Online Access and Control of Laboratory Stations using Video Conference Systems

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Abstract—**This Innovative Practice full paper presents the use of video conference systems to access online laboratory stations.**

Online laboratories are a solution for institutions that offer online or blended educational programs and want to offer hands-on training to their students, and for institutions that do not have the infrastructure to set up some specific experiments. They are defined as an alternative to provide remote access through internet connection to real equipment or virtual experiments located in another place. The use of online laboratories can reduce costs in terms of space, equipment, maintenance, personnel, among others. Most of the laboratory stations available in laboratory rooms in educational institutions include some type of software installed in a computer that allows the students to setup, configure, and program the laboratory equipment for their experiments. These software systems can be proprietary systems provided by the manufacturer of the laboratory equipment, and also can be systems provided by third party companies. This paper presents an alternative method of accessing and controlling laboratory stations using functionalities available in video communication platforms such as Zoom or Microsoft Teams, that offer options for remote controlling of a computer and can receive feedback from the shared screen feature. In this scheme, an external controller is attached to the laboratory equipment to provide bidirectional commands interchange between the user computer and the laboratory station. As part of the outcome of this work, a functional prototype of an online laboratory was made applying an alternative scheme that uses the communication system Zoom API. This prototype enables a Zoom session between the user and the local laboratory machine to interact with the first party software installed in the machine.

Index Terms—**Engineering Education, Learning Engineering, Online Laboratory Stations, STEM, Video Conference Systems.**

I. Introduction

During the last year Covid-19 pandemic created a very challenging scenario for education. Since 2020, with the pandemic, several of the classes in almost every country around the world have been imparted through a video conference system. Traditional systems integrated to Learning Management Systems (LMSs) such as Adobe Connect [1] or open source solution such as BigBlueButton [2], had an increase in their demands, but the platforms such as Zoom [3], Microsoft Teams [4], Google Meet [5] and Cisco Webex [6], were the platforms that dominated the marker either in the corporate or in the academic context. Some possible reasons are their reliability, the intuitiveness of their graphic user interfaces, and the development of plugins or APIs (Application Programming Interfaces) that made possible their integration with LMSs, offering a certain level of security to these remote class sessions.

Most of the challenges in online education appear when teachers want to teach remotely topics that normally require practical experimentation in a laboratory, examples are laboratory classes in Physics, Chemistry, Electronics, Control Systems, etc. Many institutions have tried to mitigate this situation testing alternatives, such as virtual laboratories, which are systems that are based on simulations, some others have tried using remote laboratory systems that provide real time access to control and test data with real lab equipment.

Existing and new industries in the field of educational laboratories have created or adapted their current solutions into solutions that can be used online by students and teachers, examples are LabsLand [7], Labster [8], Acrome Robotics [9], Quanser [10], among others. These companies have proven that it is possible to offer a comparable level of learning and some of them have proposed novel interaction mechanisms, such as the inclusion of immersive graphic user interfaces with 2d/3d environments, videos, animations, interactions through a Virtual Reality headset and augmented or mixed reality devices. Business models have also evolved permitting the access to the laboratory experiments as a service, having the alternative of just paying for the laboratory services demanded for a specific class or for individual users, or models based on the interchange of laboratory accesses; institution A can use labs offered by institution B and vice versa.

Local laboratory equipment providers and third party software providers offer proprietary software systems that normally have to be installed in computers located in the laboratory facilities. An alternative method for remotely accessing and controlling these software systems is through the use of functionalities available in video communication platforms such as Zoom, Microsoft Teams, Google Meet, among others. The users can interact with the remote software/hardware and receive immediate feedback. In this scheme, an external controller is attached to the laboratory equipment to provide bidirectional commands interchange between the user computer and the laboratory station.

This paper presents a software tool that allows the access of students to control a remote laboratory station located in a lab facility, using the same set of software tools utilized by the students when they are present in the lab facility. The interfacing was created using a Moodle LMS integrated with Zoom video conference system.

The paper is organized as following. Section II discusses online laboratories in the context of education. Section III presents the most common platforms used to support the online classes. Section IV describes the implementation of the proposed tool.Section V presents the survey given to the students to evaluate their perception of the system and its results, and finally conclusions and future work are presented on section VI.

II. Online Laboratories in the Educational Context

During the year 2020 an unprecedented increase in the demand for online laboratories created an opportunity for laboratory equipment and online laboratory providers to offer new solutions that attempt to mitigate the lack of lab experience that the students were having, due to the impossibility of attending the classes in person.

The World Bank recently reported the crisis that many countries are facing due to the pandemic. This crisis has impacted the access to education as well as the quality of the education. For instance, in the Eastern Caribbean States composed of Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines, Anguilla, and Montserrat, more than 25% of all students do not have adequate connectivity. Despite ongoing efforts to provide virtual education, many students have no access to it [11].

Online laboratories have been a great tool used by teachers and students during the last two decades to add the hands-on experience portion to the online courses. Institutions that have put more effort in developing and implementing some kind of online laboratories in the past, could rely on them during the Covid-19 crisis, helping them to at least offer some laboratory experiences to the students.

Systems that help in the management of remote and virtual laboratories have been also a key factor to simplify the development of these types of resources. The company Lab in a Window has developed an Online Laboratory Management System (OLMS), that implements the Smart Adaptive Remote Laboratory (SARL) System [13] whose "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".

III. Platforms used to Support the Online Instruction

Due to the Covid-19 pandemic, educational institutions switched to an online instruction modality. Different platforms are used to support synchronous online classes. The most common platforms are: Adobe Connect, Cisco Webex, BigBlueButton, Zoom, Skype [14], Skype for Business [15], Microsoft Teams, Microsoft Lync [16], Google Hangouts [17] and Google Meet, among others. This section presents some context of these systems and a summary of their features.

A. Zoom

Zoom is an American communications technology company founded in 2011 and headquartered in San Jose, California. It provides services such as video, voice, content sharing, and chat. It uses a cloud software platform that can be run in different devices, (mobile devices, desktops, telephones, and room systems) [3]. It also has the possibility of controlling the host desktop computer, which makes it ideal for remote laboratory experiments.

Zoom services' prices fluctuate from 150 to 300 US dollars per year per license. They also offer a free service that have some usage restrictions.

Research has been done on the use of Zoom as the video conference system in online classes and laboratories [18]. Zoom has been used to perform undergraduate research in the topic of biology [19], as a remote laboratory in anatomy education [20] and undergraduate chemistry laboratory classes [21], among others. Authors of [22] presented a study of the performance and perception of students using Labs-Land online laboratories using Zoom as a video laboratory room. At the beginning of each laboratory session, the students were given an explanation of the laboratory activities they needed to develop, and then breakout rooms were assigned to the group of students to work on the laboratory activities.

As of September of 2020, more than 100,000 schools in 25 countries were using Zoom for their video conferences and classes [23].

To help in the integration of Zoom in different platforms, the company has open its API [24], allowing developers to use the services of Zoom on their own developments. Developers can use this API to build applications or services for private or public use. To facilitate the deployment of the developed applications, Zoom has created the Zoom App Market Place [25] that works as a app store where developers can publish their applications and users can download them.

B. Microsoft Platforms

1) Skype
Skype is an application launched in 2003, to provide video chat and voice calls using a Peer-to-peer (P2P) protocol. Skype was acquired by Microsoft in 2011 and until 2019 was the 6^{th} most downloaded app of the decade [26]. Skype has a non-paid version that has been used by teachers, schools, and charities that focused on educational projects.

2) Microsoft Lync
   Microsoft Lync was re-branded to Skype for Business in 2015.
3) Skype for Business
   Skype for business supported text, audio, and video chat. Additional features were synchronization of the Microsoft outlook contacts, collaboration through Whiteboard documents and PowerPoint documents, desktop and application share and polling lists. Since September 2019, Skype for Business is no longer offered to new Office 365 subscribers, they are now being offered Microsoft Teams instead.
4) Microsoft Teams
   Microsoft Teams offers workspace chat and video conferencing, file storage, and application integration. Similarly, to Zoom platform, Microsoft Teams has the possibility of controlling the host desktop computer. Microsoft Teams is included as part of the Microsoft 365 Business plans and fluctuates between 60 to 300 US dollars per year per license. They also offer a free service with restrictions on recording sessions, and limited number of participant per session. Microsoft Teams is replacing Skype for Business and Microsoft Classroom. Due to the convenience of being part of the Microsoft 365 plan, more than 230,000 educational institutions have being using Microsoft teams as they video conference platform during the last year [27], [28].

C. Google Platforms

1) Google Hangouts
   Google Hangouts is a communications platform from Google. Originally started as a feature of the social network Google+, but later was released as an independent product accessible from Google+ or Gmail. Google Hangout offered a clean and simple user interface that took advantage of the Google ecosystem of integrated applications, such as Gmail, Google Calendar, Google Docs, among others. Initially it only supported 10 concurrent users, but after 2016 it started the support of up to 25 concurrent users, making it more suitable for academic and corporate use. This product was popular among students and educational institutions that had the G-Suite as their online application ecosystem for their communications and data storage support. With the idea of having more costumers in the corporate sector, Google split the system into two individual platforms: Google Meet and Google Chat. Google is also integrating new services such as Google Voice, a service that allows users to have their own IP telephone line to make and receive calls to/from landlines or cellphones.
2) Google Meet
   Launched in 2017, this platform is implemented over the architecture of Google Hangouts, with a capacity of up to 30 participants. It offers compatibility with multiple internet browsers and mobile devices. During the Covid-19 pandemic, the use of Google Meet has grown considerably, but it still was not as popular as Zoom or Microsoft Teams. Recently Google Meet has increased its capacity of concurrent user connected on a single meeting to 250 participants. Right now, Google Meet is widely used in companies and universities.

D. Cisco Webex

Cisco Webex provides a system to host online meetings and as most of the current systems, it allows a presentation mode and interactions between participants through the use of the chat. One of its strengths is the security when allowing the access of unauthorized participants to the virtual meetings or class sessions. Features include listen and search recordings, track class attendance, creation of breakout groups to share ideas or teamwork activities such as collaborate on projects, and edit files.

E. Adobe Connect

Adobe Connect allows educators and students to interact in a virtual environment. This system in pre-pandemic times had notorious advantages in the educational context over generic systems such as Google Hangouts (Later called Meet), Microsoft Skype for Business (later called Microsoft Teams) or Early versions of Zoom, adding features that provided more interaction possibilities between students and teachers. For instance, in this system the students could raise their hand and give feedback to the instructor by clapping or showing acceptance or rejection emojis. This tool also provides a mechanism to independently record the video of the instructor camera, the presentation, and the chat interactions, creating an editable project for the session, and allowing the instructor to later edit their recording in multiple ways.

F. BigBlueButton

BigBlueButton is an open-source web conferencing solution for online learning that provides real-time sharing of audio, video, slides, whiteboard, chat and screen. It also allows participants to join the conferences with their webcams and invite guest speakers.

This platform allows the instructor to record the lessons or meetings, and share them with the students. Users of Chrome and Firefox browsers will benefit from high-quality, low-latency Web Real-Time Communication (WebRTC) audio. It also includes a whiteboard to write and draw during the presentations in real-time. As many of the covered systems, users can share their desktop to present. This system has been commonly used over open source Learning Management Systems, such as Moodle.

Table I presents a summary of the main features of the reviewed platforms.

IV. Design and Implementation of the Proposed Remote Laboratory

This section presents the design and implementation of the proposed remote laboratory. The first part of the section presents the architecture of integration of a Learning Management System (LMS), an Online Laboratory Management

System (OLMS), and a video conference platform. The second part of the section, presents the adaptation of a microprocessors laboratory activity to be completed remotely by the students. For this example scenario, the laboratory instructor enables a module in the LMS that includes the laboratory activity and the access to the remote session. The specific example presented in this scenario uses the Smart Adaptive Remote Laboratory (SARL) OLMS, the Zoom video conference platform and the Moodle LMS. Video conferencing system Zoom was chosen due to its popularity among educational institutions, and also because its API that provides flexibility for adapting and customizing the service according to the online laboratory requirements.

TABLE I
COMPARISON OF THE EVALUATED PLATFORMS

Platform	Open Source	API for dev	Integration with LMS	Remote Control
Zoom	NO	YES	YES	YES
Microsoft Teams	NO	YES	YES	YES (Required enable by admin)
Cisco Webex	NO	YES	YES	YES
Google Meet	YES	YES	YES	YES (Required extra conf)
Adobe Connect	NO	NO	YES	YES
BigBlue Button	YES	YES	YES	YES (Not tested)

A. System Integration Architecture

The proposed system provides user access to the remote laboratory activities through the LMS. These laboratory activities are retrieved directly from the OLMS and loaded into the LMS. The system also integrates the physical laboratory station located in the remote laboratory facility. The laboratory station needs to be connected to a computer that will run the software needed by the local laboratory station, e.g drivers, IDE, debugger, Command Window Interface, etc. This computer also serves as communication interface between the user and the lab station through the use of the video conference system. For this purpose, a web camera is needed to provide feedback to the student about the current state of laboratory station. Figure 1 presents the architecture of this integrated system.

B. Use Case Implementation

This example shows a use case of the proposed integration. This laboratory activity, developed on the topic of Microprocessors, asks the student to write a program and run it in a remote micro-controller. For this purpose, the student uses the remote IDE installed in a computer located in the university campus physical laboratory.

All the interaction occurs through a pre-configured Zoom session. Once the student has the code written, compiled and debugged, the student is asked to test the program using the remote micro-controller laboratory equipment; this micro-controller is part of the remote laboratory station.

The setup includes the micro-controller attached to the laboratory computer that is connected to internet, and it is running the set of tools required for this interaction.

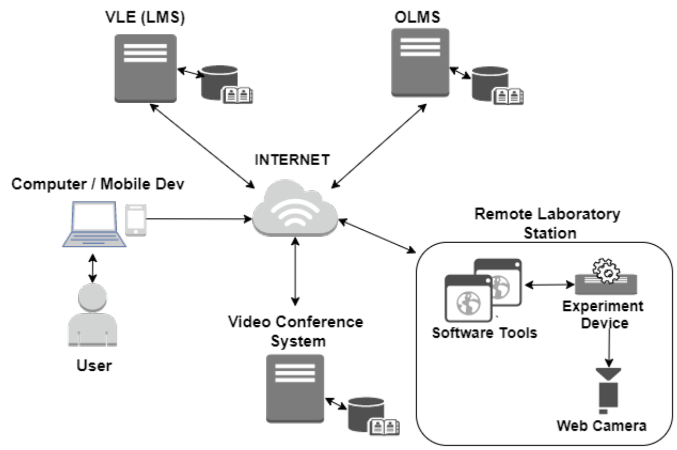

Fig. 1. Online Laboratory System Integration Architecture

1) Laboratory Activity Definition:

- **Title:** Testing UART and Display
- **Purpose:** The user may control multiple input/output devices (e.g., OLED display, LED out) on the DK-TM4C123G development kit [29]. The OLED shall display TEXT values. For this laboratory, UART communication shall use polled input/output processing
- **Objectives:**
  1) Increase usage of the TM4C123G Development Board
  2) Implement UART communication between the TM4C123G and a PC workstation
  3) Use of the C programming language
  4) Utilize functions and constants in TivaWare® Peripheral Driver Library (PDL)
- **Requirements:** Develop a program using the DK-TM4C123G peripheral driver library (PDL) and demonstrate its functionality on the Tiva TM4C123G microcontroller unit (MCU). The program should utilize UART0 to print a welcome message and a send a message through UART

2) LMS and OLMS Integration: The laboratory activity was originally created by the instructor using the OLMS, which is the manager of online laboratory resources. This platform also allows the interaction with remote, virtual or hybrid laboratories, offering features such as: laboratory activities authoring, galleries management, auto grading, interactions capturing, among others. This system can be integrated to the LMS through LTI technology to retrieve laboratory activities previously created by the instructor.

Figure 2 shows the access page that includes the activity integrated in the LMS Moodle as one of the module activities of the course. This page also contains the access to the remote session where the student will interact with the software and give commands to the laboratory equipment.

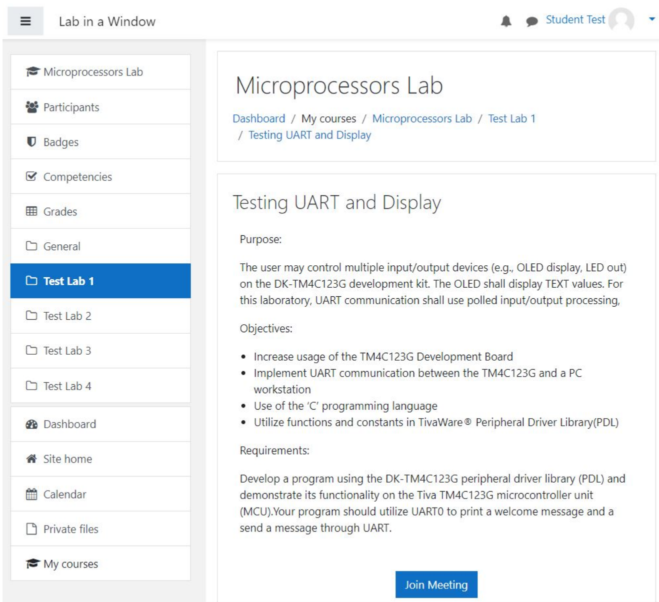

Fig. 2. Moodle Laboratory Interface - Student View

3) Laboratory Station Software and Additional Requirements: For this specific example, the students use the software IAR Embedded Workbench for Arm® [30]. This software is an integrated development environment, that includes C/C++ Cross Compilers. It generates a compact code that runs in the Arm®-based micro-processors.

Among the features, this tool includes debugging functionality, memory and registers monitors, static and run-time analysis. This software, as others in the market, is proprietary. It is a stand-alone application that runs locally in the computer, and the educational institution should activate one license per each computer acting as laboratory station.

This example can be also implemented using other software editors for micro-controllers like Code Composer from Texas Instruments TI [31], Arduino IDE [32], among others.

4) Laboratory Activity Interaction: For this purpose, the laboratory instructor must define an appointment for the student that will be interacting with one specific laboratory station. This approach does not allow multiple students using the same laboratory station. The instructor will need to setup multiple stations in the laboratory facility if concurrency in needed.

Once the student accesses the Zoom video conference session available within the Moodle activity module, the controls are given to the student. This allows the student to interact with the software to write the program, compile it and send the compiled code directly to the micro-controller. The student receives feedback trough the camera or directly through the command's terminal. The control of the remote computer is given through the Zoom "Request Shared Screen Control" option. In the right side of the screen of the Zoom session, a real time video streaming of the laboratory equipment is sent from the web camera located in the laboratory facility. The student can pin this camera source to have a bigger view of the video signal.

Alternating between the laboratory equipment and the experiment view can be done by the student from the Zoom interface. This allows the student to verify if the program is giving the expected results, for example, if the value printed in the laboratory equipment screen is correct or not.

When the user requires more than one tool in the screen running in the host computer, the instructor needs to configure these options when configuring the sharing options. Figure 3 presents a view where an additional window is shared for the UART serial communication interactions. For this specific laboratory activity, the students are asked to print a text message in the laboratory equipment OLED screen as well as send a text message through the UART peripheral from the laboratory equipment to the computer.

V. Students Perception Survey and Results

The example laboratory activity was tested with 5 students from the Micro-processors Systems laboratory class of 13 students, during an introductory laboratory activity at the beginning of the spring 2021 semester. The students were asked to access the online session and to complete the activity suggested. A study was conducted to evaluate the perception of the students about their online laboratory experience.

At the end of the semester a survey with 5 questions was given to the students that participated in the online experience to collect data about their perception and experience using the system.

Survey Questions:

1) Would you able to complete the task, based on the available resources of the online laboratory?
   a. Not Completed
   b. Completed
2) How does the online laboratory experience compare to a face to face laboratory experience?
   a. Worst
   b. Similar
   c. Better
3) How do you classify the level of control you had of the hardware system provided during the online laboratory activity?

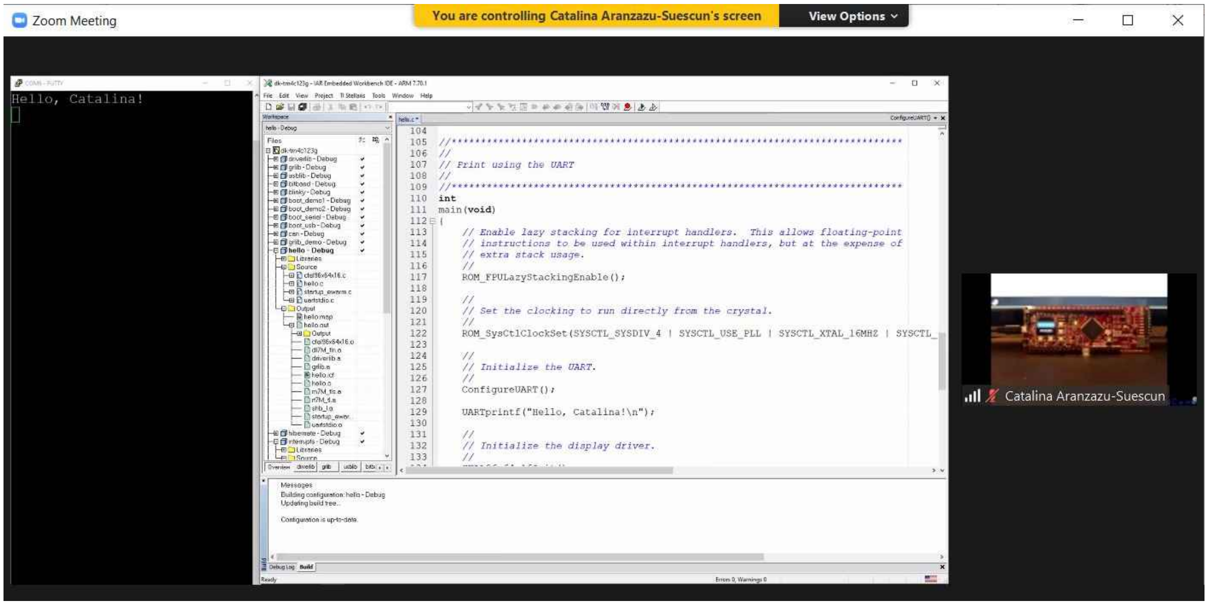

Fig. 3. Online Laboratory, Programming and UART View

TABLE II
STUDENT' SURVEY RESULTS

Question	Student 1	Student 2	Student 3	Student 4	Student 5
Q1	Completed	Completed	Not Completed	Completed	Completed
Q2	Better	Similar	Worst	Similar	Similar
Q3	Good	Good	Very Limited	Limited	Limited
Q4	Excellent	Excellent	Good	Good	Good
Q5	Lab Room	Lab Room	Lab Room	Lab Room	Lab Room

   a. Very Limited
   b. Limited
   c. Good
   d. Excellent

4) How do you classify the level of control you had of the software system provided during the online laboratory activity?
   a. Very Limited
   b. Limited
   c. Good
   d. Excellent
5) If you have to choose between the online laboratory or doing the activity in person in the laboratory room, which do you prefer?
   a. Online Laboratory
   b. Laboratory Room

The answers of the students are presented in table II

Based on the survey results, we found that in general the students feel more comfortable working in the physical laboratory room. A reason for this is the amount of help and interaction they have in the face to face session compared to the online sessions.

In terms of the perception manipulating the hardware and software of the online laboratory, it is clear that they did not have problems controlling the remote software. However, that was not the case with the hardware. The reason is that there were not too many controls of the hardware besides the reset function.

Four out of the five students participating in the test completed satisfactorily the activity.

A. *System Integration Limitations*

The integration was successfully completed using Moodle LMS, SARL OLMS and Zoom. However the integration with other video conference systems has not being tested yet.

Limitations of the available plugins of Zoom for the LMS Moodle, require the customization of these tools to automatize the process of screen sharing and remote control of the host computer automatically when the user joins the video conference session. These limitations need to be addressed with the video conference system selected.

Due to the fact that most of software tools running in the host computer are proprietary, it is difficult for the OLMS to implement features, such as the automatic grading of the laboratory activities or tracking interactions of the users when using those software platforms. The problem can be solved when open-source platforms are used to control the laboratory experiments.

The impossibility to physically interact with the hardware creates problems when the teacher wants to create more interactive activities.

VI. Conclusions and Future Work

The integration of video conference systems to online laboratory experience has opened the possibilities for using remotely different types of online laboratory resources, especially those that use proprietary software.

This integration also provides to students a more flexible and integrated environment of online laboratory experimentation, considering all the limitations of access that arose during these challenging times.

Future developments include the full automation of the virtual session and complete integration of the OLMS that will allow the teacher to compose and reuse previously created laboratory activities as well as schedule the laboratory sessions for individual students.

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