

# Design of an Online Laboratory Authoring Tool

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**Abstract**—This Innovative Practice full paper presents a software system which purpose is to be used to compose online laboratory experiences.

Online Laboratories have improved their reliability and interoperability thanks to innovative developments proposed in recent years. New companies in this area have proposed novel interaction mechanisms such as the inclusion of immersive graphic user interfaces as well as the possibilities for access laboratory experiments as a service, having the alternative of just paying for the laboratory services demanded, for an specific class or for individual users. In terms of technology it is now possible to have multiple laboratory instances running from a single laboratory infrastructure or laboratory station. In terms of standardization, big efforts have been made by the Institute of Electrical and Electronics Engineers (IEEE) and the community of Online Laboratories to release in 2019 the first standard 1876-2019 - IEEE Standard for Networked Smart Learning Objects for Online Laboratories.

The software system presented in this work uses a set of available resources including virtual laboratories (simulation based), local laboratory equipment, remote laboratories, laboratory activities, assessment definition and learning content (text, audio, video, etc). The system provides to the users a friendly set of tools to compose their laboratory experiences, following the IEEE 1876-2019 standard definition. The output composed laboratory experiment is saved as a Smart Laboratory Learning Object (SLLO) including mechanisms to be self-adaptable according to variables such as laboratory activities difficulty level, user previous results on the same or similar laboratory activities, and user expertise in the topic (determined based on information retrieved from the Learning Management System LMS).

**Index Terms**—Engineering Education, Online Laboratory Experiments Composer, Online Laboratory Management System, Smart Adaptive Remote Laboratory, Smart laboratory Learning Objects, Learning Engineering, STEM, xAPI.

## I. INTRODUCTION

In recent years, new companies such as: LabsLand [1], Labster [2] among others, have proposed novel interaction mechanisms such as the inclusion of immersive graphic user interfaces as well as the possibilities for access laboratory experiments as a service, having the alternative of just paying for the laboratory services demanded, for an specific class or for individual users. An innovative model of operation includes access to online laboratories based on the interchange of laboratory accesses; institution A can use labs offered by institution B and vice versa.

Online laboratories can be implemented as a process that considers the students individual learning goals. These systems can adapt to provide laboratory activities that leverage their learning outcomes. Online laboratory experimentation facilitates learning experiences focused on the individual, by the exposure of individuals to these laboratory activities the students can accomplish "learning through reflection on doing" [3].

Experiential learning [4] can be implemented on online laboratory experiences. In the Kolb's four-step experiential learning model (ELM), see Figure 1, the learner is exposed to a "concrete experience". In this case, the apparatus or online laboratory station is where the learner physically experiences the phenomena. The "reflective observation", is generated when the student modify different inputs and observe different outputs from the experiment. Then, the learner considers what is working and what is not working properly. When the student thinks about alternatives to improve on its outcome, building on the concepts and understanding the process, is when the student is in the "abstract conceptualization" stage. Every attempt to improve their previous results based on their knowledge from the previous experience, thoughts and reflections is the "active experimentation" stage.

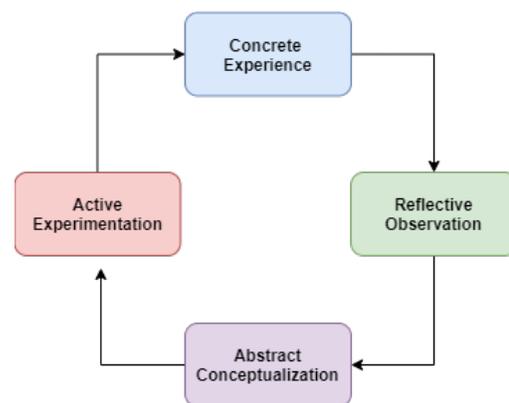


Fig. 1. Kolb's Experiential Learning Model (ELM) [4]

Current online laboratories technology allows having multiple online laboratory instances running from a single physical laboratory infrastructure or laboratory station. An example

of this is Virtual Instrument Systems In Reality (VISIR) [5] infrastructure that can be connected to a server to offer remote laboratories and allow connection of multiple users by enabling subsets of the components required by the users.

Adaptive user interfaces have been applied in a variety of software applications, such as commercial web applications, educational and research applications, among others. In the context of online laboratories, some advances have been done adapting the interface of the simulations and allowing the user to personalize the interface.

An adaptive user interface in software gives the possibility of a software interface to change according to some input parameters defined for the users or identified automatically by the system. Some advances have been done in the user interfaces for online laboratories [7] and remote laboratories [6], [8] that provide alternatives to improve the user experience with the remote laboratory.

Salzmann et al, [8] proposed the Smart Device specification, allowing the automatic generation of a basic client application. Their approach decouples the client from the server providing the interfaces to connect them.

Hamadou et al, [6] developed an interface designer that allow users to design online laboratory interfaces dragging and dropping graphical components. The interface design is stored in an XML file that is transferred to the server and executed by an ActiveX controller that displays the result to the user in real time. This process has been named by the authors as PolymorphiX.

In terms of standardization, big efforts have been made by IEEE and the community of online laboratories to release in 2019 the first standard 1876-2019 - IEEE Standard for Networked Smart Learning Objects for Online Laboratories [9]. The first level of the standard offers any online laboratory (lab) as a service (Laboratory as a Service or LaaS). The standard also defines methods for integrating online laboratories as smart learning objects in learning environments and learning object repositories.

This paper presents the software module proposed authoring of online laboratory experiences. These laboratory experiments are based on a set of available resources including virtual laboratories (simulation-based laboratories), remote laboratories, local laboratory equipment, laboratory activities, assessment definition and learning content (text, audio, video, etc). The system provides to the users a friendly software environment to compose their laboratory experiences, following the IEEE 1876-2019 standard definition. These has possibilities to be saved as a laboratory learning object to be deployed on an Online Laboratory Management System (OLMS) or a traditional Learning Management System (LMS). The output composed laboratory experiment can also be saved as a Smart Laboratory Learning Object (SLLO) including the same features plus enabling mechanisms to be self-adaptable according to variables such as laboratory activities difficulty level, user previous results on the same or similar laboratory activities, and user expertise in the topic.

The paper is organized as following: Section II discusses

online laboratories and the use of Experience API (xAPI) context. Section III, presents the definition of Smart Adaptive Remote Laboratory SARL and Smart Laboratory Learning Object SLLO. Section IV describes the Online Laboratory Experiments Composer. Section V shows the implementation of a laboratory experiment using the Composer and finally conclusions are presented on section VI.

## II. ONLINE LABORATORIES AND xAPI

Within the educational context, there is an important demand for online laboratories services. Online laboratories play an important role in academic areas like physics, chemistry, biology, medicine, and engineering. There are two main elements in the educational context that online laboratories providers need to take in account. A first consideration is the role of the users: the users can be teachers, administrators, or students. Each role will use the services in a different way. Secondly, the integration and interoperability are important when there is demanded to combine and integrate these services with other educational platforms.

IEEE Education Society formed the IEEE-SA P1876 Working Group on Networked Smart Learning Objects for Online Laboratories responding to the need for integration, contextualization, and interoperability in online laboratories. In March of 2019, the IEEE 1876 standard was approved and released to the public. This standard proposes a layered architecture for the design, implementation, and deployment of online laboratories in the educational context that can be interoperable and compatible with Virtual Learning Environments (VLEs).

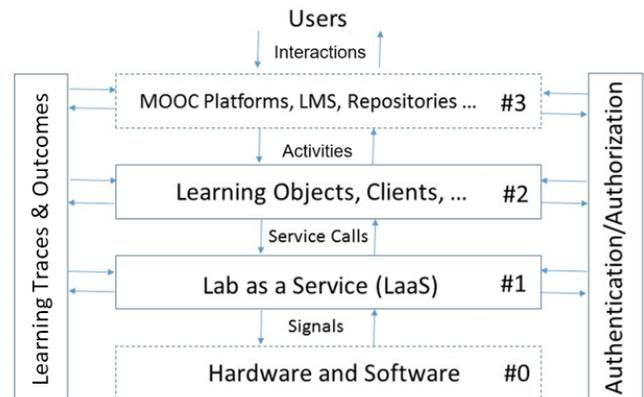


Fig. 2. IEEE 1876-2019 standard layered architecture [9]

Figure 2, presents the proposed architecture. The first layer in the bottom part of the figure is the hardware and software (layer #0), that supports the online laboratory operations. Second, Laboratory as Service (layer #1) that defines the wrapping of the laboratory functionalities as services (LaaS). Third, is the Laboratory learning Object (layer #2) that defines all the metadata necessary for the integration with educational platforms described in layer #3. Two transversal layers are defined in this model, Learning Traces & Outcomes layer, manages all the tracking and system logs as support for security and experiences reports used for future learning analytics

processes. An Authentication and Authorization layer validates the identity of users and their permissions over accessing protected objects across the system.

Online laboratories have been identified as a solution to provide hands-on experiences to distance education students [10], [11]. Some advantages of remote laboratories over real and virtual laboratories that have been identified are availability, security, reasonable cost, calibration control, among others.

xAPI [12], also called Tin Can API or Experience API, is a technology that allows the collection and distribution of online or offline user's experiences in the form of statements stored in a Learner Record Store (LRS) allowing assessment rubrics and learning analytic to be applied in online laboratories. xAPI is under standardization process by the IEEE Industry Councils Industry Collaboration for Learning Engineering (ICICLE) initiative [13]. xAPI libraries are available for a wide range of web technologies, either running on the client side or on the server side. xAPI has evolved rapidly during the last years and is now being implemented, not only in the educational context, but also in other types of systems.

The presented online laboratory system includes all the features described previously in terms of hands-on experiences, standards compliance, technology integration, and the addition of an innovative authoring tool that allows teachers to create, customize and deploy online laboratory experiments following a systematic process to generate SLLOs, making this laboratory experiments flexible, editable, adaptable and interoperable.

### III. SMART ADAPTIVE REMOTE LABORATORIES (SARL) AND SMART LABORATORY LEARNING OBJECTS (SLLO)

The SARL architecture proposed in [14] supports the adaptability of online laboratory graphic user interfaces GUI and activities according to the students' background and previous results (information reported by the VLE and the Remote Laboratory management System (RLMS) or (OLMS)). One laboratory experiment platform can be used for different laboratory assignments, topics, and courses. The SARL architecture has been implemented in a prototype, this includes the use of a RLMS with four basic modules are: user manager, scheduler, resources manager and the smart adapter. The user manager gives the user two services: the login interface to authenticate the user into the system, and the registration interface for new users. The user credentials can be provided directly by the user if he is accessing the RLMS directly or passed directly from the VLE through the implementation of a single sign on scheme. The scheduler gives teachers the ability to reserve the experiments in windows of time for groups of students. Then, the teacher can choose different remote laboratories related with his course and reserve them to his class, blocking the access to students from different classes. The students can schedule slots of time inside the window reserved by their teacher.

The resource manager manages all the remote laboratories available in the system. From there it is possible to configure the setting and basic operation of the laboratory such as:

connect new laboratories, update, remove etc. Finally, the smart adapter provides the teachers a designer mode in which the professor defines the activities and can compose the laboratory stations with multiple remote laboratories. In this module, the teacher defines versions of the laboratory such as difficulty level of every activity of the laboratory, experience requirements and prerequisites (another laboratories or activities inside the same laboratory). The remote laboratory component can be one or many laboratories and can be distributed in different locations.

The integration with the VLE was implemented using Learning Tools Interoperability (LTI). In this way, the students can access the laboratory directly from the VLE. The VLE platform chosen for the prototype was the Moodle LMS. This open source platform allows the configuration of the LTI connection between the RLMS and the LMS. The teacher can integrate the laboratories in the course and define the parameters for the smart adapter directly from the LMS.

The Smart Adaptive Remote Laboratory (SARL) architecture was designed to allow users to have individualized experiences when using online laboratory experiments. The student experience is created in the form of Smart Laboratory-based Learning Objects (SLLO) that includes laboratory activities, assessment information, student information, and information about the access to the remote laboratory experiments. In general, these objects can be managed by an Online Laboratory Management System (OLMS).

The SARL architecture includes the RLMS for the management of remote laboratories. This manager can be integrated to a Virtual Learning Environment (VLE), that could be a Content Management System (CMS), Learning Management System (LMS), or any other type of VLE. The VLE system will share the user information and roles with the RLMS system. This integration is possible using standard technologies such as Learning Tools Interoperability (LTI) or through the implementation of web services. LTI module provides session information to the RLMS session manager and allows the correct user laboratory interface visualization inside the VLE.

The experience API (xAPI) module is responsible to inform about on the user interaction with the system and to report information to the Learning Analytics module. The Smart Adapter retrieves the laboratory activities and assessment content from the VLE and connect them with one or more Online Laboratory Experiment to create SLLOs.

The Smart Laboratory Learning Object (SLLO) was proposed as a package that can be deployed independently on a local computer or web server and provides access to laboratory experiences including one or more activities and access to local or remote resources [15].

The SLLO can include different items such as class materials, examples, laboratory activities and the access to the hardware experiments needed for a specific laboratory. The user interactions and administrative information is collected and stored in the Learner Record Store (LRS) in the form of xAPI statements and it is ready to be accessed by the VLE or any other platform. The system supports different config-

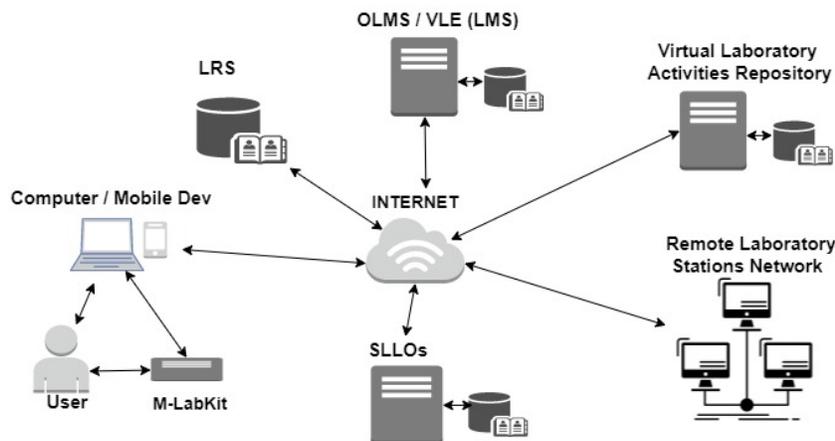


Fig. 3. Diagram of SLLOs interactions with OLMS Systems, virtual labs and remote laboratory stations [15]

urations of LRSs to comply with the stakeholders required privacy and security definitions.

Figure 3 presents the components that interact together with the SLLOs objects, virtual laboratory activities are available as resources as well as remote laboratory stations. The Online Laboratory Management System (OLMS) or a generic Virtual Learning Environment such as a Learning Management System LMS will serve as the deployment system and as the host of the student interactions. As an improvement, it is possible to have reporting capabilities and learning analytics integrating xAPI.

#### IV. ONLINE LABORATORY EXPERIMENTS COMPOSER

This section is focused on the development of an online laboratory experiments composer that uses the capabilities of the SARL architecture and that can be integrated into an OLMS. This Online Laboratory Experiments Composer can be used by teachers or laboratory administrators to create instances of laboratory experiments based on a set of available resources. The online laboratory experiments created in the composer can be saved and exported as a SLLO to be used on different OLMSs.

The Online Laboratory Experiments Composer make use of the set of available resources in the OLMS. The author can also add new resources such as activities, online laboratory stations, online laboratory experiments or external resources. The Online laboratory Experiments Composer has been defined as part of the laboratory experiment authoring module of the SARL architecture.

The Online Laboratory Experiments Composer design includes possibilities to put together elements that are used by trainees during the online laboratory experimentation sessions; elements such as: Laboratory learning activities, virtual laboratories (simulation based laboratories), access to local laboratory equipment, remote laboratories, assessment definition and additional learning content (text, audio, video, etc). These elements can be managed by the teacher or laboratory manager according to their definition for the online laboratory experiment.

The online laboratory experiment can contain one or more activities attached to one or more online laboratory stations, as well as the possibility of attaching local or external digital resources.

Once the teacher or administrator finish composing or edit a specific online laboratory experiment, it can be stored in the OLMS Laboratory Resource Manager, and then, it can be later posted as an available resource in the student Laboratory Gallery. The Process of creation of an online laboratory Experiment using the Online Laboratory Experiment Composer is presented in Figure 4.

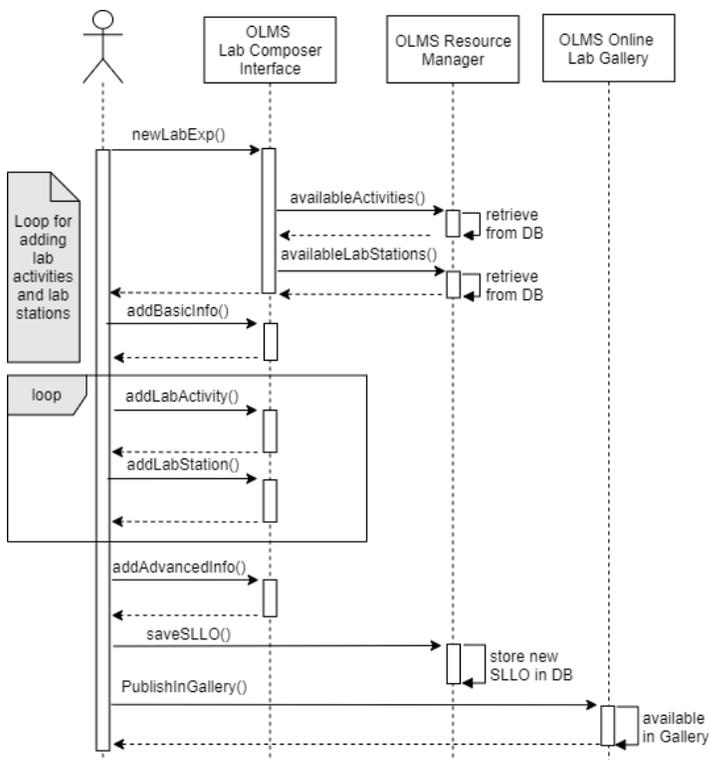


Fig. 4. Creation of a SLLO using the Online Laboratory Experiment Composer

An implementation of a prototype of an OLMS based on the SARL architecture has been developed to test the features proposed in SARL. These features included the support of user roles in the context of education, management and integration of low-cost remote, virtual and hybrid online laboratories, student's hands-on skills development. The features are supported through the integration of SARL with an OLMS. The student's mobile laboratory kits allow the validation of laboratory activities and interaction with remote or virtual laboratories, integration with virtual learning environments, an online Laboratory Authoring module.

The Authoring module includes the online laboratory experiments composer, learning analytics and customized reports for students, teachers and administrators based on the use of xAPI. Finally, security and safety mechanisms to support the reliability of the system and to prevent intentional harmful action against the users or the infrastructure should be implemented.

The user "home" section in the OLMS implemented prototype is presented in Figure 5.

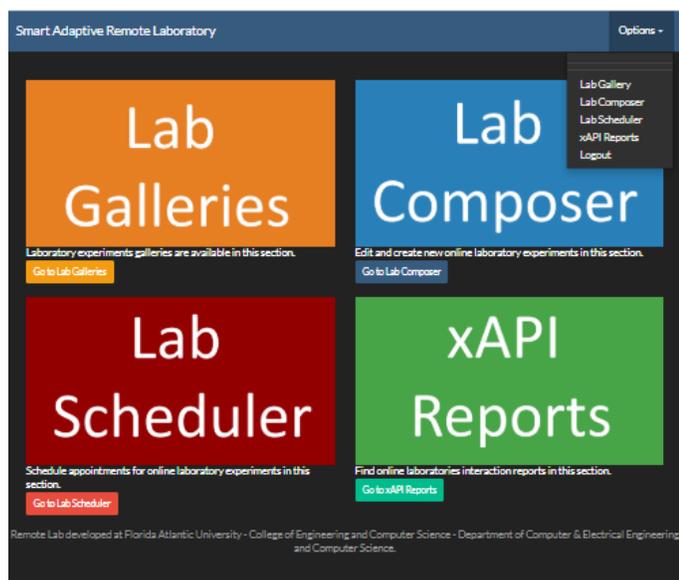


Fig. 5. Smart Adaptive Remote Laboratory (SARL) OLMS - Teacher Role Graphic User Interface "Home Section"

The figure presents the access to the laboratory galleries which is the place where the students can access all the online laboratory experiments available for them. The laboratory scheduler where the teacher, laboratory manager or student can arrange appointments to access one of the available synchronous online laboratory experiments. In this section the teacher can access to reserve one or more laboratory experiments for its use or to be used by a group of students. The xAPI reports provide to students, teachers and administrators access to detailed or aggregated reports about the students interactions in the system, and finally, the interface presents the online laboratory experiments composer.

Figure 6, presents the graphic user interface of the online laboratory experiment composer. In this module, the teacher or

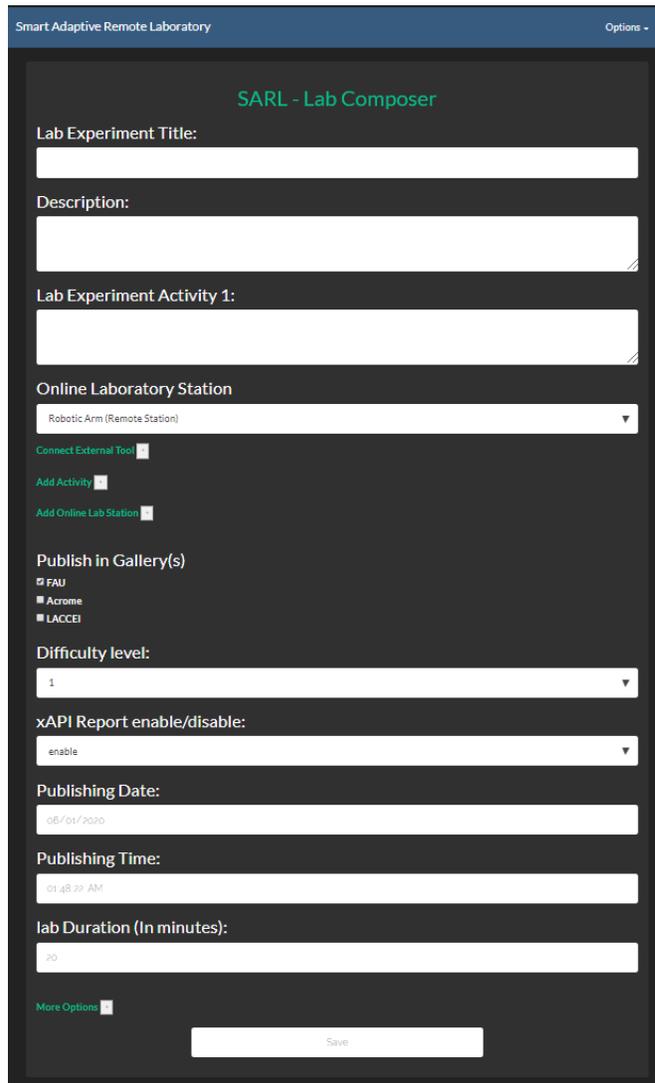


Fig. 6. OLMS - Online Laboratory Experiment Composer Graphic User Interface

laboratory manager can create or load new activities using the available resources in the OLMS. The teacher or laboratory manager must define a title and description using the editing tools in the interface. Once the activity is defined, it can be assigned to one or more of the online laboratory stations available.

As "more options" for the composed SLLO, the user can configure the following option in the online laboratory composer:

- Definition of topic for the laboratory experiment
- Definition of type of laboratory (Virtual, Remote, Mobile or Hybrid)
- Definition of type of connectivity and synchronicity of the laboratory
- Definition of the assessment for the activity
- Definition of deliverable for each of the activities
- Definition of prerequisites that the students should com-

- Definition of co-requisites that the students should complete
- Option to hide or to have the activity visible to the students
- Add specific analytics and parameters for the xAPI reports

As a future work, it is planned to have a hybrid composer, where the smart adapter module of the SARL architecture will suggest possible activities and online laboratory stations to the professor or laboratory manager and they can adjust these suggestions to an specific rubric or goal in the course.

The smart adapter module also will have a feature that automatically compose new online laboratory experiments based on the resources available in the OLMS, previous interactions of the student with online laboratories and information about their performance reported in the LMS. These auto generated SLLOs will be suggested to the students as training laboratory experiments.

#### V. IMPLEMENTATION OF A LABORATORY EXPERIMENT THAT USES THE ONLINE LABORATORY EXPERIMENT COMPOSER

This section shows the creation and deployment of an online laboratory experiment demo. This process includes the definition of the laboratory experiment in terms of activities, laboratory stations, assessment and additional information required for the operation of the laboratory experiment over a web environment.

This laboratory experiment uses a robotic arm as the online laboratory station that is accessed remotely by the student.

The teacher configures the activities and other parameters using the Online Laboratory Experiment Composer.

This online laboratory experiment includes two activities to control the robotic arm laboratory station.

Table I shows the defined SLLO information of the activity 1 for the Boolean expression and programming online laboratory experiment.

Figure 7 presents the interface of the online laboratory experiment including the activities previously described, generated using the Online Laboratory Experiments Composer using the robotic arm laboratory station.

In the left side of the online laboratory experiment interface, the student can find the two activities assigned for this online laboratory experiment. In the right side, the live video streaming of the remote laboratory station is presented in a window. This allows the user to see the behavior of the robotic arm in real time. The robotic arm can be controlled while the activities are developed using the control panel in the GUI. The laboratory station is also used as a way to validate the student activities results.

##### A. Activity 1

The objective of the activity 1 is to learn the use of Karnaugh maps to simplify a Boolean expression and the implementation of logical circuits using NAND gates. If the

students had the correct simplified expression implemented in an all-NAND gates circuits, the robotic arm will generate a sequence of movements to grab a ball.

The Boolean expression is preset by the teacher or laboratory manager.

TABLE I  
SLLO INFORMATION FOR THE ROBOTIC ARM LOGIC DESIGN AND PROGRAMMING ONLINE LABORATORY EXPERIMENT

Field Name	Content
title	Boolean Expression and programming
description	Design and implement a Boolean expression using logic gates to control a robotic arm. Program the robotic arm to move object to specific locations
topic(s)	Boolean expressions and programming
type_of_lab	Hybrid
connectivity	Online
synchronicity	Synchronous
activity(s)	Activity_1: Simplify the Boolean expression: $A'BC + AB'C + AB'C'$ and implement it in an all NAND circuit. Activity_2: Using Python Language, write a code to make the robotic arm move a ball from position A to position B.
assessment	auto-graded
deliverables	Kmap; minimum Boolean expression, circuit using NAND gates; implemented circuit in the laboratorykit; test the circuit with the remote lab; programming of robotic arm
creation_date	01/08/2020
publishing_date	01/11/2020
prereq_lab	None
lab_duration	60 min
difficulty	2
lab_stations	1
visibility	1
xapi_enable	1
xapi_actor	studentID, LabKitNumber, RoboticArm
xapi_lab_objects	RoboticArm1, ball
xapi_lab_verbs	attempted, completed, interacted, collected, moved

##### B. Activity 2

The objective of activity 2 is to program the remote robotic arm to follow a sequence of movements that make the robotic arm move a ball from position A to position B.

For the online laboratory programming environment and commands execution, Python language was used as a programming language together with a customized version of the Google blocks programming tool “Blockly” [16]. The software interfaces for the laboratories were created using PHP and Javascript.

The grading for this online laboratory experiment is assigned automatically by the system as satisfactory or not satisfactory. The assessment criteria is defined by the teacher including validation of answers, number of attempts, time used by the student during the activities or any other parameter defined by the teacher.

The experiential learning is implemented on this online laboratory experiment by presenting to students the online laboratory station functionalities, the students can freely interact with the laboratory station, modifying inputs and receiving

Smart Adaptive Remote Laboratory
Options ▾

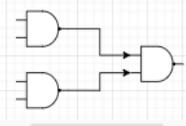
Online Laboratory Experiment - Boolean Expressions and Programming

**Activity 1:** Simplify the Boolean expression:  $A'BC + AB'C + AB'C'$  and implement it in an all nand circuit.

Type your simplest Boolean expression:

Validate Expression

File Edit View Arrange Extras Help Unsaved changes. Click here to save



Page-1

Submit

**Activity 2:** Using Python Language, write a code to make the robotic arm move a ball from position A to position B.

Python Code Editor:

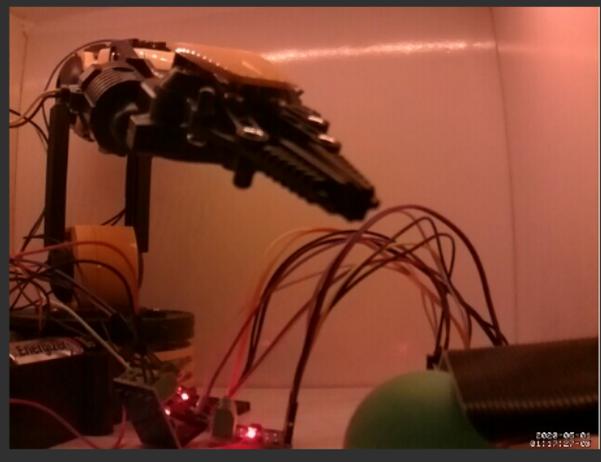
```

serial = spi(port=0, device=0, gpio=noop())
device = max7219(serial, cascaded=1)
seg = sevensegment(device)
GPIO.setmode(GPIO.BCM)
GPIO.setup(26, GPIO.OUT)
p = GPIO.PWM(26,50)
p.start(5)
    
```

The code above is the last code saved.

Save
Run code
Submit

**Laboratory Station: Robotic Arm**



Camera live streaming

**Robotic Arm Controls:**

CLOSE

UP M2

UP M3

UP M4

OPEN

DOWN M2

DOWN M3

DOWN M4

LEFT

RIGHT

Fig. 7. SLLO Robotic Arm activities created using the Online Laboratory Experiments Composer

outputs. Then, based on the observations and the activities requested the students start an iterative process of interaction by doing changes on the parameters. During this process, the students conceptualizes and are able to improve the current results based on results from their previous attempts, their knowledge from the previous experience, their thoughts and reflections.

Currently a set of 8 online laboratory experiments in the topic of Logic Design are being tested at Florida Atlantic University.

These online laboratories have been implemented following the same approach of development as the demo presented in this section.

## VI. CONCLUSIONS

This experience has opened the possibilities for integrating different types of online laboratory resources and to give to teachers, administrators, and students a more flexible and integrated environment of online experimentation.

The Online Laboratory Experiments Composer can be used by teachers or laboratory managers to create instances of laboratory experiments based on a set of available resources, this resources follow the definition of the standard IEEE-1876 and will be interoperable with other platforms once they provide compatibility with SLLO objects.

Currently a set of fully functional online laboratory experiments in the topic of Logic Design, are being tested at Florida Atlantic University. With this test it is being measured the

perception and outcomes of a group of online students. These online laboratories have been implemented using the proposed online laboratory composer and have been integrated in the course gallery in the Online Laboratory Management System.

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