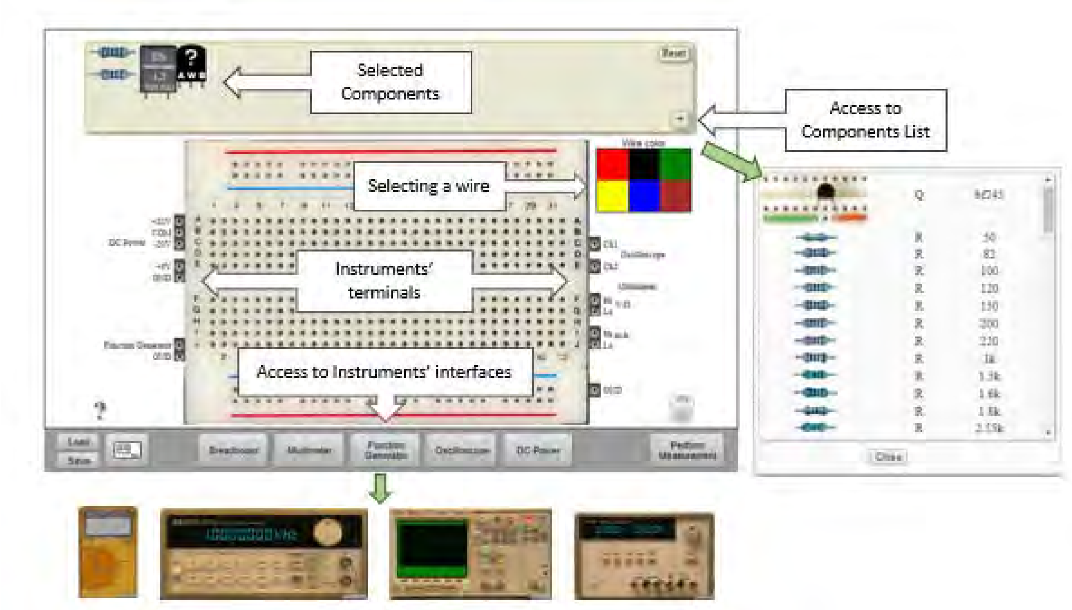

Fig. 5. VISIR Client Interface

When the user has finished configuring the instrumentation can press the "perform experiment" button to perform the measurement on the physical equipment. The Experiment client send the experiment to Equipment server by XML protocol [10]. The XML protocol is also used to receive the results of the experiment.

2.2 Measurement server

The measuring server is the VISIR engine, it is a software application developed in Microsoft Visual C++ and can be run on a separate server or in the same as the rest of the VISIR software. The main functions of the measurement server are as follows:

1. Ease of use, to this contributes besides other things: automatic memory management, simple reading and writing of operations or being a dynamic typed language. Reducing programming times versus other languages
2. XML Server, which receives the XML requests from the experimental client, parses and returns the XML response to the client.
3. Authentication Module, verifies the credentials and permissions of the users, assigns them a single session key and the valid one in each request of the client.
4. EqCom, its functions are, communicating via TCP/IP with the Equipment Server, sending the circuit to build, configuring the instrumentation and receiving the answers from this. All this through a protocol defined for that purpose [11].

2.3 Equipment Server

The Equipment Server software is a LABVIEW development. This application controls the instrumentation and matrix switching board. The Equipment Server receives the validated experiment from Measurement server by TCP/IP, executes it and returns the results.

2.4 RLMS

The RLMS provides the initial and config web pages, user authentication and authorization methods, management of access to the different laboratories and a database (used to store users, circuits and laboratory information). There are several options of RMLS, the original of VISIR is OpenLabsweb [12] and is programmed in the PHP language. Another interesting RMLS alternative option is Weblab-Deusto [13].

3 IOT Remote Laboratory

For the experiments of an IoT remote laboratory is interesting the concepts of VISIR exposed in section II. Where the user can drag and drop sensors, manipulators and communication devices to a breadboard and wire them virtually. Another interesting option of VISIR for an IoT remote laboratory is to be able to interact with instrumentation. This way the user can validate if the reading of the programmable device corresponds to the value of the sensor, can generate signals identical to those of a sensor to validate a software, check if a manipulator is active, etc...

Therefore, it has been considered interesting to take as the base of a remote VISIR laboratory. But adding access to the programming of an ARM device as if it were an additional instrument. As has been advanced in the introduction, the ARM device chosen is the Raspberry PI. The Raspberry PI Foundation has created a Debian-specific distribution for this device called Raspbian. This operating system includes an integrated development and learning environment (IDLE) for Python. Idle is destined to be an integrated development environment (IDE) simple and suitable for beginners, especially in an educational environment

.

But Raspbian presents two major problems as a remote laboratory development environment:

1. There is a need for strong access policies, there is a great danger that users, either intentionally or by accident, can leave the system inoperable.
2. The VISIR Multiplex (where several users can perform their experiments at the same time) is very complex to implement, in addition, the greater the number of users who access at the same time to the Raspberry PI the performance of the same decreases considerably.

Following the principles of VISIR, the solution to these problems is in the virtualization of the operating system. In the next section, the architecture implemented to achieve this is exposed in greater detail.

4 Implementation

The programming language chosen for the IoT arm devices remote lab implementation has been Python. This language is ideal compared to others thanks to its multi-platform support, this is a great advantage because the code can be used on different types of servers and is not limited to a single operating system. Other advantages that this language offers are:

1. Ease of use, to this contributes besides other things: automatic memory management, simple reading and writing of operations or being a dynamic typed language. Reducing programming times versus other languages.
2. Readability of the code, the structure of the code promotes a way of writing that facilitates its reading later. This gives a great advantage to the maintenance or extensions of the code, that allows to incorporate new technologies to our laboratory in a simple way and to avoid that it becomes obsolete.
3. Abundance of libraries. There are many libraries available to extend the basic Python functionality to any field. For example, SQLAlchemy, bottle, PYPDF2, etc.

As the main disadvantage of this its Runtime versus other languages, an identical code in Python and C runs in less time in the latter. This disadvantage is due to two of the advantages of Python indicated above, language typed dynamically and interpreted (the latter favors the multiplatform). Therefore, this disadvantage and more considering the continuous advance of the processors every day faster does not limit the use of Python for remote labs.

The architecture of the remote laboratory Fig. 6 is based on the VISIR but has been rewritten the entire measurement server in Python. The biggest problem that this type of labs presents is to protect the operating system of the ARM device, as already mentioned. To do so, it has decided to virtualize the OS Raspbian in Virtual Box and make use of "snapshot" of this, allowing us to freeze in a default state the OS. Because Raspbian is a Debian-based distribution, there is a version of the first for devices other than the Raspberry Pi (Raspbian desktop). This Raspbian desktop is identical to the raspberry, but does not count as it is logical, with access to the GPIOs. To fix this, the RPI library is modified. GPIO in such a way that it is accessed virtually by an Ethernet socket to the GPIOs of a Raspberry Pi.

On the side, the Raspberry Pi runs an application that includes a socket server. This server manages the queue of requests to access the GPIOs (allows several users to access the GPIOs with little latency in the replies) and making changes in the GPIOs at the request of the libraries of the Raspbian Desktop.

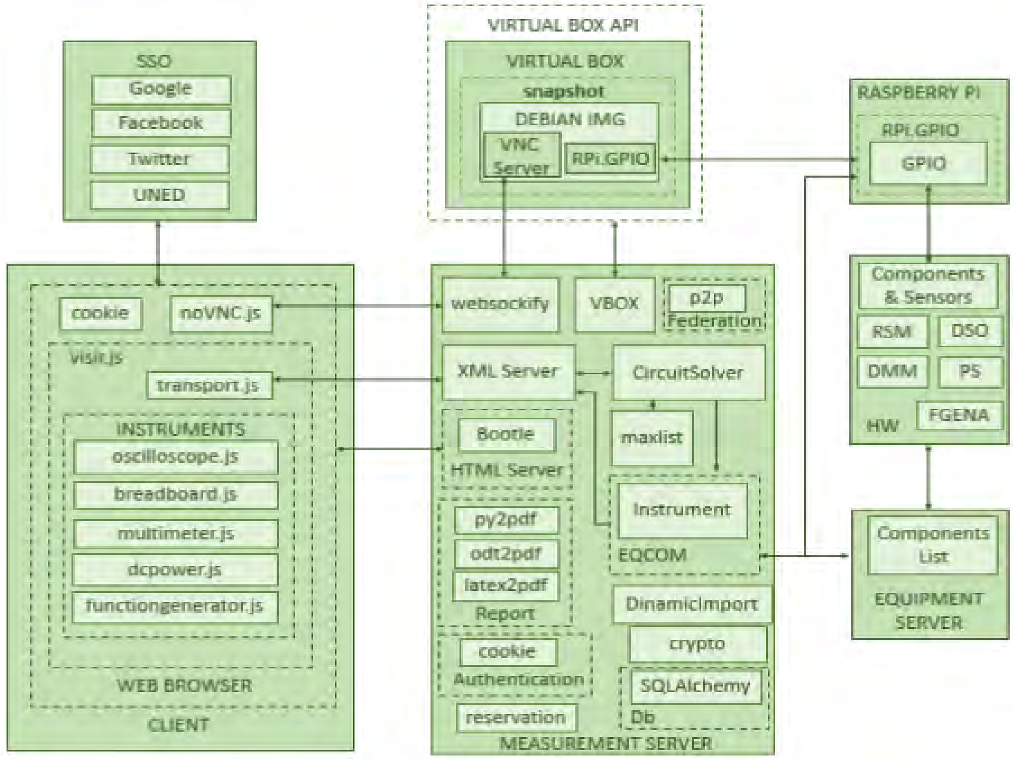

Fig. 6. IoT Remote Laboratory Architecture

To manage the virtual box (manage, destroy, boot images of OS, etc.) is used the Python library that communicates with this through the Virtual Box API. On the other hand, Raspbian images run a VNC server (Virtual Computing network) allowing access to the desktop remotely.

As the client must access through his web browser, on the client side is the remote desktop of the raspberry PI as if it were one more instrument (Fig 7). This is done thanks to the JavaScript library NoVNC.js on the client side and to the library in Python websockify [14].

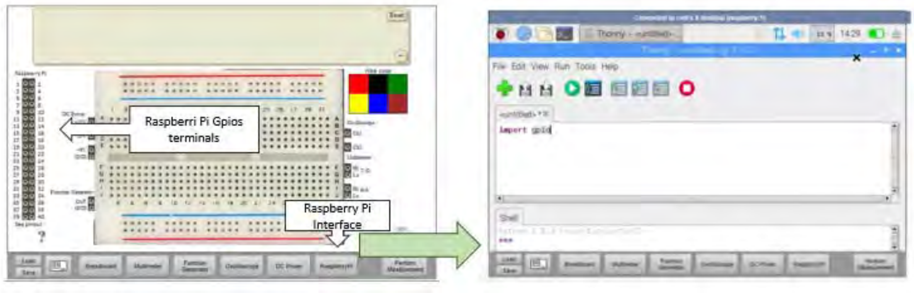

Fig. 7. New client Interface

To build the circuits and manage the instrumentation connected to the GPIOs of the raspberry PI, our measurement server follows the architecture of VISIR. To do this, a XML server has been written (which processes the requests of the clients) a circuit solver module (that does the functions of virtual tutor, validating the circuits) and the EQCom (in charge of communicating with the Equipment Server and with the Raspberry Pi, helping the latter with the management of the GPIOs). This XML server is listening to client requests and creates a thread per request (the maximum number of sessions to handle can be configured). Parses these requests to obtain the circuit and the configuration of the instrumentation and pass this data to the circuit solver. This module, circuit Solver, analyzes the circuit and compares it (as in VISIR) with the list of permitted circuits (Maxlist) previously created by qualified personnel to not compromise the system. If the circuit is validated, it passes to the stack of the module EQCom, which converts the circuit and the instrumentation configurations requested by the client into commands (commands defined in the communications protocol of the VISIR Equipment server) and that will be sent to the equipment server and the Raspberry Pi by Ethernet. The values measured by the instrumentation are sent from the Equipment Server to the EQcom module in the form of commands, which are processed. The data obtained by the EQcom are forwarded to the XML server that parses them and sends them as a response to the client.

On the server of measure has embedded the HTTP server, this is based on the Python web framework Bottle. This allows us to include web dynamics in a simpler way giving the server new services. Some of these features are:

1. SSO-based authentication capability, Google, Facebook.
2. Generation of reports with results and sending these automatically to the email of the client and/or instructor.
3. Cookie-based federation and management reserves.

5 Conclusions

The system presented extends the teaching capacities of VISIR, as well as continuing to be fully compatible. Providing the ability to make the programming of ARM devices accessible and allowing the device to interact with sensors and communication interfaces and all this remotely and available 24h, 365 days.

As future improvements will be to expand the number of sensors available from this base platform and to be complemented by practical training with theoretical teaching material, such as videos or PDFs.

6 Acknowledgment

The authors acknowledge the support of the Escuela de Doctorado de la UNED, the S2013/ICE-2715 - eMadrid project, PILAR project Erasmus+ Strategic Partnership nº 2016-1-ES01-KA203-025327 (Platform Integration of Laboratories based on the Architecture of visiR). And the e-LIVES. e-Learning InnoVative Engineering Solutions- Erasmus+ Capacity Building in Higher Education 2017 - 585938-EPP-12017-1-FR-EPPKA2-CBHE-J, the Education Innovation Project (PIE) of UNED, “Desarrollos Avanzados Multi-Objetivo de Laboratorios Remotos para Actividades Educativas – DAMO-LRAE”, from the Academic and Quality Vicerectorate and the IUED of the UNED and to the project 2018-IEQ18 from the Industrial Engineering Technical School of UNED.

7 References

1. *I. Gustavsson, J. Zackrisson and J. Lundberg, "VISIR work in progress,"* 2014 IEEE Global Engineering Education Conference (EDUCON)*, Istanbul, 2014, pp. 1139-1148. doi: 10.1109/EDUCON.2014.6826253*
2. *M. F. Soria et al., "First Practical Steps on the Educational Activities Using VISIR and Remote Laboratories at UNSE in Partnership with UNED inside the VISIR+ Project," 2018 IEEE World Engineering Education Conference (EDUNINE), Buenos Aires, 2018, pp. 1-5. doi: 10.1109/EDUNINE.2018.8450995*
3. *T. Fischer and J. Scheidinger, "VISIR - Microcontroller extensions," Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation (REV), Bangkok, 2015, pp. 177-179. doi: 10.1109/REV.2015.7087287*
4. *M. Tawfik et al., "Online Experiments With DC/DC Converters Using the VISIR Remote Laboratory," in IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, vol. 10, no. 4, pp. 310-318, Nov. 2015. doi: 10.1109/RITA.2015.2486459*
5. *J. Garcia-Zubia et al., "Empirical Analysis of the Use of the VISIR Remote Lab in Teaching Analog Electronics," in IEEE Transactions on Education, vol. 60, no. 2, pp. 149-156, May 2017. doi: 10.1109/TE.2016.2608790*

6. *V. Pardeshi, S. Sagar, S. Murmurwar and P. Hage, "Health monitoring systems using IoT and Raspberry Pi — A review," 2017 International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), Bangalore, 2017, pp. 134-137. doi: 10.1109/ICIMIA.2017.7975587*
7. *V. Beltran, J. A. Martinez, A. Skarmeta and P. Martinez-Julia, "An ARM-compliant IoT platform: Security by design for the smart home," 2016 IEEE 5th Global Conference on Consumer Electronics, Kyoto, 2016, pp. 1-2. doi: 10.1109/GCCE.2016.7800512*
8. *G. Shang-Fu and Y. Xiao-Qing, "Solution of Home Security Based on ARM and ZigBee," 2016 International Symposium on Computer, Consumer and Control (IS3C), Xi'an, 2016, pp. 89-91. doi: 10.1109/IS3C.2016.33*
9. *E. Basil and S. D. Sawant, "IoT based traffic light control system using Raspberry Pi," 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), Chennai, 2017, pp. 1078-1081. doi: 10.1109/ICECDS.2017.8389604*
10. *URL:https://github.com/VISIRServer/Measurement/blob/master/src/docs/Interface.doc, Website Title: GitHub/VISIRServer/Measurement Date Published: May 3, 2016, Date Accessed: October 07, 2018*
11. *URL https://github.com/VISIRServer/Equipment/blob/master/Docs/Protv4_1.pdf Website Title: GitHub/VISIRServer/Equipment Date Published: May 3, 2016, Date Accessed: October 07, 2018*
12. *M. Gourmaj, A. Naddami, A. Fahli and M. Moussetad, "Integration of virtual instrument systems in reality (VISIR) OpenLabs with Khouribga OnlineLab," 2015 International Conference on Interactive Collaborative Learning (ICL), Florence, 2015, pp. 793-797. doi: 10.1109/ICL.2015.7318129*
13. *L. Rodriguez-Gil, P. Orduña, J. García-Zubia and D. López-de-Ipiña, "Advanced integration of OpenLabs VISIR (Virtual Instrument Systems in Reality) with Weblab-Deusto," 2012 9th International Conference on Remote Engineering and Virtual Instrumentation (REV), Bilbao, 2012, pp. 1-7. doi: 10.1109/REV.2012.6293150*
14. *URL:https://github.com/novnc/websockify, Website Title: GitHub/novnc/websockify Date Published: September 10, 2018, Date Accessed: October 07, 2018*

Work in progress: Proof of concept: Remote Laboratory Raspberry Pi + FPAA

Alejandro Macho
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
amacho@ieec.uned.es

Pablo Baizán
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
pbaizan@ieec.uned.es

Manuel Blazquez
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
mblazquez@ieec.uned.es

Félix García-Loro
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
fgarcialoro@ieec.uned.es

Elio Sancristobal
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
elio@ieec.uned.es

Gabriel Díaz
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
gdiaz@ieec.uned.es

Rosario Gil
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
rgil@ieec.uned.es

Clara Perez
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
clarapm@ieec.uned.es

Manuel Castro
Electrical and Computer Engineering Department.
Spanish University for Distance Education, UNED.
Madrid, Spain.
mcastro@ieec.uned.es

***Abstract*— Remote education in engineering has been proven to be difficult in some practical areas. However, these practical areas and, more specifically, labs are high valuable for students and very important to help them grasp their theoretical knowledge.**

In the electronics field labs are crucial to understand every concept, and these labs should not be only simulation-based labs but real ones. Following this course of action, VISIR has been demonstrated its ability to accomplish with this task, however some limitations appear when building some circuits and, of course, not every case is covered.

A proof of concept of an FPAA based-lab controlled and supported by a Raspberry Pi will be developed in this conference paper analyzing its benefits and possible synergies with other projects and labs with the objective of accessing to the potential and features of the FPAA in remote engineering education.

Keywords— FPAA, Raspberry Pi, Remote Labs.

I. INTRODUCTION

In engineering, as in most practical areas of knowledge, real hands-on experiences are crucial. However, sometimes is difficult for students to access labs or available facilities in order to perform some practical activities.

Remote laboratories have been proved to be very useful in these cases. Distance education is a key option for students who are working or cannot move to another location and being able to do real lab practices is an outstanding tool to let these students grasp every concept.

In the electronic field, analog electronics learning is one of the most important steps in a lot of engineering studies. However, this field depends on real values of resistance, capacitors and so on, and that is the reason why real remote labs are so important. Simulation could not be enough to grasp every concept.

Remote laboratories for analog practices are having interesting results, like VISIR [1, 2], but it is not possible to cover every single possibility in an analog circuit, or it is not easy to create complex lab practices. In Fig 1 it is possible to observe the complexity of VISIR.

Figure 1. VISIR Instruments and RSM boards assembly

Field-programmable analog array, or FPAA, can be used to add more functionalities to remote laboratories, or make them more flexible. This can be done through dynamic reconfiguration.

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

II. FPAA AND DYNAMIC RECONFIGURATION

Dynamic reconfiguration is the ability to change its settings or update some functionalities and parameters without a reset in, in this case, the FPAA. It allows the FPAA to adapt itself to different situations and circumstances.

The aforementioned data lead us to believe that this technique can be used in FPAA to improve remote labs capabilities. But it is important to test it separately.

In a first step, it is important to check if FPAA capabilities are useful in an educational environment. It was studied in prior studies [3] and it was verified that its features could be very helpful in laboratories because of its flexibility and safety in certain areas.

FPAA dynamic reconfiguration needs to be controlled by another device. This requirement can be fulfilled by using a powerful PIC or a personal computer but it makes it hard to implement in a remote lab.

Cheap and easy-to-use microcontrollers like Arduino or Raspberry Pi could be used to control the FPAA dynamic reconfiguration, and testing that is the goal of this work.

A. Anadigm AN221E04 FPAA and AN221K04-V3

The AN221E04 FPAA used in this work is from Anadigm, one of the main manufacturers. The main reasons are price, flexibility and capabilities, because in academic environments this is crucial.

This Anadigm FPAA is composed by a 2x2 matrix of CAB [4] that are interconnected and have four configurable analog input/output cells and two more analog outputs, as shown in Figure 2.

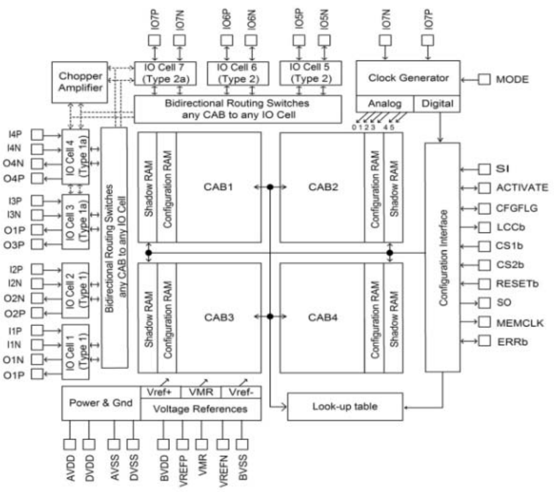

Figure 2. CAB structure of the AN221E04 [5]

This chip has two memory blocks where configuration is stored, one of them is the Shadow RAM (SRAM) which is the special memory block that allows dynamic reconfiguration. AN221E04 is part of the AN221K04-V3 development board.

This board contains a PIC that controls the FPAA programming and configuration; the board can also be connected to a PC through a serial port.

The AN221K04-V3 development kit allows the AN221E04 chip to use two different types of dynamic reconfiguration: the state-driven method and the algorithmic method.

While the first one is intended to store several pre-designed configurations and the PIC can decide when to use each one (for example a different configuration each minute), the algorithmic method can be used to change the CAB parameters to any configuration in any moment or any circumstance.

The algorithmic method is more flexible and powerful than the state-driven one, however both are very useful for academic purposes, specially since the state-driven method is much easier to implement.

In any case, some control is needed, especially in the algorithmic method, which requires a powerful microcontroller like PIC32, Raspberry Pi or a computer.

III. APPS FOR EDUCATION

Dynamic reconfiguration can be used as a tool for education because it allows students to interact with some features and properties of several elements in the electronics field in an easy and safe way.

Using the algorithmic method, some applications for PC can be developed to help students grasp concepts more efficiently and quicker.

These apps (an example is shown in Figure 3) can guide students to perform several experiments, always under certain limits configured by the teacher or expert.

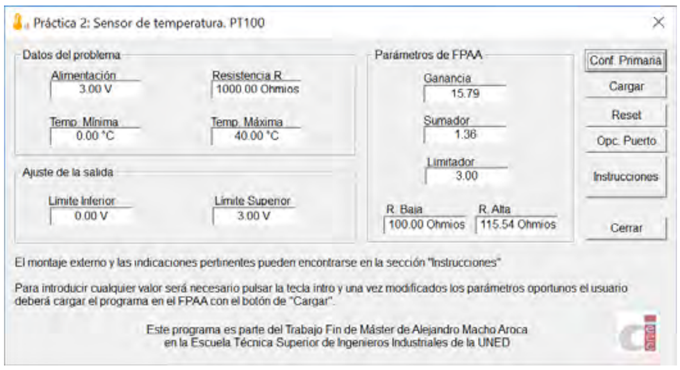

Figure 3. App for dynamic reconfiguration [3]

These limits are very important because they are the only restriction that can ensure proper operation. This software restrictions help to protect hardware, both other devices and the FPAA itself.

This app implementation can guide the student too, with instructions and schemes. It can also translate technical parameters into real world terms (for example temperature instead of resistance) and it allows students to grasp concepts in a more efficiency way.

These developments need a powerful controller to work, because it requires some C libraries to execute the dynamic reconfiguration.

On the other hand, the state-driven method works efficiently in some circumstances when every situation is known during the experiment design phase. In this case there is no need of a powerful controller and, because of that, it is much cheaper to implement.

IV. Remote Laboratories

Remote laboratories are intended for students who cannot attend a real laboratory. However, hands-on work is a must to understand theorical lessons. These laboratories are accessed by users all over the world at any time with minimum human interaction and maintenance.

FPAA are a great tool to increase the remote lab capabilities and possibilities. However, its control by distance is a challenge and the main issue analyzed in this work.

These features are required to guarantee a proper operation:

- Security: access to the FPAA configuration parameters or the controller should be private and controlled. The implementation method must ensure the safety of the hardware.
- Log: each interaction must be logged in order to identify bugs and errors.
- Stability: if an error occurs the system needs to reboot without human interaction.
- Connectivity: controller should support internet communication and reconnection if needed.
- Adaptability: lessons and students' practices change over time, that is why the system should be able to perform different tasks.
- Speed: several users are intended to use the remote lab at the same time, so the system needs to perform properly under these conditions.

V. Proof of Concept

Technical constraints and features have been studied for this work, specially communications requirements and capabilities.

Different approaches have been considered for this proof of concept: Arduino, Remote PC and Raspberry Pi.

Because of its cost, easiness of use and the amount of available resources, Raspberry Pi is the device chosen to execute the experiment.

Since the algorithmic method from Anadigm is implemented using C++ libraries, these can be executed in the Raspberry or, if needed, the library can be translated to Python. These libraries are used to obtain the configuration bit-stream to be transferred to the FPAA.

Raspberry Pi will be connected to the internet and will serve a user-friendly interface where the user can modify some parameters and then the Raspberry Pi will load this new configuration to the FPAA.

Results can be read by the Raspberry Pi itself or they will be obtained using another system, like VISIR, or other instrumentation compatible with the controller.

Raspberry Pi will be able to use the state-drive method too since it can transfer a master configuration to the FPAA and then trigger the state change using one or several of its I/O pins.

VI. Open and Known Issues

Algorithmic method is a very interesting tool when it is used in a continuous manner. That means that it would be interesting for students if they could modify parameters going from the first value to the final one going through all the values in between. Of course, while using the FPAA that way, no other user could use the device.

This problem is being addressed trying to use the FPAA in a shared time model, but the FPAA internal constraints limit the iterations or changes per second.

However, if students are working on the same practice, reconfigurations times allow to use the shared time model.

Initial configuration is created by Anadigm software. It is not a problem for practices and experiments defined by professors or lab assistants, but it does not allow open experiments. Other options and devices are being studied in order to make this possible. Some of these options are:

- Create a new builder in order to let students upload and design open projects.
- Create master designs that allow students use more capabilities of the FPAA, although they will still have certain limitations.
- Let participants use a virtual desktop in order to execute Anadigm software. This option will lock the device for only one student.

Reconfiguration times differ from one function to another, so the professor should take that into account when designing it. A master time controller can be developed to control all reconfiguration times no matter what design is being used.

VII. Opportunities

FPAA can also work in daisy chain; that could reduce the number of controllers needed and boost the capabilities of the system. FPAA working in that mode can interact with each other, building greater and more complex systems.

The FPAA is not limited only to final applications or practices, and it can help remote labs performing auxiliary tasks like signal conditioning, filtering or working as components that are not available in the remote lab.

Discrete components cost could be reduced and its live time increased due to a better care thanks to the FPAA used like a safety tool.

Desktop applications using the algorithmic method are a great tool for non-engineering students, and they can use the remote lab any time, from their own schools and with no need of having discrete components on their labs or going to the engineering faculty. Specially when there is not such a possibility.

VIII. Expected Results

The main expected output of this proof of concept, due to prior works, is that FPAA can improve significantly the possibilities of a remote laboratory, specially VISIR, since it is the remote lab used in the experiment.

Some constrains are also expected because of reconfiguration times and FPAA resources limitations.

A partial integration with VISIR is intended to be achieved with this work, but a full integration with VISIR capabilities and circuit solver is a much more complex task.

Acknowledgment

The authors acknowledge the support of the Escuela de Doctorado de la UNED, the S2013/ICE-2715 - eMadrid project, PILAR project Erasmus+ Strategic Partnership nº 2016-1-ES01-KA203-025327 (Platform Integration of Laboratories based on the Architecture of visiR). And the e-LIVES. e-Learning InnoVative Engineering Solutions-Erasmus+ Capacity Building in Higher Education 2017 - 585938-EPP-12017-1-FR-EPPKA2-CBHE-J, the Education Innovation Project (PIE) of UNED, “Desarrollos Avanzados Multi-Objetivo de Laboratorios Remotos para Actividades Educativas – DAMO-LRAE”, from the Academic and Quality Vicerectorate and the IUED of the UNED and to the project 2018-IEQ18 from the Industrial Engineering Technical School of UNED.

References

[1] J. Garcia-Zubia, J. Cuadros, S. Romero, U. Hernandez-Jayo, P. Orduna, M. Guenaga, L. Gonzalez-Sabate, I. Gustavsson, Fakulteten för teknikvetenskaper, Institutionen för tillämpad signalbehandling, Institutionen för signalbehandling, Blekinge Tekniska Högskola, Avdelningen för elektroteknik and Sektionen för ingenjörsvetenskap, '"Empirical Analysis of the Use of the VISIR Remote Lab in Teaching Analog Electronics," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 149-156.

[2] M. Tawfik, E. Sancristobal, S. Martin, C. Gil, A. Pesquera, P. Losada, G. Diaz, J. Peire, M. Castro, J. García-Zubia, U. Hernández, P. Orduña, I. Angulo, M.C. Costa Lobo, M.A. Marques, M.C. Viegas and G.R. Alves, '"VISIR: Experiences and Challenges," *International Journal of Online Engineering (iJOE)*, vol. 8, no. 1, pp. 25-32.

[3] A. Macho, M. Garcia Teruel, P. Baizan, M. Blazquez, F. Garcia-Loro, E. Sancristobal, G. Diaz, R. Gil and M. Castro, '"Dynamic reconfiguration in FPAA and its use in education," *2017 IEEE Frontiers in Education Conference (FIE)*, pp. 1-7.

[4] E.K.F. Lee and P.G. Gulak, '"A CMOS field-programmable analog array," *IEEE J Solid State Circuits*, vol. 26, no. 12, pp. 1860-1867.

[5] Anadigm, '"AN221E04 Datasheet Dynamically Reconfigurable FPAA With Enhanced I/O,", vol. DS030100-U006c.

Dynamic Reconfiguration in FPAA and its use in Education

Alejandro Macho
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
amacho@ieec.uned.es

Manuel Garcia Teruel
Electrical, Electronics, Automation and Communications Engineering Department
University of Castilla-La Mancha, UCLM
Albacete, Spain
manuel.garcia@uclm.es

Pablo Baizan
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
pbaizan@ieec.uned.es

Manuel Blazquez
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
mblazquez@ieec.uned.es

Felix Garcia-Loro
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
fgarcialoro@ieec.uned.es

Elio Sancristobal
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
elio@ieec.uned.es

Gabriel Diaz
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
gdiaz@ieec.uned.es

Rosario Gil
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
rgil@ieec.uned.e

Manuel Castro
Electrical and Computer Engineering Department, DIEEC
Spanish University for Distance Education, UNED
Madrid, Spain
mcastro@ieec.uned.es

***Abstract*— The purpose of this article is to study the dynamic reconfiguration in FPAA and, because of its potential, its academic applications. State driven and algorithmic reconfiguration methods have been considered during this work. Since these devices are not as well-known as FPGA, it is interesting to study its characteristics and abilities. The algorithmic method has been developed, obtaining conclusions about its use in education for technical and non-technical fields.**

***Index Terms*— FPAA, Dynamic Reconfiguration, Anadigm, Education, Lab**

I. Introduction

Reconfiguration is one of the most versatile and powerful techniques in the electronics field. Microcontrollers or FPGA can be reconfigured but, for instance, most of microcontrollers cannot be dynamically reconfigured. In other words, they need to be reset in order to work with the new configuration.

Dynamic reconfiguration avoids this issue and allows devices to change their functionality without a reset. FPAA, which are not as widely known as FPGA, can use this technology to reconfigure themselves, achieving different analog behaviors. It can be used in education, where this dynamic reconfiguration provides new tools and new possibilities to students and professors, and in several fields like avionics, signal processing, etc.

The importance of this technique in education resides in the ability of these devices in adapting themselves quickly to many situations while everything is under control in a safety environment.

This work tries to develop an example of educational application that could be applied to empower students to get more concepts while working at labs (or in remote labs). In order to achieve that, and with the aim to let other researchers or students to put this in practice, this work has used a simple methodology of six steps, that can be found on its own section. Anadigm devices have been used in this work, since it is the main manufacturer and its devices are cheap enough to be considered for educational purposes. Anadigm design and simulation software have been used but, as described during this report, simulation tools are sometimes insufficient. It is also an objective of this work to do an analysis about the different reconfigurations methods: the algorithmic method and the state driven method. The first one of these methods is the most powerful for educational and industrial applications, that is the reason why this method has been studied in a deeper way. Despite that some other works study the FPAA, this work aims to study its ability to dynamically reconfigure itself and introduce its application in education for technical and non-technical students. Analyzing, also, its benefits for students, professors and education centers. This practical work is the foundation of this article.

An educational development can be found in this article and it will show the different approaches that can support the learning of engineering students, electronic related studies or not, and even non-engineering students. Researchers can use

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

this information to develop new tools and applications to many education fields, and it could be also applied to remote labs. Definitions, a briefly history introduction, a comparison of the two methods of reconfiguration, the limits of the simulation tools and, of course, the conclusions of the use in education of FPAA dynamic reconfiguration, compose this article. This publication is a result of the Master Thesis of the author [1].

II. Definition and Material

A. FPAA

Research in programmable analog devices has not been as wide as in logic devices. The term FPAA was first used by Lee, K. and Gulak, P. in 1991 [2], introducing the CAB concept. These CAB are units which can develop different functions and can be interconnected between them in order to perform complex tasks. The most common interconnection technology is the MOS transistor controlled by a digital memory [2-6].

A field-programmable analog array (FPAA) is an integrated device containing configurable analog blocks (CAB) which are interconnected between them. FPAA are usually application driven because of their different architectures and operation modes.

Nowadays, there are different architectures where other basic units are used instead of CAB or they change the way that CAB are routed [7]. These architectures can operate in continuous and discrete time.

B. Discrete Time FPAA

Analog devices usually work and operate in a continuous time environment where each input or output signals can exist in an unlimited range of values. In continuous time, FPAA switch matrix's parasitic inductance, capacitance and noise contributions should be taken into account.

In order to avoid these problems while achieving more flexibility, discrete time devices are used. These FPAA use sample and hold circuits in each CAB output, obtaining a continuous signal but operating in discrete time with high frequency. In this kind of devices, switching noise and aliasing must be taken into consideration during the design phase [8].

The main technique used in discrete time FPAA is the switched capacitor technology. With this technology, a resistor can be obtained from a capacitor. Figure 1 illustrates how switched capacitors are configured as resistors. The resistance value will change according to the sampling frequency (f=1/T) [9].

This is one of the most important concepts of an FPAA because this technology allows for the creation of different resistors and can change its value on the fly. This is one of the fundamentals of dynamic reconfiguration.

C. State of the Art

FPAA are not as widely spread as their digital equivalent, FPGA, so there is not a lot of research in this field. There is also a device that uses mixed-signal processing, the FPMA [10]. These kinds of devices are even less used than FPAA. The reason is that hybrid FPGA-FPAA systems are achieving great results and it is complex to develop a new mixed technology like FPMA.

However, the robust capabilities of FPAA have been used in several disciplines for very specific functions like adaptive filters for the health field, in instrumentation [11-15] or hybrid FPGA-FPAA systems [16].

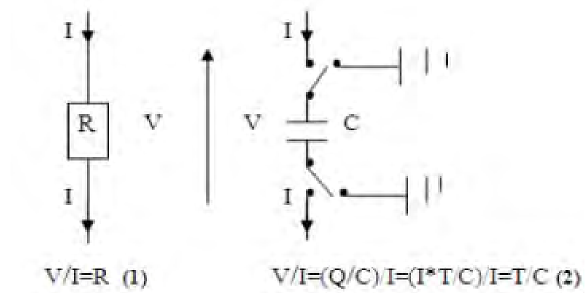

Figure 1. Switched Capacitor, [9].

D. Anadigm AN221E04 FPAA and AN221K04-V3

There are very few manufacturers of FPAA, with Anadigm being the principal developer. There is not a great amount of on-chip solutions, but because of its price and possibilities, the AN221E04 is the chip used in this development.

The AN221E04 [17] device, the first one of the second generation, consists of a 2x2 matrix of CABs that can be interconnected between them. These CABs are surrounded by analog input/output cells (4 configurable I/O cells and 2 output cells) with active elements like filters or amplifiers. The architecture scheme can be found in Figure 2.

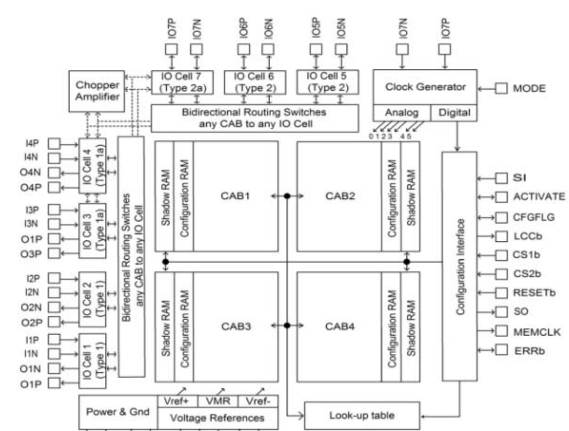

Figure 2. CAB structure of the AN221E04, [17]

This device includes 2 built-in memory blocks where configuration is stored. There is one SRAM block and a special memory block called Shadow RAM (SRAM). This special block allows the device to reconfigure itself dynamically and is the most important feature that makes dynamic reconfiguration possible.

The AN221E04 chip can be found in the AN221K04-V3 development board, among others, and it includes a PIC to program the FPAA and a good interface to test the device and to develop with it. The board also includes a serial port to connect the FPAA with a computer in order to program the chip. This FPAA-PC connection is very important in reconfiguration when used in educational environments.

E. AnadigmDesigner 2

Designing and implementing a circuit in the FPAA can be done through Electronic Design Automation (EDA) software. AnadigmDesigner2 [18] is the solution from the board manufacturer used in this project.

The process of implementing a design is made simple thanks to Configurable Analog Module (CAM). These modules can be dropped and connected in a visual interface in order to obtain the desired functionality. The software also provides an Assistant in order to facilitate the understanding of capabilities and limits of each CAM for the user. Figure 3. shows the AnadigmDesigner2 user interface.

This EDA software also includes different reconfiguration methods that can be easily used by the user. These methods depend on the chip and board used.

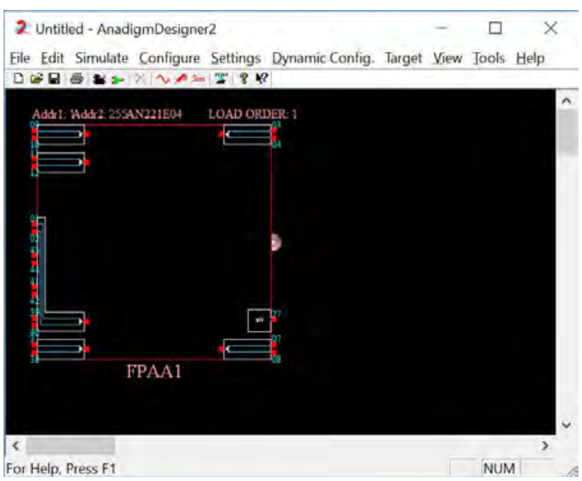

Figure 3. AnadigmDesigner2 user interface

III. Dynamic Reconfiguration Methods

Dynamic reconfiguration in FPAA modifies some parameters and functionalities of certain CAM. This reconfiguration is made on-the-fly because of Shadow SRAM memory blocks, as mentioned above. Anadigm allows the FPAA to reconfigured dynamically through two different processes: the state-driven method [19] and the algorithmic method [20, 21].

Operating under the state-driven method implies that all possible states are known during the design stage. These different states should be known, designed and stored in order to load them when necessary. This kind of reconfiguration is usually used in sound effects where transitions are set by time periods. In order to run this method, a microcontroller like a PIC [19] is necessary to store and load different FPAA configurations.

The algorithmic method is a more complex and has a bigger potential than the state driven method because of its functionalities. One of the main problems of the state driven method is memory limit, so it is not possible to store infinite transitions and configurations. The algorithmic technique avoids this problem since it uses a C library to generate a new configuration and, then, it loads the new configuration. So, it needs only memory to store the C library and the ability to execute it. A common PC or PIC are usually suitable to use this technique.

The aforementioned data lead us to believe that the algorithmic method is better and that it generates more opportunities and functionalities than the state driven method. It is true, but the state driven method is a great option and suitable in low-cost systems with low resources like memory or processing capacity.

IV. Methodology

Methodology and best practices are crucial in order to achieve good results and to guarantee a correct development. The methodology used in this project runs through the following stages.

A. System designing.

First of all, the system needs to be designed and the functional and technical requirements must be accomplished. This design can contain any operation that can be implemented in the FPAA with CAM. During this stage, FPAA electrical limitations like voltage limit should be taken into account.

B. AnadgimDesigner2 implementation.

Once the system is designed, this functionality should be implemented into the FPAA using CAM while wiring each one to another in regard to obtaining the desired behavior. Limitations of each CAM and its parameters range must be considered in next stages, so it is a good practice to implement the circuit taken care about parameters ranges.

C. C libraries.

AnadigmDesigner2 can export a C library with all functions related to the CAM used. Doing that as well is good practice because it minimizes the required memory size for the library in the PC or microcontroller.

D. Creating the control program.

The control program is in charge of all reconfiguration commands. In this project, the control program is implemented in a computer which is wired to the development board by the serial port. The C libraries should be included in this step and an appropriate interface has to be designed in order to facilitate the operation for users.

E. Implementing the design and configuration limits.

In analog systems, limits are the most important constraint. Suitable ranges, for instance, are ones of those limits that should be taken into account. CAM parameters can only work in a range of parameters and the entire FPAA cannot work with more than 4 V. These constraints should be implemented in the developed control software to avoid any problem during the reconfiguration. This is a critical stage and any error could possibly damage the entire board.

F. Compiling and testing.

Finally, we can compile the program and test the results. Visual Studio 2010 and Visual Studio 2015 have been used as compilers in this project. Please note that some interface features can vary from one version to another. Other C++ compilers can be used and libraries can be translated into other programming languages.

V. SIMULATING THE FPAA DESIGN

One of the most important steps during the design process is the simulation stage. This step is even more important in education, because students often do not have enough devices to test their designs and simulation allows them to save time and even to do a pre-work from home.

In order to simulate a design in a FPAA there are not many options but there are some generic ones like [22]. However, these solutions are not really focus on final applications and are not user friendly with most of students.

AnadigmDesigner2 offers a simulation solution for designs made for their devices. This solution offer a user-friendly interface with enough capabilities to test most of designs.

This simulation is made in a time domain, where the user is able to adapt the different clocks in the device and the input. However, there are also limitations, for example it is not possible to simulate a current input.

Simulation in FPAA is quite behind the FPGA or PIC simulation but current tools allow student to easily test different solutions and designs.

VI. EXAMPLE: IMPLEMENTING DYNAMIC RECONFIGURATION ADAPTING A TEMPERATURE SENSOR

Common problems while adapting sensors are resolution and precision. Most of times, a conditioner circuit is needed to adapt the values measured in order to be converted to a digital signal in a proper way.

A PT100 conditioner circuit can be implemented in a FPAA using only a few CAM (the scheme is shown in Figure 4). First, ranges and goals should be named, in this example the measured range goes from 0 °C to 40 °C and the output should be read by a PIC, which can only read tensions from 0 V to 3 V.

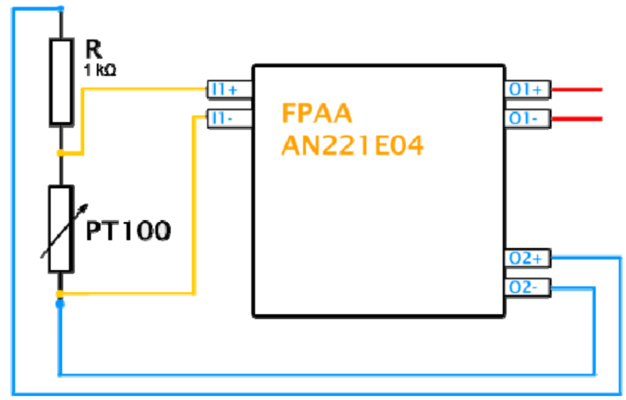

Figure 4. Scheme, PT100 conditioner design for FPAA

PT100 resistive values are:

$$PT100_{0\,°C} = 100\,\Omega$$
$$PT100_{40\,°C} = 115.54\,\Omega$$

The supply source is provided by the FPAA and the actual value should be read. In this case, the value applied to the voltage divider is 2.88 V. The real resistance value is 1001 Ω. Adding a pre-amplification stage of 5 V/V:

$$V_{PT100\,(0°C)} = \frac{2.88}{1001+100} \cdot 100 \cdot 5 = 1.3079\ V$$
$$V_{PT100\,(40°C)} = \frac{2.88}{1001+115.54} \cdot 115.54 \cdot 5 = 1.4901\ V$$

In order to adapt the signal to the range chosen (0 V, 3 V):

$$(1.3079 + y) \cdot x = 0\ V$$
$$(1.4901 + y) \cdot x = 3\ V$$

And, the solution is:

$$x = 16.47 \qquad y = -1.307$$

Note that the internal operational limit for the FPAA is 4 V, so any calculation should not exceed that limit in any stage of the process.

The design should be implemented in the FPAA as shown in Figure 5. A gain-limiter CAM has been used in order to protect the reader device of voltages higher than 3 V.

Finally, dynamic reconfiguration is applied using the algorithmic method, the C libraries and Visual Studio. A program has been developed and it allows the user to adapt the temperature and output ranges without making any analysis or calculation. Program, in Figure 6, reconfigures the board when it is running on a PC connected to the board.

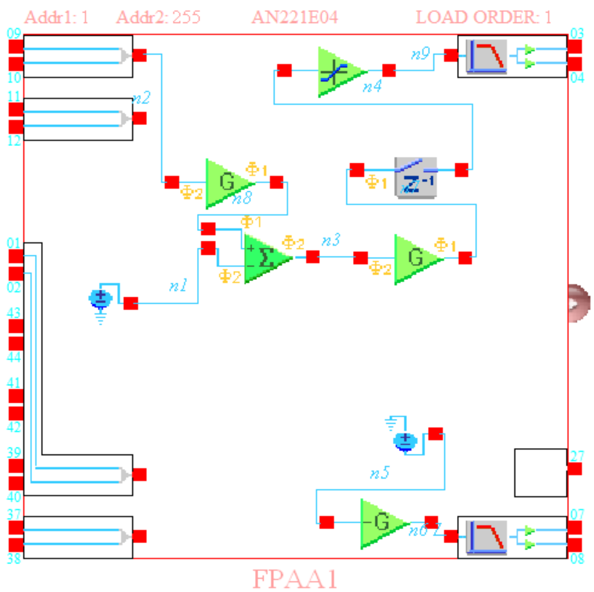

Figure 5. Implemented Design

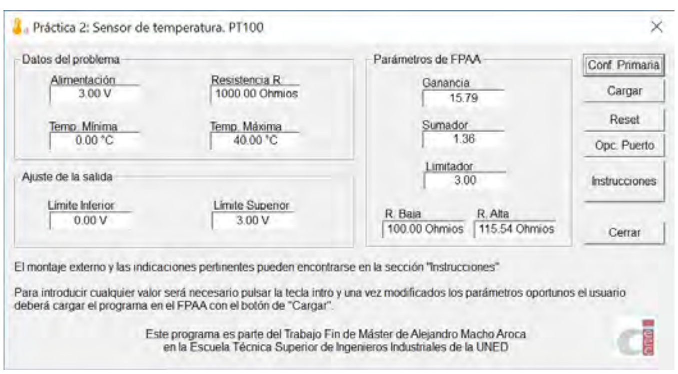

Figure 6. User interface of the developed program

VII. FPAA IN EDUCATION

FPAA allow student to test analog design in an easy way in a controlled and safety environment. This situation can lead in laboratories where FPAA is a main component of them.

A. *Education in engineering*

1) *Electrical and Electronics Engineering*

Students of electrical or electronics engineering are familiarized with analog concepts and they are able to create applications using discrete components. However, in a higher level, where inputs or analog processing is only a little part of their applications, they usually do not have enough time in labs to test different options or to fix errors.

In these cases, student can be supported by the FPAA [23] to generate inputs, noise, filters or to adapt their outputs in order to read them in another device. It will save time and components required to build a solution, but the most important thing is that it will allow the student to reach new knowledge and concepts using the same amount of time in university labs.

Students can use the dynamic reconfiguration to build robust systems and applications with many functionalities and options and, of course, it can be applied to other areas like control, where students usually think about microcontrollers [24].

2) *Non-electrical or electronics engineering students*

For example, mechanical engineering students can be interested in knowing how electrical concepts and circumstances can interfere in their works. These students usually do not have the knowledge to build custom solutions with discrete components in order to achieve their goals. In these situations, the FPAA can help them to experiment without the necessity of investing too much time acquiring the knowledge required to create this kind of applications. Professors can build solutions using dynamic reconfiguration to let their students to experiment with electrical concepts like frequencies, currents, voltages, integrators, etc. without having a deep understanding of these concepts. Using this option will lead in a more understanding of these practical concepts and to interact with them with only a few hours in labs, instead of investing hours in classes and accomplishing less goals.

B. *Non-engineering education*

There are many fields where electricals and electronics concepts are used and let students get a better understanding of their fields of study. For example, in medicine or in biology. Students can experiment with different frequencies and currents to know how they affect to a human being, to the heart or a tissue. However, these students usually do not have the technical background required to build a custom solution or to modify an existent one. Labs based on FPAA give a great amount of experiments where students can learn and get a deeper understanding of the electrical concepts involved and saving time to really get the concepts of their studies.

C. *For educational institutions*

Educational institutions can use FPAA based labs to save resources and spreading the opportunities they bring to students. Furthermore, if the FPAA are well designed and designed focusing in educational purposes, they are the perfect safety environment to study and learn, to grasp deep concepts and avoiding time consuming errors and knowledge barriers to non-technical students. These labs can be also deployed to server as a remote laboratory because of their dynamic reconfiguration capability students and, of course, large FPAA system could improve the features of these labs [25]. Thanks to this capability, students can perform different experiments, changing parameters in real time and observing the results.

VIII. RESULTS

A. *Developed Programs*

Four different programs have been developed in order to experiment with the possibilities of the algorithmic method in the dynamic reconfiguration: a lighting control program, a temperature measurement control, a light controlled trigger and a program to control two interconnected boards.

The programs reconfigure the FPAA in different ways. For example, when a slider bar is moved or when a new configuration, which has been checked by the user, is loaded. These developments work with a photodiode and a PT100 sensors and reconfigure the FPAA to operate under different situations with different goals. That shows how dynamic reconfiguration can be a tool to support students but also as a final application.

B. Dynamic Reconfiguration in Education

These programs have been used in four lab practices by students where dynamic reconfiguration has an active or passive role. The reconfiguration can be used to test more designs in less time while avoiding the probability of failure. For example, a filter CAM can be dynamically reconfigured to vary its pass frequency. In this case, the student will not need to modify the design he or she made.

Playing an active role, dynamic reconfiguration used by students can show them how to create applications for real situations and how to use resources, time and components, in a more efficient way. Following a series of instructions, students are able to create their own reconfiguration programs. With them, they can study a great deal of situations with only one circuit and without changing any components.

FPAA are not as known as FPGA, so this kind of techniques and methods help these devices be known by the scientific community and students. Its potential in several fields is outstanding and hybrid auto-reconfigurable systems (FPGA-FPAA, PIC-FPAA) [16] can make a difference in control issues.

IX. Conclusion

Dynamic reconfiguration in programmable analog devices is a new technique that allows the device to reconfigure themselves without changing their components and without a reset. Most analog systems present different issues because of temperature changes, different noises or tolerances. Dynamic reconfiguration avoids these problems because of the adaptability of the systems that uses this technique.

However, there are also limits in this technology and these limits depend on the reconfiguration method. In the state-driven method, limitations appear because of memory and non-adaptability constraints. It is also a problem that all reconfigurations should be known during the design stage, so it is not a true adaptive system. The algorithmic method needs a power controller or a PC to work, since it needs to execute the C libraries. Reconfiguration timing must be taken in account. Each CAM has its own timing. Due to that timing, performing a great quantity of reconfigurations in a short period of time can make the device reset itself. To avoid this kind of problems they should be considered during the design stage and it is not easy to know these constraints before testing.

A. Next Steps

Following the technique explained in this report the next step is to implement it in autonomous intelligent systems. A hybrid FPGA-FPAA system would be able to sense the environment and reconfigure itself in order to improve its performance. Research in this field can provide a good point for other investigations like predictive adaptive expert control, fuzzy logic, auto-calibrated measurements [12, 13], smart grids [11] or neural networks [2, 14, 26] science.

An interesting next step in the education field is that dynamic reconfiguration can be used in many fields, not only engineering. Developing simulated environments that can be reconfigured allows students and professors to learn and investigate with better and quicker tools.

Acknowledgments

The authors acknowledge the support of the eMadrid project (Investigación y Desarrollo de Tecnologías Educativas en la Comunidad de Madrid) - S2013/ICE-2715, VISIR+ project (Educational Modules for Electric and Electronic Circuits Theory and Practice following an Enquiry-based Teaching and Learning Methodology supported by VISIR), Erasmus+ Capacity Building in Higher Education 2015 nº 561735-EPP-1- 2015-1-PT-EPPKA2-CBHE-JP and PILAR project (Platform Integration of Laboratories based on the Architecture of visiR), Erasmus+ Strategic Partnership nº 2016-1- ES01-KA203-025327. And to the Education Innovation Project (PIE) of UNED, GID2016-17-1, “Prácticas remotas de electrónica en la UNED, Europa y Latinoamérica con Visir – PR-VISIR”, from the Academic and Quality Vicerectorate and the IUED (Instituto Universitario de Educación a Distancia) of the UNED.

This work is made within the Spanish University for Distance Education (UNED), in Spain, as part of the PhD Program on Advanced Electronics.

References

[1] A. Macho, "'La Reconfiguración Dinámica en FPAA, sus Aplicaciones y el Estudio de su Implementación en Sistemas de Educación," Master Thesis, Electrical and Computer Engineering Department. Spanish University for Distance Education, UNED, Madrid, Spain. Jul. 2016.

[2] E.K.F. Lee and P.G. Gulak, "'A CMOS field-programmable analog array," *IEEE J Solid State Circuits*, vol. 26, no. 12, pp. 1860-1867.

[3] D. Anderson, C. Marcjan, D. Bersch, H. Anderson, P. Hu, O. Palusinski, D. Gettman, I. Macbeth and A. Bratt, "'A field programmable analog array and its application," *Proceedings of CICC 97 - Custom Integrated Circuits Conference*, pp. 555-558.

[4] S.T. Chang, B.R. Hayes-Gill and C.J. Paull, "'Multi-function block for a switched current field programmable

analogue array," *Proceedings of the 39th Midwest Symposium on Circuits and Systems*, vol. 1, pp. 158-161 vol.1.

[5] V.C. Gaudet and P.G. Gulak, "'CMOS implementation of a current conveyor-based field-programmable analog array," *Conference Record of the Thirty-First Asilomar Conference on Signals, Systems and Computers (Cat. No.97CB36136)*, vol. 2, pp. 1156-1159 vol.2.

[6] B. Pankiewicz, M. Wojcikowski, S. Szczepanski and Y. Sun, "'A CMOS field programmable analog array and its application in continuous-time OTA-C filter design," *ISCAS 2001. The 2001 IEEE International Symposium on Circuits and Systems (Cat. No.01CH37196)*, vol. 1, pp. 5-8 vol. 1.

[7] S.H.K. Embabi, X. Quan, N. Oki, A. Manjrekar and E. Sánchez-Sinencio, "'A Current-Mode based Field-Programmable Analog Array for Signal Processing Applications," *Analog Integr.Cir.Signal Proc.*, vol. 17, no. 1, pp. 125-142.

[8] S.H. Tyson, "'Field Programmable Analog Arrays: A Floating Gate Approach," School of Electrical and Computer Engineering, Georgia Institute of Technology, 2004.

[9] M. Karmani, C. Khedhiri and B. Hamdi, "'Analog Integrated Circuit Design and Testing using the field programmable analog array technology," *IJAET*, vol. 1, no. 4, pp. 1-9.

[10] J. Stehlik and D. Becvar, "'Field Programmable Mixed-Signal Arrays (FPMA) Using Versatile Current/Voltage Conveyor Structures," *Personal Wireless Communications*, vol. 245, pp. 628-636.

[11] A.S. Deese and C.O. Nwankpa, "'Design and Testing of Custom FPAA Hardware With Improved Scalability for Emulation of Smart Grids," *IEEE Transactions on Smart Grid*, vol. 5, no. 3, pp. 1369-1378.

[12] M. Kouider, M. Nadi, J. Prado and D. Kourtiche, "'Embedded system design and implementation of standard auto-calibrated measurement chain,", pp. 377-382.

[13] D.P. Morales, A. Garcia, A.J. Palma, M.A. Carvajal, E. Castillo and L.F. Capitan-Vallvey, "'Enhancing ADC resolution through Field Programmable Analog Array dynamic reconfiguration," *2008 International Conference on Field Programmable Logic and Applications*, pp. 635-638.

[14] A. Zbrzeski, P. Hasler, F. Kolbl, E. Syed, N. Lewis and S. Renaud, "'A programmable bioamplifier on FPAA for in vivo neural recording," *2010 Biomedical Circuits and Systems Conference (BioCAS)*, pp. 114-117.

[15] M.A. Terry, J. Marcus, M. Farrell, V. Aggarwal and U. O'Reilly, "'GRACE: Generative Robust Analog Circuit Exploration," *Applications of Evolutionary Computing*, vol. 3907, pp. 332-343.

[16] L. Znamirowski, O.A. Palusinski and C. Reiser, "'Optimization Technique for Dynamic Reconfiguration of Programmable Analog/Digital Arrays," *Analog Integr.Cir.Signal Proc.*, vol. 31, no. 1, pp. 19-30.

[17] Anadigm, "'AN221E04 Datasheet Dynamically Reconfigurable FPAA With Enhanced I/O,", vol. DS030100-U006c.

[18] Anadigm.com. (2017). AnadigmDesigner®2 Software. [online] Available at: http://www.anadigm.com/anadigmdesigner2.asp [Accessed 20 Apr. 2017].

[19] Anadigm, "'App Note - 305 Application Note: State-Driven Control of a dpASP using a Microchip PIC.", vol. AN231010-U305.

[20] Anadigm, "'App Note - 208 Creating a DLL from An adigmDesigner2 C-code,", vol. AN221009-U208A.

[21] Anadigm, "'Apex Filter Demo Application Note,", vol. AN231K02-D001 B.

[22] A. Minocha, "'Simulation Tool for FPAA,", vol. 2016, no. 06-05, 2012.

[23] M. Collins, J. Hasler and S. Shah, "'An approach to using RASP tools in analog systems education," *FIE*, pp. 1.

[24] C. Choi, "'Comparing microcontroller and analog methods for tracking control experiments," *2015 IEEE Frontiers in Education Conference (FIE)*, pp. 1-4.

[25] C.M. Twigg and P.E. Hasler, "'Incorporating Large-Scale FPAAs Into Analog Design and Test Courses," *IEEE Transactions on Education*, vol. 51, no. 3, pp. 319-324.

[26] P. Rocke, B. McGinley, J. Maher, F. Morgan and J. Harkin, "'Investigating the Suitability of FPAAs for Evolved Hardware Spiking Neural Networks," *Evolvable Systems: From Biology to Hardware*, vol. 5216, pp. 118-129.

Experiencia didáctica en la escuela secundaria con el laboratorio remoto VISIR

Manuel Blázquez, Alejandro Macho, Pablo Baizán, Félix García, Elio San Cristobal, Gabriel Diaz, Manuel Castro, Pedro Plaza

Departamento de Ingeniería Elecgrica, Electronica y de Control
Universidad Nacional de Educación a Distancia - UNED
Madrid, España

mblazquez@ieec.uned.es, amacho@ieec.uned.es, pbaizane@ieec.uned.es, fgarcialoro@ieec.uned.es,elio@ieec.uned.es,gdiaz@ieec.uned.es, mcastro@ieec.uned.es, pplaza@ieec.uned.es

***Abstract*— El laboratorio VISIR es una herramienta utilizada como laboratorio remoto en el ámbito de la educación superior. En esta comunicación se presentan las características de un curso llevado a cabo en el contexto de la educación secundaria en Tecnología para el aprendizaje de la Electricidad en el que se ha combinado VISIR y una metodología específicamente diseñada para la experiencia y que se basa en la taxonomía de Bloom-Anderson. El empleo de VISIR ha servido para reforzar con la práctica de medidas eléctricas, la adquisición de los conocimientos teóricos sobre los fundamentos de la Electricidad y la metodología para optimizar dicho aprendizaje hacia el desarrollo de destrezas y habilidades cognitivas.**

Se presentan igualmente los resultados de aprendizaje de los estudiantes participantes en la experiencia y se comparan estos resultados con la percepción que tienen los propios estudiantes sobre su aprendizaje.

Keywords*— Laboratorio remoto, VISIR, Educación secundaria, Bloom-Anderson, medidas eléctricas, electricidad, proceso de enseñanza aprendizaje

I. INTRODUCCIÓN

VISIR es un laboratorio remoto enfocado al aprendizaje de la Electricidad y la Electrónica, bien conocido en el ámbito académico y de ingeniería [1, 3]. Su diseño se corresponde con una herramienta de aprendizaje para la práctica en cursos de pregrado y postgrado, pero no se tienen evidencias de que se haya como recurso para enseñar temas relacionados con la tecnología en la escuela secundaria. En este documento, se presenta un trabajo de investigación para mostrar el diseño, desarrollo, implementación y resultados de aprendizaje de una experiencia educativa con estudiantes de secundaria, cuyo propósito es la optimización del aprendizaje de magnitudes eléctricas y circuitos.

En realidad, para impulsar la optimización del aprendizaje de la electricidad en este tipo de estudiantes tan jóvenes, las herramientas tecnológicas no son suficientes. También se ha diseñado una metodología específica para llevar a cabo el proceso de enseñanza-aprendizaje. Para ello, la metodología se ha basado en las características de la taxonomía de Bloom-Anderson [2], con el fin de organizar las etapas de aprendizaje mediante la activación de un grupo de habilidades cognitivas de los alumnos de la Enseñanza Secundaria Obligatoria.

Así, el laboratorio remoto VISIR [6] ha sido el recurso utilizado para abordar el núcleo de las actividades, por medio del cual se han realizado medidas de magnitudes eléctricas en diversos componentes y circuitos.

Ambas propuestas han conformado la experiencia didáctica desde dos planos: el metodológico y el contextual. El planteamiento metodológico se ha aplicado a todos los alumnos ya que estamos convencidos de que el aprendizaje ha de estar centrado en el alumno y adaptado a las necesidad de cada uno de ellos. Pero, para medir las diferencias en el planteamiento contextual, es decir, en los recursos que se emplean para fomentar el aprendizaje de los contenidos de electricidad, se han creado dos grupos de trabajo entre los estudiantes participantes. Un primer grupo ha utilizado dispositivos de instrumentación comunes en cualquier laboratorio y se ha conformado como el grupo de referencia, mientras que un segundo grupo de estudiantes ha realizado las mediciones con el laboratorio remoto VISIR, estableciendo así el grupo de control.

La experiencia ha sido guiada por un documento de trabajo en el que se han incluido explicaciones y actividades didácticas, específicamente diseñadas utilizando una aproximación constructivista [11] que pretende destacar el desarrollo de habilidades cognitivas [2].

II. JUSTIFICACIÓN METODOLOGICA

En el mundo de la educación y sobre todo, en la educación en Ingeniería, los profesores estamos acostumbrados a enfocar el aprendizaje hacia la memorización y repetición de los procesos como herramienta didáctica fundamental. Así uno de los pilares del aprendizaje se basa en un planteamiento didáctico centrado en el profesor, el cual transmite sus conocimientos a los estudiantes, los cuales han de ejercitar la memoria y la repetición de ejercicios. La comprensión conceptual, queda por tanto, relegada a un segundo plano y va a depender en gran medida de las habilidades del propio estudiante. Este planteamiento se basa, por tanto, en aplicar una metodología puramente conductista [12] , en la que el profesor confía en que el estudiante sepa alcanzar el aprendizaje significativo por sí mismo. La forma de evaluar queda reducida, en la mayor parte de los casos, a la realización de exámenes y test, que miden de forma puntual el grado de adquisición del conocimiento por el estudiante. En cierto modo, se trata de evaluar una situación dinámica mediante una foto

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

final. La metodología propuesta pretende pues, evaluar el progreso de los estudiantes en cada una de las acciones y actividades que lleve a cabo y precisamente en este aspecto, hemos encontrado el planteamiento propuesto por Bloom-Anderson como el ideal para monitorizar estos progresos.

La anteriormente citada concepción conductista de la enseñanza se justifica a menudo, desde el ámbito docente, con la enorme cantidad de materia que un estudiante de Ingeniería tiene que asimilar y el poco tiempo disponible para conseguir sus objetivos de aprendizaje. Y aquí reside precisamente la razón de ser del trabajo de investigación que en este papel se presenta, bajo la hipótesis de que trabajar en el aprendizaje de los conceptos, magnitudes y procedimientos relacionados con la Electricidad y la Electrónica desde los cursos de educación secundaria, permitirá a los estudiantes asimilar los conocimientos de forma más sólida. A diferencia de los estudiantes universitarios, los alumnos de la etapa de secundaria están más abiertos al aprendizaje procedimental y comprensivo y son más reacios a aspectos como la memorización o el empleo de ecuaciones matemáticas. A la hora de diseñar la experiencia, este aspecto ha sido prioritario y hemos encontrado en la taxonomía de Bloom-Anderson características óptimas para nuestros propósitos.

2.1 La taxonomía de Bloom-Anderson

Bloom primeramente en 1948 y Anderson, en una revisión de 2001 [2], desarrollaron una clasificación de destrezas cognitivas, desde las más sencillas hasta las más complejas con el fin de establecer una norma que sirviera de guia en los procesos de evaluación del aprendizaje. Estas destrezas fueron agrupadas en dos niveles en las que se representan las capacidades mentales dirigidas hacia el empleo de la memoria o hacia el desarrollo creativo. Sendos niveles, definidos como habilidades de pensamiento o destrezas cognitivas de orden inferior y superior, se definen como *Low Order Thinking Skills* (LOTS) y *High Order Thinking Skills* (HOTS), respectivamente. Para ser más preciso, y de acuerdo con el esquema de la figura 1, las LOTS corresponden con las destrezas cognitivas relacionadas con la memorización, la comprensión de los elementos teóricos del conocimiento y su aplicación en la resolución de problemas. Por otro lado, las HOTS son aquellas destrezas que dotan al estudiante de capacidad de análisis de un problema, de evaluación de los contextos y de creación de nuevos escenarios.

Por lo tanto, uno de los objetivos del trabajo de investigación que aquí se presenta, tratará de evaluar el grado de consolidación de los LOTS y como consecuencia, su relación con el grado de alcance de los HOTS. Creemos que este planteamiento es correcto desde el punto de vista constructivista y ayudará a los estudiantes de educación secundaria a optimizar el aprendizaje de los fenómenos eléctricos y como consecuencia, mejorar sus destrezas cognitivas a la hora de aplicar una correcta estrategia de cálculo de los circuitos eléctricos.

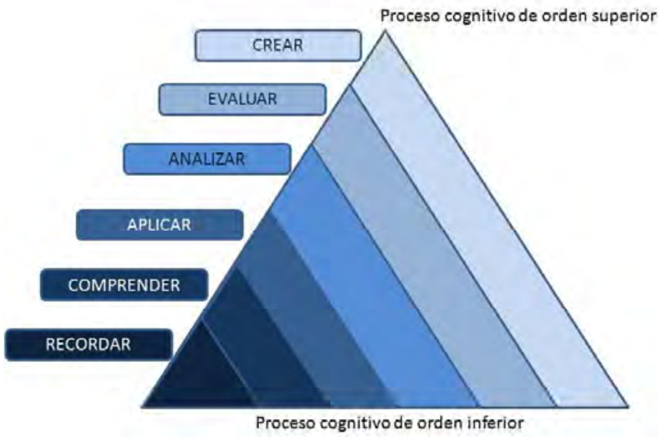

Fig. 1. Esquema de la taxonomía de Bloom-Anderson según los niveles cognitivos

2.2 El laboratorio remoto VISIR

Existen multitud de referencias a simuladores de circuitos eléctricos y laboratorios virtuales [10,13] , recursos que proliferaron en gran medida en la década de los 1990s. No obstante, con el cambio del milenio, muchos investigadores pensaron en la posibilidad de utilizar laboratorios que pudieran ser manejados de forma remota, empleado la web como medio de acceso. Este es el caso de VISIR (*Virtual Instrument Systems In Reality*), desarrollado en primera instancia por Ingvaar Gustavsson del Blekinge Institute of Technology en 2001 [8].

Aunque VISIR ya ha sido extensamente descrito en otras publicaciones como la llevada a cabo por Tawfik et al. en 2011 [1], se trata de un sistema que ofrece un entorno virtual al usuario a través de acceso web, mediante el cual se puede manipular las conexiones de un sistema de dispositivos eléctricos y electrónicos (plataforma PXI). La constitución de los dispositivos disponibles en el laboratorio para llevar a cabo las medidas se programa mediante la *Component List* (CL) o lista de componentes, que se cargará en el *Equipment Server Software* (ESS) o software de servidor de equipos. Los dispositivos en CL se combinan entonces con el *Measurement Server* o servidor de medidas para realizar las mediciones requeridas por el usuario.

Entre ambos extremos, el *User Interface* (Interfaz de usuario) y el *Server Equipment* (Equipamiento de servidor), se encuentran etapas intermedias que automatizan el acceso del usuario al sistema y la comunicación. Tal y como se observa en la figura 2, el proceso, desde el punto de vista del usuario, es sencillo, ya que se centra en acceder al sistema mediante sus credenciales y operar en el interfaz de usuario. El equipamiento dispone de un servidor Web y un gestor de base de datos que proporcionará la comunicación con el usuario a través del interfaz. Este interfaz tiene una operativa similar a la que se utilizaría en cualquier laboratorio presencial, empleando una breadboard sobre la que alojar los diferentes componentes eléctricos o electrónicos y procediendo a incorporar las diversas conexiones que configuran un circuito dado.

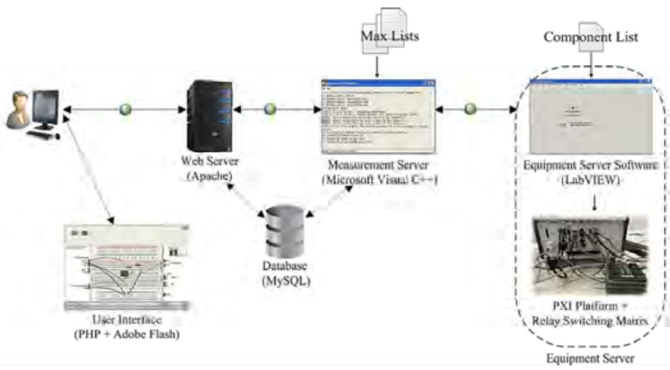

Fig. 2. Representación esquemática de los componentes de VISIR (Fuente: Tawfik et al. 2011)

Por otro lado, una de las utilidades de VISIR es la posibilidad de contar con instrumentos de medida de voltaje, intensidad eléctrica y resistencia eléctrica, con lo que el estudiante podrá realizar de forma autónoma las mediciones requeridas en cualquier protocolo de prácticas.

2.3 Diseño de la experiencia de aprendizaje

Para abordar los contenidos curriculares de la materia de Tecnología en la etapa de Educación Secundaria, se han fijado una serie de conceptos en el marco del diseño de la experiencia didáctica propuesta. Estos conceptos tienen carácter progresivo, y se enfocarán hacia el estudio de las magnitudes eléctricas, los resistores y otros componentes de los circuitos eléctricos, las configuraciones serie, paralelo y mixto de circuitos, la asociación de resistencias y el concepto de resistencia equivalente. La parte práctica contendrá los procedimientos de medida, la instrumentación y los dispositivos de medida y el concepto de error en la medida.

A fin de poder comparar, el impacto en el aprendizaje, la asimilación de contenidos y el desarrollo de destrezas relacionadas con la medida de magnitudes eléctricas, se ha dado a la totalidad del alumnado el mismo protocolo de prácticas, que consiste en un documento que contiene tanto explicaciones teóricas como propuestas de trabajo práctico y que ha sido diseñado siguiendo un diseño específico que atiende a las particularidades de la taxonomía de Bloom.

De forma adicional, se ha creado una plataforma educativa desarrollada en Moodle, con formato de MOOC, en la que se ha dispuesto la documentación de prácticas, así como otros materiales didácticos apropiados como videos de apoyo para el empleo del laboratorio remoto y para facilitar la comprensión del documento de prácticas. Los videos que se han incluido son de corta duración (entre 2 minutos y 8 minutos) y su objetivo es servir de guía a los alumnos en la secuenciación de actividades teóricas y prácticas. La plataforma educativa es accesible con cualquier navegador web mediante la URL http://62.204.201.27/moodle/.

Los alumnos participantes en este trabajo de investigación provienen de diversos grupos de los dos primeros cursos de Educación Secundaria. En total, han participado 147 estudiantes, 84 chicos y 63 chicas. La experiencia didáctica se ha llevado a cabo a lo largo de 6 sesiones de 55 minutos, distribuyendo las actividades tal y como se indica en la tabla 1.

TABLA I. TEMPORALIZACIÓN DE ACTIVIDADES SESIÓN A SESIÓN.

Actividad
Información general del proyecto Realización del cuestionario inicial
Visualización del video "*Que son VISIR y los laboratorios remotos?* " (solo para alumnos del laboratorio remoto) Visualización del video "*La estructura del curso de medidas eléctricas básicas* " mientras los alumnos proceden a la lectura del protocolo de prácticas.
Reconocimiento de la plataforma de medida de VISIR Visualización del video "*La metodología aplicada a las prácticas con VISIR* " Visualización del video "*Medida de resistencia eléctrica* (Nivel 1)" Realización de la práctica 1
Realización de la práctica 2 Visualización del video " *Medida de resistencias asociadas* (Nivel 2)" Realización de la práctica 3 y práctica 4
Revisión y finalización del protocolo de prácticas Entrega del protocolo de prácticas (curso 1º)
Visualización del video "*Estrategia útil para el cálculo de magnitudes eléctricas en circuitos mixtos*" Visualización del video "*Medidas de voltaje y corriente eléctrica con VISIR* (Nivel 3)" Realización de la práctica 5 y de la práctica 6 Revisión y finalización del protocolo de prácticas (2º curso) Entrega del protocolo de prácticas (2º curso)
Realización del cuestionario final Visualización del video "*Revisión de las prácticas y nuevas perspectivas de aprendizaje con VISIR*"

En la tabla anterior se observa que además de las actividades propias de la experiencia se han provisto de dos cuestionarios que los alumnos han tenido que completar al inicio y al final de la experiencia. Ambos cuestionarios contienen preguntas sobre sus conocimientos y expectativas respecto a las medidas eléctricas y al empleo de instrumentación. Los cuestionarios tienen la finalidad de medir la percepción subjetiva de los alumnos ante la experiencia didáctica.

Con el fin de poder contrastar los resultados de aprendizaje, se ha pensado en dividir a los grupos en dos grupos, un primer grupo de referencia y un segundo grupo de control. Ambos grupos han utilizado el mismo tiempo para las actividades y la misma documentación de prácticas. Los estudiantes del grupo de referencia, que se ha denominado Laboratorio presencial, han contado con aparatos de medida y dispositivos eléctricos reales y por tanto, han realizado las prácticas conectando manualmente diversas resistencias eléctricas en una breadboard y han medido con un multímetro. Por otro lado, el grupo de control, que se ha denominado Laboratorio Remoto, han utilizado el laboratorio remoto VISIR para realizar las conexiones en los circuitos y conectar la instrumentación. Así, la distribución de estudiantes según el laboratorio se ha reflejado en la tabla 2.

TABLA II. AGRUPAMIENTO DE LOS PARTICIPANTES DE ACUERDO AL GÉNERO Y AL TIPO DE LABORATORIO

		Laboratorio presencial	Remote Lab	Total
1º curso	Chicos	32	36	68
	Chicas	27	22	49
2º curso	Chicos	10	6	16
	Chicas	5	9	14
	TOTAL	74	73	147

III. PERCEPCIÓN SUBJETIVA DE LOS ESTUDIANTES SOBRE LA EXPERIENCIA

Con el fin de conocer la percepción de los estudiantes frente a su propio aprendizaje, se han realizado dos cuestionarios, que se realizarán por los estudiantes respectivamente antes (pre-test) y después (post-test) de la realización de la experiencia. Ambos cuestionarios exponen preguntas con el fin de recabar información sobre las expectativas y motivaciones, los contenidos y la metodología y el tipo de laboratorio que se utiliza en la experiencia de medidas eléctricas. Cada uno de los 147 alumnos participantes en la experiencia ha respondido a 25 preguntas, que se han distribuido en 5 bloques.

2.4 Resultados de los datos más significativos de los cuestionarios

En el primer apartado, se ha realizado la pregunta " *Would you like to work in your professional future in a position related to Technology?"*, (en castellano, ¿Te gustaría cuyas respuestas nos parece muy significativas). Los estudiantes podían responder "Yes" que se ha valorado con un 2, "Not clear yet" (No lo tengo claro todavía, en castellano) que se ha valorado con un 1 o "No" cuyo valor ha sido asignado a 0.

En la siguiente figura se puede ver la distribución de las respuestas. Tanto las respuestas dadas en el cuestionario inicial como en el final han coincidido. En ellas, se observa una indefinición generalizada ante su futuro, debido a su corta edad, pero también se observa como las chicas les atrae menos un futuro profesional relacionado con la tecnología. El porcentaje de rechazo de las chicas (35%) es similar al porcentaje de atracción por la Tecnología de los chicos (33%)

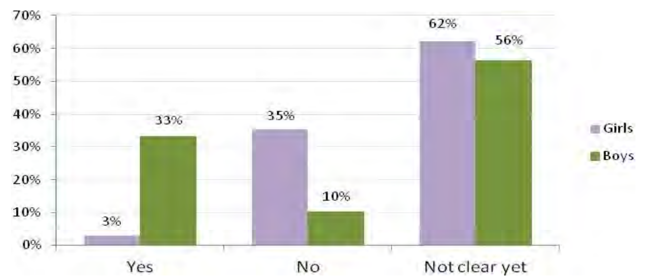

Fig. 3. Fig. 1. Answers to: "Would you like to work in your professional future in a position related to Technology?"

En el segundo bloque, los estudiantes son preguntados sobre sus conocimientos de electricidad, específicamente sobre las magnitudes eléctricas, sobre si son capaces de interpretar el esquema de un circuito eléctrico y de reconocer los componentes eléctricos más habituales, si bien la más importante se dirige a la valoración que hacen los estudiantes sobre su destreza en el uso de un multímetro, resultados que se muestran en la tabla 3 mediante un valor en una escala de 10.

TABLA III. PERCEPCIÓN DE LOS ESTUDIANTES SOBRE LA ADQUISICIÓN DE NUEVAS DESTREZAS CON EL EMPLEO DE UN MULTIMERO

	Género		Laboratorio	
	Chicos	Chicas	Remoto	Presencial
Media del test inicial	4.73	4.29	4.68	4.77
Media del test final	7.94	7.64	8.17	7.71
Factor de mejora	3.21	3.35	3.49	2.94

En la anterior tabla 3 se observa como los alumnos, consideraban antes de hacer las prácticas que sus conocimientos sobre el empleo de un multímetro eran insuficientes. Tras la realización de la experiencia, todos ellos reconocen haber mejorado de forma significativa en esta destreza. La percepción de mejora es mayor en chicas que en chicos y también es mayor en aquellos alumnos que han utilizado el laboratorio remoto.

En el tercer bloque de preguntas, se preguntaba sobre sus expectativas y motivación ante nuevos conocimientos. La pregunta principal está relacionada sobre si ellos son conscientes de adquirir nuevas destrezas con la realización de las prácticas. Las respuestas antes y después de haberlas realizado son significativas y diferentes dependiendo del agrupamiento, tal y como se observa en los datos en una escala de 10 en la tabla 4. Se puede observar que mientras los chicos reconocen haber mejorado en sus capacidades, las chicas indican que esperaban haber obtenido más conocimientos y destrezas tras la realización de la experiencia.

TABLA IV. VALORACIÓN DE LOS ALUMNOS SOBRE LA UTILIDAD DEL CURSO EN LA ADQUISICIÓN DE DESTREZAS Y CONOCIMIENTOS

	Género		Laboratorio	
	Chicas	Chicas	Remoto	Presencial
Initial test avg.	7.71	8.20	7.95	7.82
Final test avg.	8.20	7.84	8.04	7.53
Mean difference	0.49	-0.37	0.09	-0.29

Igualmente ocurre si agrupamos los datos en relación al tipo de laboratorio utilizado. Los estudiantes que han practicado con el laboratorio remoto VISIR indican que esperaban adquirir un determinado nivel de adquisición de destrezas y tras la realización de la experiencia, han corroborado ese dato. Por otro lado, los alumnos que han utilizado instrumentación del laboratorio presencial, reconocen haber adquirido un nivel ligeramente inferior del que esperaban.

El cuarto bloque de preguntas, las preguntas se dirigen hacia la más importante: "Creo que después de hacer las prácticas, habré aprendido de forma permanente como se hacen las medidas eléctricas" en el cuestionario inicial y "Creo que después de hacer las prácticas, he aprendido de forma permanente como se hacen las medidas eléctricas". En cierto modo, la medida de estas respuestas dará una idea del convencimiento del propio estudiante a su aprendizaje.

TABLA V. VALORACIÓN DE LOS ALUMNOS SOBRE SU APRENDIZAJE SIGNIFICATIVO Y PERMANENTE

	Gender		Laboratory	
	Boys	**Girls**	**Remote**	**Actual**
Initial test avg	7.26	7.23	6.90	7.40
Final test avg	7.31	7.01	7.12	7.35
Mean difference	0.05	-0.2	0.22	-0.05

Al analizar las respuestas expuestas en la tabla 5, se observa que tanto chicos como chicas tienen a priori confianza en la experiencia didáctica para su consolidar su aprendizaje. Esta confianza se mantiene en los chicos tras realizar la experiencia, pero se reduce en el caso de las chicas. En relación al agrupamiento según laboratorios, se observa que los estudiantes que han utilizado VISIR tienen confianza en haber consolidado sus conocimientos, mientras que en los alumnos que han utilizado el Laboratorio presencial se puede interpretar que se han cumplido sus expectativas.

Finalmente, los autores estábamos muy interesados en la percepción que tienen los estudiantes sobre el formato del laboratorio y para ello, las preguntas finales (Preguntas 21 a 25) han sido:

- Q21. Creo que el diseño del laboratorio es atractivo
- Q22. Creo que el diseño del laboratorio es intuitivo y fácil de manejar
- Q23. Creo que el empleo del laboratorio me ha ayudado a asimilar más fácilmente como funciona la electricidad
- Q24. Considero importante que el laboratorio se adecúe a mis necesidades.
- Q25. Creo que después de utilizar el laboratorio, mis conocimientos y comprensión de los componentes y circuitos eléctricos han mejorado.

La respuesta de los alumnos se ha recogido en una tabla en la que se muestran la proporción de alumnos que han contestado con valoración negativa (en rojo) y que han contestado positivamente (en verde). En general se observa mayorías de respuestas positivas, si bien hay que destacar la cantidad de alumnos que piensan que el laboratorio remoto VISIR no es fácil de usar ni intuitivo. Por otro lado, un tercio de los alumnos que han empleado el laboratorio presencial piensa que no se ha adaptado a sus necesidades.

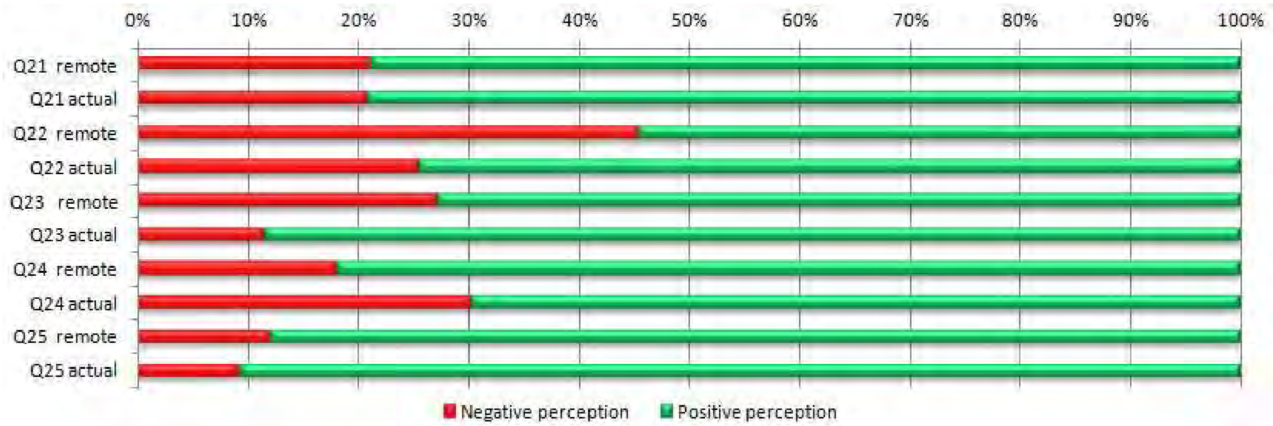

Fig. 4. Análisis de las preguntas relacionadas con el impacto de los laboratorios en la mejora del aprendizaje de los alumnos.

IV. RESULTADOS DE APRENDIZAJE

El trabajo de investigación que aquí se presenta tiene dos claros objetivos educativos. El primero se enfoca hacia la evaluación del impacto que la realización de las prácticas ha tenido en la adquisición de conocimientos teóricos con el fin de valorar la idoneidad del laboratorio remoto VISIR como recurso de aprendizaje. El segundo consistirá en la validación de la hipótesis de que el grado de consolidación de LOTS (*Low order thinking skills*) influye en la adquisición de HOTS (*High order thinking skills*).

De forma general, queremos exponer en primer lugar los resultados obtenidos por los estudiantes en la realización de las pruebas. Estas calificaciones objetivas, divididas por curso, se han incluido en la tabla 6. A la vista de estos valores, las calificaciones obtenidas en el Nivel 1 son bastante mediocres y muy similares entre alumnos del *Laboratorio presencial* y de *VISIR remote lab*. En este caso, se producen dos circunstancias que explican estas bajas calificaciones. Por un lado, los alumnos no han estudiado nunca temas relacionados con Electricidad y el empleo de reglas matemáticas les resulta complicado. Por otro, también es la primera vez que utilizan instrumentación. Ambos factores aumentan su incidencia con el poco tiempo de duración de las actividades.

TABLA VI. NOTAS MEDIAS DE LOS ESTUDIANTES DEPENDIENDO DEL TIPO DE LABORATORIO USADO Y DEL GÉNERO

	Tipo de laboratorio		Género	
	Presencial	VISIR	Chicas	Chicos
Students	59	58	49	68
Media Nivel 1	4.71	4.66	5.43	4.17
Media Nivel 2	5.86	4.69	6.14	4.56
Media Nivel 3	4.33	5.43	6.26	3.41

Estas diferencias se amplían cuando se trata de comparar los resultados de las actividades del Nivel 2, mejorando en el caso del *Laboratorio presencial*. Es posible que el empleo de VISIR, requiera un cierto aprendizaje que los alumnos de corta edad no han realizado. Es precisamente en el Nivel 3, el más complejo, en el que los estudiantes de VISIR obtienen mejores calificaciones de forma significativa.

En cuanto al análisis de los datos relativos al género, es muy destacable la diferencia en las calificaciones entre chicos y chicas. Las diferencias son mayores a medida que aumenta la dificultad en el manejo del laboratorio.

4.1 Impacto de la realización de prácticas en el aprendizaje

Los estudiantes han utilizado el protocolo de prácticas como documento guía en el que han contestado a las actividades propuestas. Algunas de ellas han sido de carácter teórico y en otras, tenían que escribir los resultados de sus mediciones como parte de la actividad práctica. En las siguientes figuras hemos representado una nube de puntos en las que el eje X corresponde con la valoración obtenida en las actividades manejo de instrumentación y medidas y en el eje Y las valoraciones en las actividades teóricas.

Como se puede observar en la serie de figuras 6 a 8, los resultados son mucho mejores en las actividades del Nivel 2, a pesar de ser un nivel más complejo. Este fenómeno entendemos que tiene mucho que ver con la familiaridad en el empleo del laboratorio en el Nivel 2 y en la dificultad de dar los primeros pasos en el Nivel 1. En un examen más exhaustivo de las valoraciones de los alumnos en función del tipo de laboratorio utilizado, se observa una mayor concentración de punto en el área definida como "*High performance área - High relation practice-learning*" (Área de alto rendimiento - Alta relación práctica-aprendizaje) en los alumnos que han utilizado VISIR. Por otro lado, nos ha parecido interesante realizar una comparativa entre estudiantes según el sexo. Este análisis ha sido motivado al observar las respuestas a las pregunta de los cuestionarios por parte de la chicas, que nos ha parecido que ofrecían una percepción de su aprendizaje inferior a la de los chicos.En las siguientes figuras 9 y 10, se ha procedido a representar las nubes de puntos por niveles. Así, la figura 9 corresponde con las valoraciones de medición del aprendizaje teórico-práctico en las chicas (a la izquierda de la gráfica) y los chicos (a la derecha de la gráfica) para las actividades del nivel 1. En la figura 10 se han representado las valoraciones para el nivel 2 de actividades.

Tal y como se puede observar, se da una situación paradójica, ya que en ambos niveles L1 y L2, existen más puntos localizados en las áreas de "*High performance*" (Alto rendimiento) y "*Good practices but low learning*" (Buenas prácticas, pero bajo nivel de aprendizaje) en el caso de las chicas, es decir, las calificaciones obtenidas por las chicas se confirman como mejores que las de los chicos. Esta situación contrasta con la opinión más modesta que tienen las chicas de su propio aprendizaje que los chicos.

4.2 Estudio de la relación LOTS-HOTS

En un segundo tipo de análisis, las actividades han sido identificadas según la incidencia que tenga en las destrezas cognitivas. Así, se han formado dos grupos de actividades, aquellas que influyen en el desarrollo de Low Order Thinking Skills (LOTS) y aquellas que permiten a los alumnos desarrollar sus High Order Thinking Skills (HOTS). Nuestra hipótesis planteada indica que para poder desarrollar destrezas HOTS es fundamental que se hayan trabajado suficientemente las destrezas inferiores LOTS. Así hemos medido de forma individual el rendimiento de los estudiantes en ambos tipos de actividades y hemos tenido en cuenta el factor de la edad del alumno, ya que muy posiblemente sea uno de los factores más importantes en el desarrollo cognitivo, sobre todo a edad adolescente. Así, en la figura 11, se ha representado una gráfica en la que se han expuesto las calificaciones obtenidas en ambos tipos de actividades, LOTS y HOTS, en alumnos de primer curso (12 años de edad). Las calificaciones de los alumnos han sido agrupadas en rangos indicados en el eje X. El eje Y representa el porcentaje de estudiantes cuya calificación se encuentra en cada rango. Así se puede observar que la mayoría de los alumnos concentran sus calificaciones en un rango entre 5 y 8 puntos sobre 10 en el caso de las destrezas LOTS, mientas que en el caso de las HOTS, la mayoría de ellos no ha pasado de una calificación de 5. En cierto modo, esto corrobora en parte la hipótesis ya que podemos identificar problemas a la hora de realizar actividades que exijan análisis y creación de situaciones.

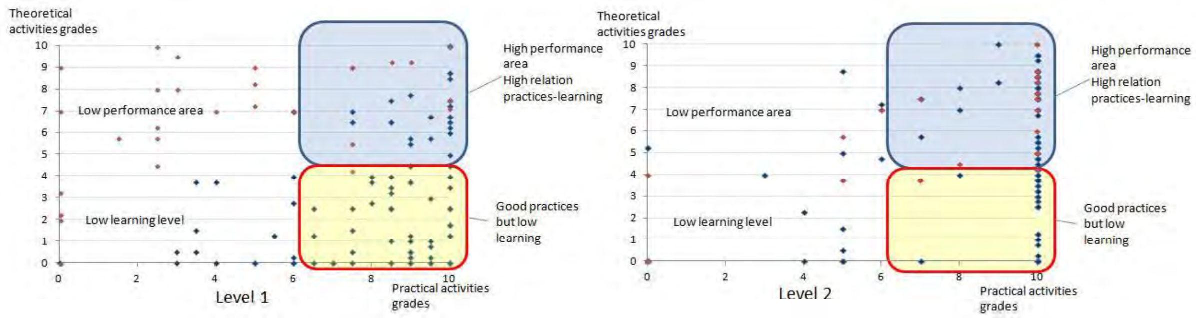

Fig. 5. Relación de las notas de las actividades prácticas y teóricas (Todos los estudiantes)

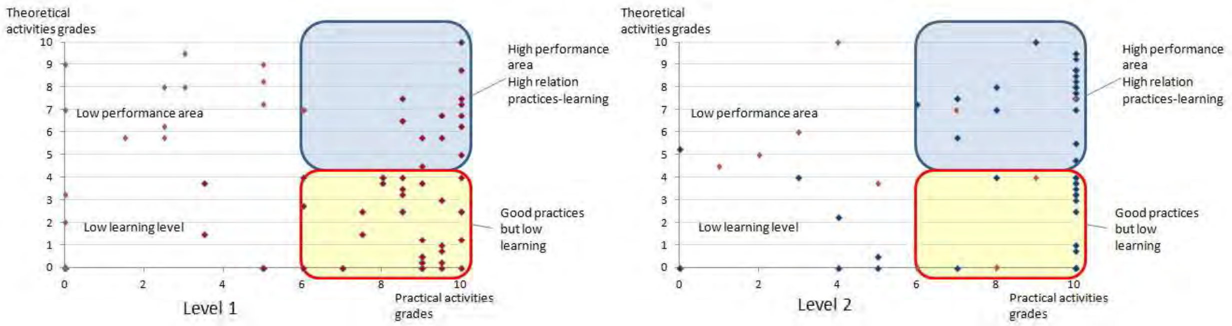

Fig. 6. Relación de las notas de las actividades prácticas y teóricas (Alumnos de laboratorio presencial)

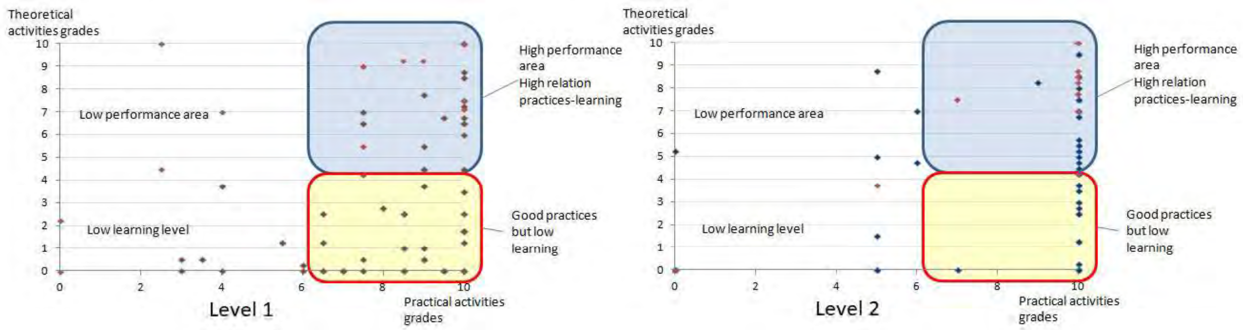

Fig. 7. Relación de las notas de las actividades prácticas y teóricas (Alumnos de VISIR)

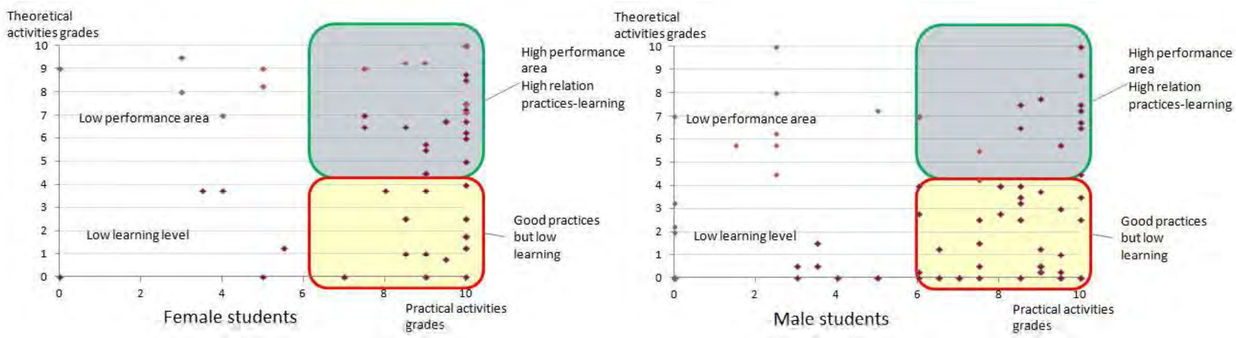

Fig. 8. Comparación de las notas de las actividades del Nivel 1 según el género

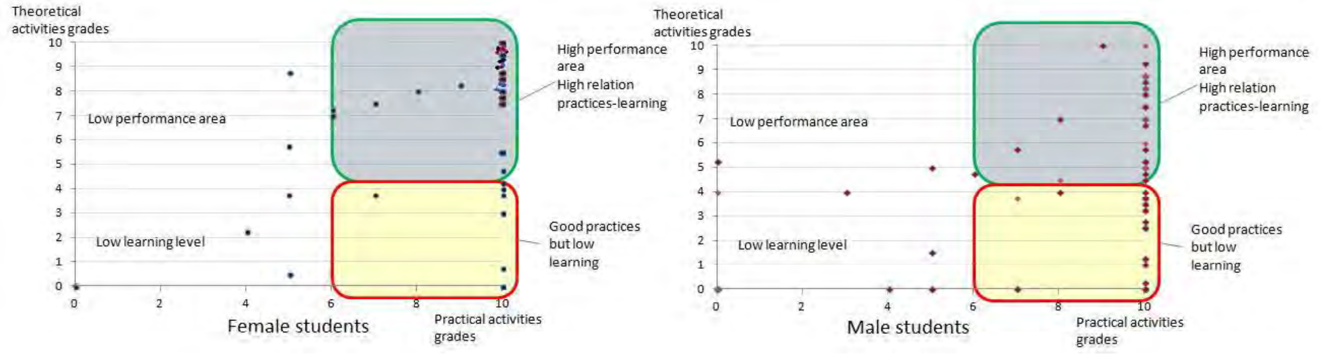

Fig. 9. Comparación de las notas de las actividades del Nivel 2 según el género

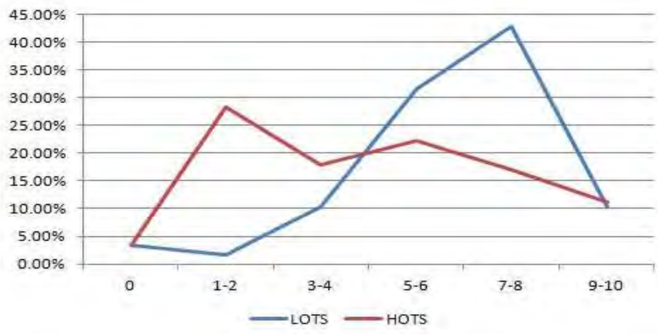

Fig. 10. Distribución de las notas de acuerdo con el tipo de actividad cognitiva (LOTS/HOTS) en alumnos de 1º curso

.

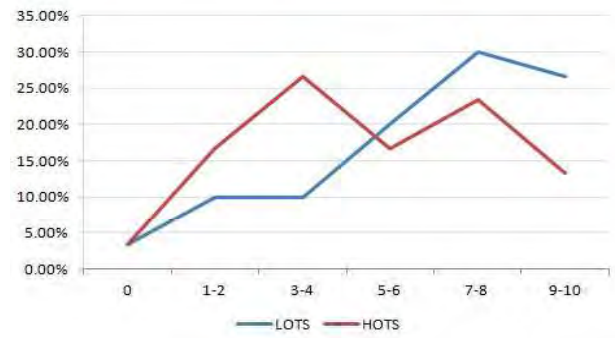

Fig. 11. Distribución de las notas de acuerdo con el tipo de actividad cognitiva (LOTS/HOTS) en alumnos de 2º curso

Para complementar estos datos, es importante observar que ha ocurrido con los estudiantes de 2º año. En la figura 12 se ha representado una gráfica con el mismo formato que en la figura 11, de forma que se puedan comparar. En este caso, la curva que representa las destrezas HOTS, es más parecida a la que representa los LOTS. Un parámetro que es conveniente analizar, ya que se trata de dos variables con un elevado grado de dependencia, es el factor de correlación (R). Utilizando los valores de la covarianza y de las varianzas particulares para cada una de las distribuciones de frecuencia, se han obtenido los valores de $R_1 = 0,49$ y $R_2 = 0.86$.

En la siguiente figura 13 se ha representado de forma simultánea sendas nubes de puntos para los estudiantes de primer curso y de segundo curso, observándose claramente porqué el factor de correlación en los alumnos de 2º curso es superior que en alumnos de primer curso. Las coordenadas de cada punto en el primer curso más concentradas en el centro del gráfico lo que reduce la relación mutua entre ambas variables, mientras que en el caso de 2º curso, los puntos se concentran a lo largo de una recta pendiente. Esto identifica claramente una relación mutua fuerte entre ambas variables LOTS y HOTS, con lo que en este caso sí podemos afirmar la validez de nuestra hipótesis.

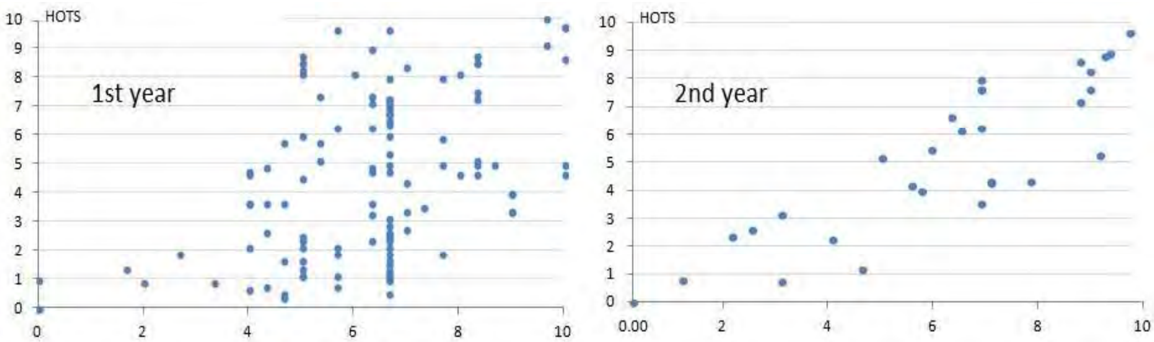

Fig. 12. Relación mutua (correlación) entre las variables LOTS y HOTS en 1º y 2º cursos

V. CONCLUSIONES

Al comienzo del trabajo de investigación que se presenta, se propusieron varios objetivos, todos ellos enmarcados en el contexto de una hipótesis. La hipótesis se ha formulado en el contexto del empleo de recursos poco habituales en la enseñanza de la Electricidad. Así, dada la disponibilidad del laboratorio remoto VISIR y de su adaptabilidad a diversos niveles educativos nos permitió pensar en la posibilidad de incluir este recurso como medio óptimo de aprendizaje. Este es uno de los objetivos marcados en la hipótesis. En segundo lugar, se pensó en que el laboratorio remoto, empleado ampliamente en el contexto de la educación en Ingeniería, se podría complementar con una metodología de nueva creación, aunque basada en las indicaciones dadas en la taxonomía de Bloom-Anderson. Así a partir de estos dos recursos, técnico y metodológico respectivamente, se ha formado a un grupo de estudiantes de educación secundaria.

Los estudiantes, cuyas edades están comprendidas entre los 12 y los 14 años de edad, han de aprender en el contexto del currículo de Educación Secundaria los temas relacionados con la Electricidad, los fenómenos y magnitudes eléctricas y los circuitos eléctricos. Hasta la fecha, la mayor parte del profesorado enseña siguiendo un modelo tradicional conductista y los autores pensamos si sería adecuado e si se podría llegar a optimizar el aprendizaje en estos estudiantes.

Así, se reunió a un conjunto de 147 alumnos y estos fueron divididos en dos grupos, un grupo de referencia que emplearía la instrumentación habitual en un laboratorio de electrónica y un grupo de control que emplearía el laboratorio remoto VISIR para la realización de circuitos y medidas en sus componentes eléctricos.

La experiencia didáctica derivada de este planteamiento ha sido satisfactoria, ya que se han obtenido unas conclusiones que permiten continuar ahondando en esta investigación.

Como primera conclusión se ha de indicar que el empleo del laboratorio VISIR tiene un impacto en el aprendizaje de los estudiantes muy similar al empleo de un laboratorio real para estudiantes de primer curso de educación secundaria (12 años de edad), aunque hemos podido verificar que dicho impacto es significativamente superior para estudiantes mayores (14 años de edad).

Como segunda conclusión se ha observado que las chicas han podido sacar mayor partido al laboratorio y a la metodología que los chicos, habiendo obtenido calificaciones superiores que los chicos de hasta un 20% de diferencia. A pesar de todo y de forma paradójica, la impresión y percepción que tienen las chicas sobre su propio aprendizaje es inferior a la que tienen los chicos, los cuales creen haber aprendido más de lo que en realidad han hecho. Es muy posible que estas conclusiones puedan justificarse desde el plano de la Psicología, pero en nuestro caso, tan solo hemos podido constatar este hecho significativo.

La edad de los alumnos también es un factor importante a la hora de asumir la metodología presentada y hemos podido verificar que la relación entre la consolidación de los Low Order Thinking Skills relacionados con la actividad memorística y con la comprensión y el desarrollo de los High Order Thinking Skills, mediante las cuales se accede al empleo de herramientas cognitivas analíticas y de pensamiento reflexivo y creativo, tiene una fuerte correlación cuando se trata de alumnos de 14 años, mientras que dicha correlación es más débil en alumnos de primer curso de educación secundaria, de 12 años de edad.

Estas conclusiones, junto con las cifras y estadísticas generadas en el trabajo de investigación no son concluyentes ni definitivas, aunque ciertamente significativas y los autores nos comprometemos a seguir estudiando y mejorando los recursos utilizados en dos vías. Una primera vía la exploraremos en el sentido de perfeccionar la metodología con el fin de conseguir un proceso que optimice el aprendizaje de la Electricidad de forma general sin importar la edad de los alumnos. Una segunda vía, consistirá en la creación de nuevas adaptaciones en el laboratorio remoto VISIR para el aprendizaje de circuitos electrónicos.

RECONOCIMIENTOS

Los autores reconocen el apoyo de la Escuela de Doctorado de la UNED, Poyecto eMadrid (Investigación y Desarrollo de Tecnologías Educativas en la Comunidad de Madrid) - S2013/ICE-2715, VISIR+ Proyecto (Educational Modules for Electric and Electronic Circuits Theory and Practice following an Enquiry-based Teaching and Learning Methodology supported by VISIR) Erasmus+ Capacity Building in Higher Education 2015 nº 561735-EPP-1-2015-1-PT-EPPKA2-CBHE-JP y proyecto PILAR (Platform Integration of Laboratories based on the Architecture of visiR), Socio estratégico de Erasmus+ nº 2016-1-ES01-KA203-025327.

REFERENCES

[1] Tawfik, Mohamed et al (2011) "VISIR Deployment in Undergraduate Engineering Practices. Global Online Laboratory". Consortium Remote Laboratories Workshop (GOLC), 2011. 978-1-4577-1944-8. GOLC Workshop in the 41st ASEE/IEEE Frontiers in Education Conference (FIE 2011).

[2] Anderson, L.(2001) "Taxonomy of educational objectives," in Encyclopedia of Educational Theory and Philosophy Anonymous Sage Publications, 01, pp. 789-791

[3] García-Zubía, Javier et al (2010) "Easily Integrable platform for the deployment of a remote laboratory for microcontrollers". EDUCON 2010 – Annual Global Engineering Education Conference - The Future of Global Learning in Engineering Education. IEEE Education Society. EDUCON 2010 Conference Book. ISBN: 978-84-96737-70-9

[4] Chen, Xuemin; Zhang, Yongpeng; Kehinde, Lawrence and Olowokere, David (2010) "Developing virtual and remote undergraduate laboratory

for engineering students", 40th ASEE/IEEE Frontiers in Education Conference Proceedings. January 13th, 2010, Arlington, VA

[5] Angulo, I. et al.. (2010) "El proyecto VISIR en la universidad de Deusto: laboratorio remoto para electrónica básica". Conference proceedings TAEE 2010 - ISBN: 978-84-96737-69-3

[6] Gustavsson, Ingvar (2001) "Laboratory experiments in distance learning". Proceedings of the ICEE 2001 Conference August 6 - 10, 2001. Oslo/Bergen, Norway. Available at: http://www.ineer.org/. Last visit: February 27th, 2017.

[7] Gustavsson, I.and e. al, (2007) "The VISIR Project - An Open Source Software Initiative for Distributed Online Laboratories," in Remote Engineering & Virtual Instrumentation (REV '07), June 2007

[8] Deniz, Dervis Z., Bulancak, Atilla and Özcan, Gökhan (2003) "A novel approach to remote laboratories". 32nd ASEE/IEEE Frontiers in Education Conference Proceedings. November 6 - 9, 2002, Boston, MA

[9] Pastor Vargas, Rafael. (2006) "Especificación formal de laboratorios virtuales y remotos: Aplicación a la Ingeniería de Control". Doctoral Thesis presente at Escuela Técnica Superior de Ingeniería Informática de la Universidad Nacional de Educación a Distancia. UNED, 2006

[10] Bragós, Ramon; Garofano, Francesc; Guasch, Aleix; Sánchez-Terrones, Benjamin (2010) A Remote Laboratory to Promote the Interaction between University and Secondary Education". EDUCON 2010 – Annual Global Engineering Education Conference - The Future of Global Learning in Engineering Education. IEEE Education Society. EDUCON 2010 Conference Book. ISBN: 978-84-96737-70-9 - Depósito legal: M-11728- 2010

[11] Bruner, J. (1966). Studies in cognitive growth: A collaboration at the Center for Cognitive Studies. New York: Wiley & Sons.

[12] Blázquez et al (2017) "Diseño de experiencias didácticas constructivistas con laboratorios remotos en el contexto de la Educación Tecnológica en la etapa de Secundaria mediante la taxonomía de Bloom-Anderson". Trabajo de Investigación para el Programa de Doctorado en Tecnologías Industriales. Departamento de Ingeniería Eléctrica, Electrónica, Control, Telemática y Química aplicada a la Ingeniería. E. T. S. Ingenieros Industriales.

[13] Dormido, S. y Esquembre, F. (2003) "*The quadruple-tank process: An interactive tool for control education*", Prco. ECC'03, 2003, Cambridge.

5. PRINCIPALES CONCLUSIONES

Referir los resultados en relación a los objetivos planteados señalando las conclusiones que se derivan de los resultados obtenidos.

Este proyecto ha permitido avanzar en la transferencia de conocimiento, creación de nuevos experimentos, objetos educativos reutilizables, nuevos cursos abiertos MOOC y el enriquecimiento de prácticas de laboratorios remotos en asignaturas de la UNED, implementando nuevos desarrollos de laboratorios en tecnologías avanzadas. Por tanto los resultados obtenidos son:

- Diseño de nuevas aplicaciones para entornos avanzados y complejos aplicables a sistemas de ingeniería y actividades de formación en STEM.
- Nuevos experimentos para los estudiantes de pre-ingeniería, ingeniería y formación para la vida
- Publicación de artículos en congresos, principalmente en EDUCON 2018 y FIE 2018, así como los que se presentarán próximamente en el REV 2019 y el EDUNINE 2019. Estos son los congresos de aplicaciones educativas de ingeniería mayores y más avanzados del mundo.
- Igualmente se ha organizado el congreso LWMOOCS en Septiembre de 2018 en la UNED donde se han presentado aportaciones dentro de las áreas de laboratorios remotos en MOOCs.
- La principal conclusión del proyecto es la utilización del laboratorio remoto VISIR para las actividades en otras áreas complementarias a la de electrónica general donde se realiza su uso mayor, en este caso en las de IoT, e-Health y FPAAs. Igualmente se ha extendido el uso de los laboratorios VISIR en secundaria, bachillerato y formación profesional para incrementar las vocaciones técnicas en los jóvenes.
- Se mantiene la colaboración con la asociación IAOE dentro del marco de la federación de laboratorios VISIR, así como con el consorcio internacional GOLC, para el uso y extensión de laboratorios remotos e ingeniería remota.
- Se ha ampliado además la colaboración con el IEEE, mayor asociación mundial de ingeniería eléctrica y electrónica, con presencia de los resultados y actividades de investigación del proyecto y de miembros del grupo en los órganos directivos a todos los niveles (nacional, estudiantil, internacional y al máximo nivel directivo).

6. REFERENCIAS

Además de las referencias previas del desarrollo del proyecto, algunas de las ideas de este proyecto se han incluido en las siguientes publicaciones con referencia de agradecimientos al presente proyecto de innovación educativa.

- García-Loro, F., Losada, P., Gil, R., Lopez-Rey, A., San Cristobal, E., Perez Molina, P., Diaz, G. y Castro, M. Real Experiments in a MOOC through Remote Lab VISIR: Challenges, Successes and Limits. IEEE Learning with MOOCs V, LWMOOCS V 2018 (Anual), MOOCs for All – A Social and International Approach, págs. 98-101 (4) [presentación Powerpoint y Poster]. Organizador: IEEE Education Society, UPM y UNED, ISBN: 978-1-5386-6533-6, 26 al 28 de Septiembre de 2018, Madrid (España).
- Plaza, P., Sancristobal, E., Carro, G., Blazquez, M., Menacho, A., Castro, M., Perez, C. y García-Loro, F. Local MOOC Solution For Thight Budgets Or Limited Internet Access. IEEE Learning with MOOCs V, LWMOOCS V 2018 (Anual), MOOCs for All – A Social

and International Approach, págs. 13-16 (4) [presentación Powerpoint y Poster]. Organizador: IEEE Education Society, UPM y UNED, ISBN: 978-1-5386-6533-6, 26 al 28 de Septiembre de 2018, Madrid (España).

- Pérez Molina, C., Sancristobal, E., Martin, S., Garcia Loro, F., Blazquez Merino, M., Baizan-Alvarez, P., Macho, A. y Castro, M. Identifying the Best Practices in e Engineering to Contribute to Build up High Quality Trainings within the European e LIVES Project. The Online, Open and Flexible Higher Education Conference 2018, EADTU: OOFHEC2018, Blended and online Learning: Changing the Educational Landscape, (Anual), págs. 2 (1-2). Organizador: EADTU y The Aahrus University, 10 al 12 de Octubre de 2018, Aahrus (Dinamarca).
- Plaza Merino, P., Sancristobal, E., Carro, G., Castro, M., Blazquez, M. y Garcia-Loro, F. Multiplatform Educational Robotics Course to Introduce Children in Robotics. FIE 2018, ASEE/IEEE Frontiers in Education Conference – Fostering Innovation Through Diversity, (Anual), págs. 1-9 (9 págs. en USB). Organizador: ASEE/IEEE, ISBN: 978-1-5386-1173-9, 3-6 de Octubre de 2018, San Jose, CA (USA).
- Garcia-Loro, F., Sancristobal, E., Diaz, G., Macho, A., Baizan, P., Blazquez, M., Castro, M., Plaza, P., Orduña, P., Auer, M., Kulesza, W., Gustavsson, I., Nilsson, K., Fidalgo, A., Alves, G., Marques, A., Hernandez.Jayo, U., Garcia-Zubia, J., Kreiter, C., Pester, A., Tavio, R., Valtonen, K. y Lehtikangas, E. PILAR: a Federation of VISIR Remote Laboratory Systems for Educational Open Activities. TALE 2018, IEEE International Conference on Teaching, Assessment and Learning for Engineering: Engineering Next-Generation Learnig, (Anual), págs. 264-271 (8 págs. en USB). Organizador: IEEE, ISBN: 978-1-5386-6521-3, 4-7 de Diciembre de 2018, Wollongong (Australia).

7. DIFICULTADES QUE SE DESEEN SEÑALAR

Indicar todas aquellas dificultades, de distinto tipo, que se hayan podido plantear en el transcurso de la realización del proyecto.

No existen dificultades remarcables debidas al presente proyecto y actividades relacionadas con el desarrollo del mismo. Se pueden remarcar las dificultades técnicas que implican el desarrollo de laboratorios remotos con tecnologías complejas y emergentes, como son las utilizadas en este proyecto de innovación educativa, Laboratorios Remotos y su uso educativo, IoT (Internet of Things), e-Health (Salud) y las FPAAs, (Field Programmable Analog Array), así como la implantación técnica de la federación de laboratorios VISIR, que se pueden resumir en la necesidad de mayor presupuesto y la búsqueda de nuevos socios y usuarios internacionales y nacionales dispuestos a trabajar en las tecnologías y la federación de VISIR.

El buscar colaboración con asociaciones y con otras universidades requiere de viajes a congresos de educación e ingeniería. Las reuniones presenciales no deben ser mensuales, pero si dos o tres al año, lo que lleva un coste de dinero y tiempo, a añadir al propio desarrollo y mantenimiento.

MODELO I.

RELACIÓN DE ESTUDIANTES A LOS QUE SE RECONOCEN CRÉDITOS ECTS PARA ESTUDIANTES QUE PARTICIPAN EN PROYECTOS DE INNOVACIÓN EDUCATIVA Y ACTIVIDADES DE INNOVACIÓN EDUCATIVA
Convocatoria 2017-2018

Nombre del proyecto/actividad de innovación
educativa: Coordinador/a:
TITULACIÓN:
FACULTAD/ESCUELA A LA QUE ESTÁ ADSCRITA LA TITULACIÓN:

(Este impreso se remitirá por correo interno firmado a la Secretaría de la Facultad correspondiente)

MUY IMPORTANTE: Los Equipos Docentes deberán confeccionar una relación por ***cada titulación****, ya que este impreso se remitirá a la Secretaría de la Facultad y a cada una de las Secciones de Alumnos responsables de cada titulación.*

Cada documento que utilice como Anexo I debe ir ***firmado por el Coordinador/a del proyecto/actividad*** *(puede enviar el archivo escaneado tras firmarlo o bien puede utilizar firma electrónica).*

Ha de tenerse en cuenta que entre los estudiantes que han participado en la experiencia puede haber estudiantes que hayan elegido la asignatura como de "libre elección" por lo que tendremos que cerciorarnos de en qué titulación están matriculados.

NIF	APELLIDOS	NOMBRE	Núm. créditos

Firma del Coordinador/a   Firma del Decano/Director de la Facultad/Escuela