Virtual and Remote Industrial Laboratory

Integration in Learning Management Systems

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During the last few decades, many industrial remote and virtual laboratories have been designed and implemented at different universities and schools with the goal of providing online experiments that are remotely available to their students from anywhere and at any time. Research into virtual and remote laboratories has shown that the vast majority of these laboratories are built using learning tools and resources that are suited to a specific institution. Thus, different universities implement the software for their particular needs and consume a significant amount of time and energy in the process. This article describes a different approach: the design and implementation of a learning management system (LMS) activity that allows sharing of electronic, control and automation, and electrical remote laboratories from different universities within industrial courses without requiring the teacher to program a single line of code.

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Background

The acquisition of skills and practical knowledge is an essential component in the education of engineering students and in the lifelong learning of engineers. Until a few decades ago, student learning mainly took place in hands-on laboratories. However, new e-learning tools have emerged over the past few decades, thanks to advances in communication, computer networks, and the evolution of programming languages [1]. Among all of these new e-learning tools, three very important solutions in industrial learning stand out:

- *LMS:* a process-oriented mechanism for organizing a set of learning activities and resources.
- *Virtual laboratories:* software programs that provide a set of simulated experiments. These are used in all types of educational fields, from chemistry to electronic experiments [2], [3].
- *Remote laboratories:* software programs capable of controlling and handling real instruments at remote locations [4]. These programs can be used by some students via the Web. Although they are capable of being used for teaching in a wide range of scientific fields such as computer science and physics [5], [40], currently, a great number of these have been developed for electronic, automation and control, or electrical courses [6]–[10].

Clearly, these e-learning tools can work independently of each other. However, if we want to ensure that our students work within a well-defined learning environment in which theory and practice are combined, suitable accurate learning scenarios should be integrated. According to Klebl [11], "a learning scenario is a social setting dedicated to learning, education, or training. It is a process of interaction between people in a specific learning situation using resources for learning within a designed environment. People in role of learners perform activities directed toward learning objectives using resources for learning. Learners may work on their own or in a group of learners."

Therefore, working on this assumption, many universities and organizations have designed and implemented their own solutions into industrial courses to ease the learning process for students. The following are the most common solutions:

- Remote and virtual laboratories are combined with hands-on laboratories and Web-learning tools [12].
- Virtual and remote laboratories are used in an ad hoc e-learning framework or system [13], [14].
- Virtual and remote laboratories are connected to a course management system (CMS) or LMS [10], [15].

All of these are adequate for the integration of one or two remote laboratories in the industrial courses of one university, but as they are ad hoc solutions, it would require a considerable amount of work to integrate many more remote laboratories. In this article, interoperability between universities is shown to be improved by a software module based on an LMS where the main objectives include the following:

- *Scalability:* The software allows the addition of a great number of laboratories from different universities into an LMS-hosted course. This sharing requires a collaboration agreement with the university that provides the remote laboratory.
- *Usability:* The software allows the teacher to be able to add laboratories to his courses without having to program a single line of code. To do this, the software provides three user interfaces: student, teacher, and administrator.
- *Portability:* The target of this contribution can be developed in multiple LMSs. Indeed, it has been developed for two major LMSs: Moodle and dotLRN. Universities using these LMSs will be able to deploy it quickly.
- *Maintainability:* This software is modular, and therefore it is very easily modified and highly maintainable.

Although this software can be used with remote or virtual laboratories from many academic disciplines, this article will focus on its use with electronic laboratories.

Current Situation

A review of the current literature shows a great number of universities or organizations that have created their own virtual and remote laboratories. This is done to support life-long learning and students' autonomous learning activities in industrial fields, such as electronics and microelectronics, power electronics and electrical drives, and control and automation [3], [4], [6]–[10].

However, most of these efforts lack a unity of design, involve custom development, and present integration issues. There is little to no reuse of software among institutions because each system is developed from scratch. To solve these problems, several initiatives emerged in the last decade to provide shareable online experiments. Example initiatives include the iLab project [16], [17], WebLab-Deusto [18], [19], and the LabShare project [20]. All of these initiatives have seen growth in the number of members and online experiments. For instance, within the iLab project, universities from five continents are now involved in the sharing of online experiments.

- *Microelectronics Device Characterization Laboratory [Massachusetts Institute of Technology (MIT)]:* This remote laboratory measures the current–voltage characteristics of various microelectronics devices.

The acquisition of skills and practical knowledge is an essential component in the education of engineering students and in the life-long learning of engineers.

- *Alternating Current (ac) Machine (University of Queensland, Australia):* This remote laboratory examines various characteristics of an ac motor by measuring the voltage, current, and power factor. Access is available through the University of Queensland.
- *Elvis Op-Amp Experiment (Obafemi Awolowo University, Nigeria):* This remote laboratory uses the dozen-impedance op-amp circuit. By placing switches from the switching matrix at strategic locations, the dozen impedance circuit makes it possible to construct up to six different op-amp circuits using a single op-amp.
- *VISIR Project carried out by the Blekinge Institute of Technology, Sweden, and integrated to iLab project by Carinthia University of Applied Sciences (Austria):* This project provides a platform to design and implement online experiments about function generators and oscilloscopes, direct current (dc) circuits, ac circuits, or metal–oxide semiconductor (MOS) transistor characterization [21].

These initiatives [16]–[21] and the remote laboratories that are designed and implemented by universities or organizations [5]–[10] share the need to offer laboratories as a pedagogical activity of an industrial learning scenario. For this reason, some proposals have considered the following ideas:

1) Adding Web pages, collaboration, communication, or assessment tools to remote laboratories [22] or creating new learning systems to support the virtual or remote laboratory [13], [14]. Although these solutions can cover the needs of educators, other well-known and widespread e-learning tools such as LMSs already offer these learning environments or services. They are therefore spending money and time and using resources over and over again in doing the same thing (see Figure 1).
2) Packing the virtual and remote laboratories within content packages that comply with e-learning standards such as IMS content packing (IMS-CP) [23] or sharable content object reference model (SCORM) [24] and are supported by the majority of LMSs [25]. The main problem with the current e-learning standards is that they were developed for packing static content and do not support interactive code that provides the communication between remote labs and the physical instruments or booking system. Today, there are several initiatives that are working to adapt these standards or develop new standards to give support to interactive software. Among them are Library of Labs (LiLa) and Open and Collaborative Environment for the Leverage of Online Instrumentation (OCELOT). LiLa is a European eContentPlus project that promotes a portal of online laboratory resources and fosters exchanges on experiments between institutions [26]. OCELOT is an open-source, collaborative online laboratory framework and middleware.

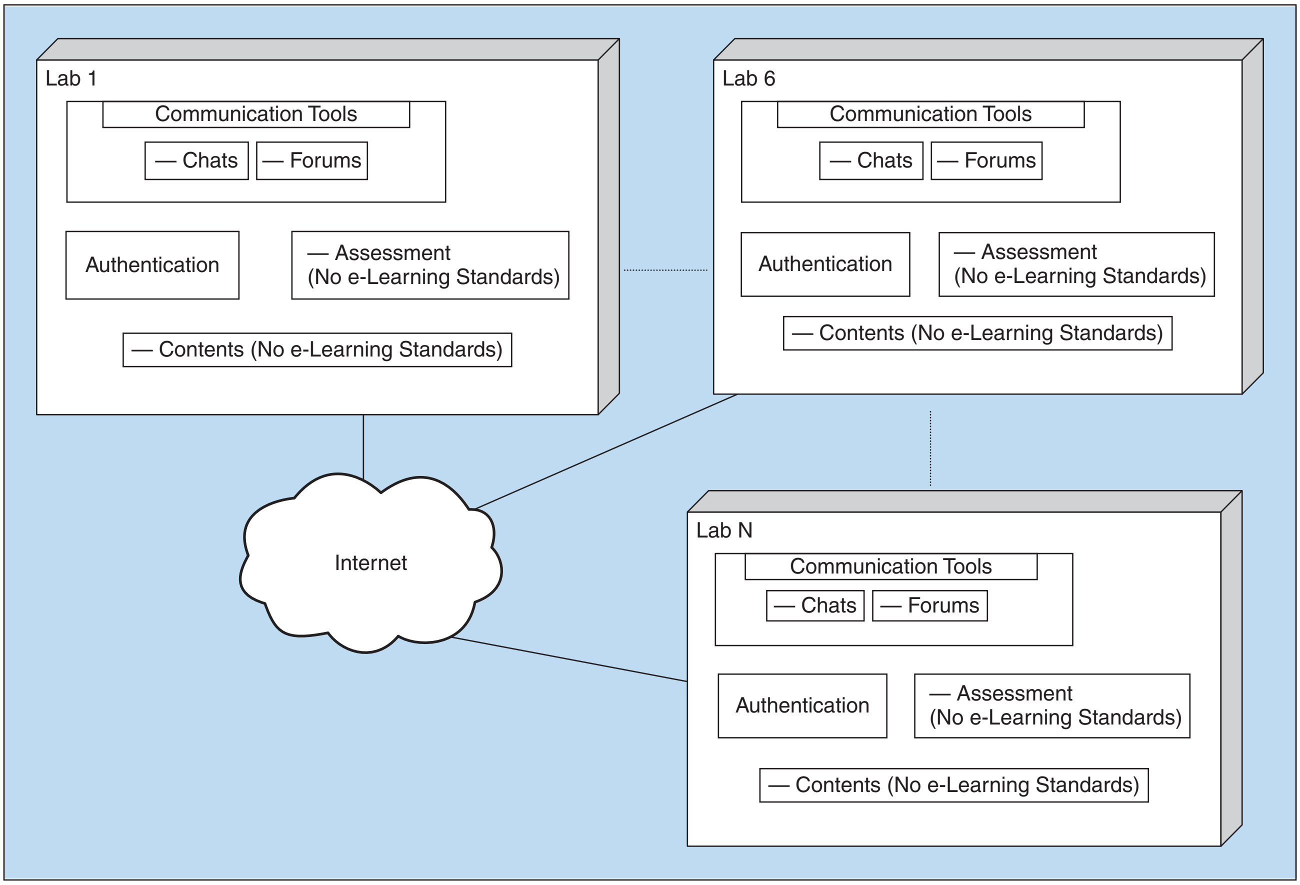

FIGURE 1 – Adding learning services to remote laboratories (duplicating efforts).

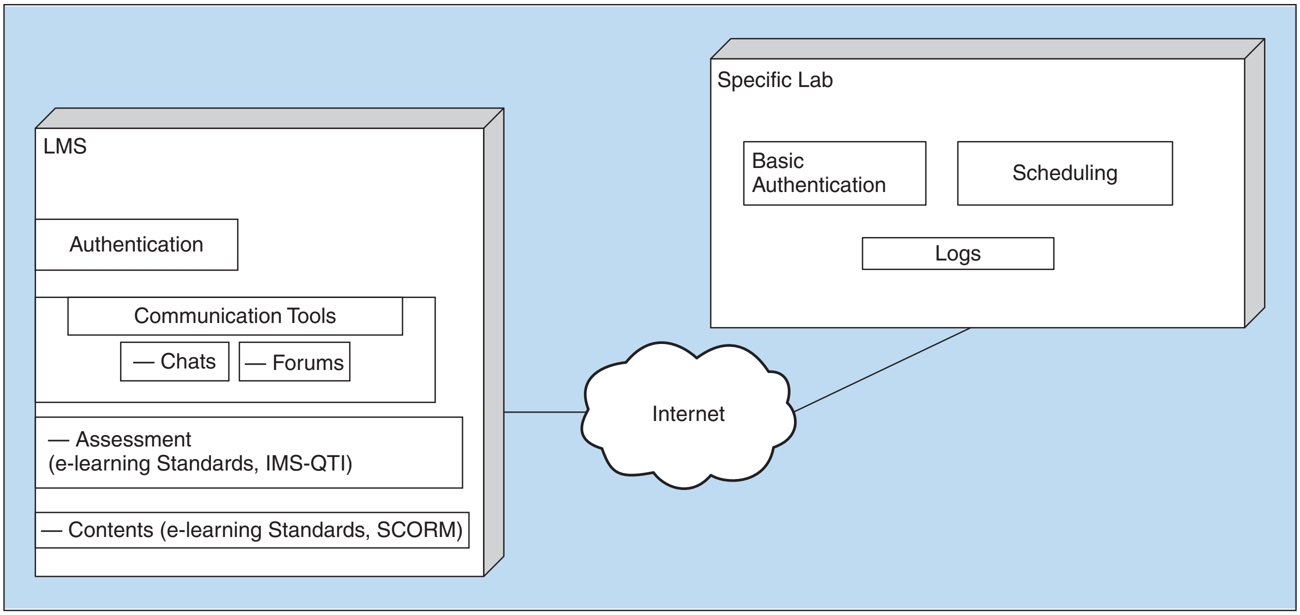

FIGURE 2 – Using LMS's learning services with a specific remote laboratory.

It uses a W3C widgets-based graphic user interface for delivering to the learner [27].

3) Creating a specific module to use the remote laboratory within a specific LMS [7], [15]. The main drawback is that this module is an ad hoc solution for a specific industrial remote laboratory. Solutions 2 and 3 allow a remote laboratory to use the LMS's e-learning services such as collaboration (wikis), communication (forums, chats), e-learning standards (question and test interoperability IMS-QTI [28], SCORM), and user tracking (Figure 2). However, as previously mentioned, e-learning standards will still have to be adapted to support software that interacts with remote laboratories. Also, the current ad hoc solutions for connecting a specific laboratory must evolve to a unified and global solution that different universities could use to share online experiments easily.

Thus, the ability to share and reuse industrial online experiments from different universities without having to program the same code over again is desirable.

This article describes a Web architecture that can be implemented in an open-source LMS. Once implemented, it provides a set of user interfaces for simplifying the integration of industrial remote laboratories from different universities within LMS courses [25], [29].

TABLE 1–E-LEARNING SERVICES PROVIDED BY LMSs, VIRTUAL, AND REMOTE LABORATORIES.

	GENERIC OVERVIEW		
SERVICES	LMSs	VIRTUAL LABORATORIES	REMOTE LABORATORIES
Authentication	Yes	(Optional)	Yes
Authorization	Yes	(Optional)	Yes
User tracking	Yes	(Optional)	Yes
Scheduling	Yes	No	Yes
Assessments tools	Yes	(Optional)	(Optional)
Communication tools	Yes	(Optional)	(Optional)
e-learning content	Yes	(Optional)	(Optional)
File storage	Yes	(Optional)	(Optional)
e-learning standards	Yes	No	No

Proposal

As previously mentioned, the literature documents a great number of industrial virtual or remote laboratories [2]–[9], either stand-alone or as part of shareable architecture [16]–[21]. However, all of them require a pedagogical component that can be created ad hoc (Figure 1) or where they can reuse e-learning services from existing learning systems such as LMSs (Figure 2).

Table 1 compares services provided by LMSs and virtual and remote laboratories. Table 2 shows the services provided by particular virtual and remote laboratories. As both tables show, LMSs already provide many of the services that are required by virtual and remote laboratories. Furthermore, LMSs provide certain services not available on them, such as assessments tools. The core contribution of this article is to demonstrate that, by integrating virtual and remote laboratories on LMSs, the former will benefit from the services provided by the latter. To evaluate this contribution, an architecture for integration is proposed and has been implemented on two independent case studies (Moodle and dotLRN), checking the new services incorporated to the virtual and remote laboratories. This architecture is said to provide standardization of results of online experiments;

interoperability; and exchange of data among virtual, remote labs and LMSs, similar to standards such as LIMS: LIMS (ASTM E1578) [43].

LMSs

LMSs are widespread learning solutions that are very useful in blended and distance learning. An LMS is a framework that delivers and manages instructional content, identifies and assesses individual and organizational learning or training goals, tracks the progress toward meeting those goals, and collects and presents data for supervising the learning process of an organization as a whole [30], [31].

These can be classified as proprietary LMSs, such as Blackboard [32], and open-source LMS, such as Moodle [33], dotLRN [34], or Sakai [35]. While any software can be classified this way, it is particularly relevant here since universities tend to require adapting the solution by modifying the system source code.

A study of several open-source LMSs shows that most of them follow a common architecture that is divided into following three layers:

1) *Database:* Each LMS has associated a database where the related data for the correct working of e-learning services are stored. For instance, all LMSs have a set of tables of user and course where the information about users and courses are stored. Also, these tables are related to each other to associate a user with one or several courses.
2) *LMS's services:* These are a set of source codes grouped in programming modules or packages (depending on the LMS) that support the functionalities of each of the e-learning services. For instance, the e-learning activity called forums has a set of associated programming pages that provide the functions for creating a forum, writing a message in the forum, and displaying the messages of a forum. To do this, the software will have to insert data into the database and retrieve data from it.
3) *Web server:* This provides an environment to execute the LMS's services and deliver content stored in the database to an Internet browser through templates.

TABLE 2–E-LEARNING SERVICES PROVIDED BY SEVERAL PARTICULAR VIRTUAL AND REMOTE LABORATORIES.

	PARTICULAR CASES				
	VIRTUAL LABS		REMOTE LABORATORIES		
SERVICES	KARNAUGH MAP [41]	WATER TANK [42]	VISIR PROJECT	WEBLAB-DEUSTO	ILAB PROJECT
Authentication	No	No	Yes	Yes	Yes
Authorization	No	No	Yes	Yes	Yes
User tracking	No	No	No	Yes	Yes
Scheduling	No	No	Yes	Yes	Yes
Assessments tools	No	No	No	No	No
Communication tools	No	No	No	No	No
e-learning content	Web pages	Web pages	No	No	No
File storage	No	No	No	Yes	Yes
e-learning standards	No	No	No	No	No

Therefore, by following this three-layer architecture, a new learning service can be created, which allows teachers to manage virtual and remote laboratories from different universities in their industrial courses. This new e-learning service will work along with the rest of the services (reusing e-learning services), such as forums, surveys, assessments, and file storage to create a complete industrial learning scenario where theory and practice are taught together.

LMSs are widespread learning solutions that are very useful in blended and distance learning.

Proposed Software Architecture

The requirements for designing the new e-learning service within the open-source LMS architecture are as follows:

1) Define the functionalities that the new e-learning service is going to provide. In the majority of cases, these functionalities will include database entry retrieval and insertion as well as the creation of new tables. Of course, these programming tasks depend on the programming language and file structure used in the LMS to create new e-learning services of an LMS.
2) Add new functionality that can be executed by a determined role such as administrator or teacher in the LMS management services.
3) Define a set of tables that will be part of the LMS database and where all the needed information will be stored. These new tables could be related among themselves and also with other tables from the LMS such as the user and/or course tables.

To define the functionalities and tables for creating a new service to manage virtual and remote laboratories, the different roles that are going to use the functionalities provided by the service (Figure 3) must be taken into account:

- The system administrator should be able to do the following:
  - Add virtual and remote laboratories to the LMS. To do this, the software must provide a set of user interfaces that data to be

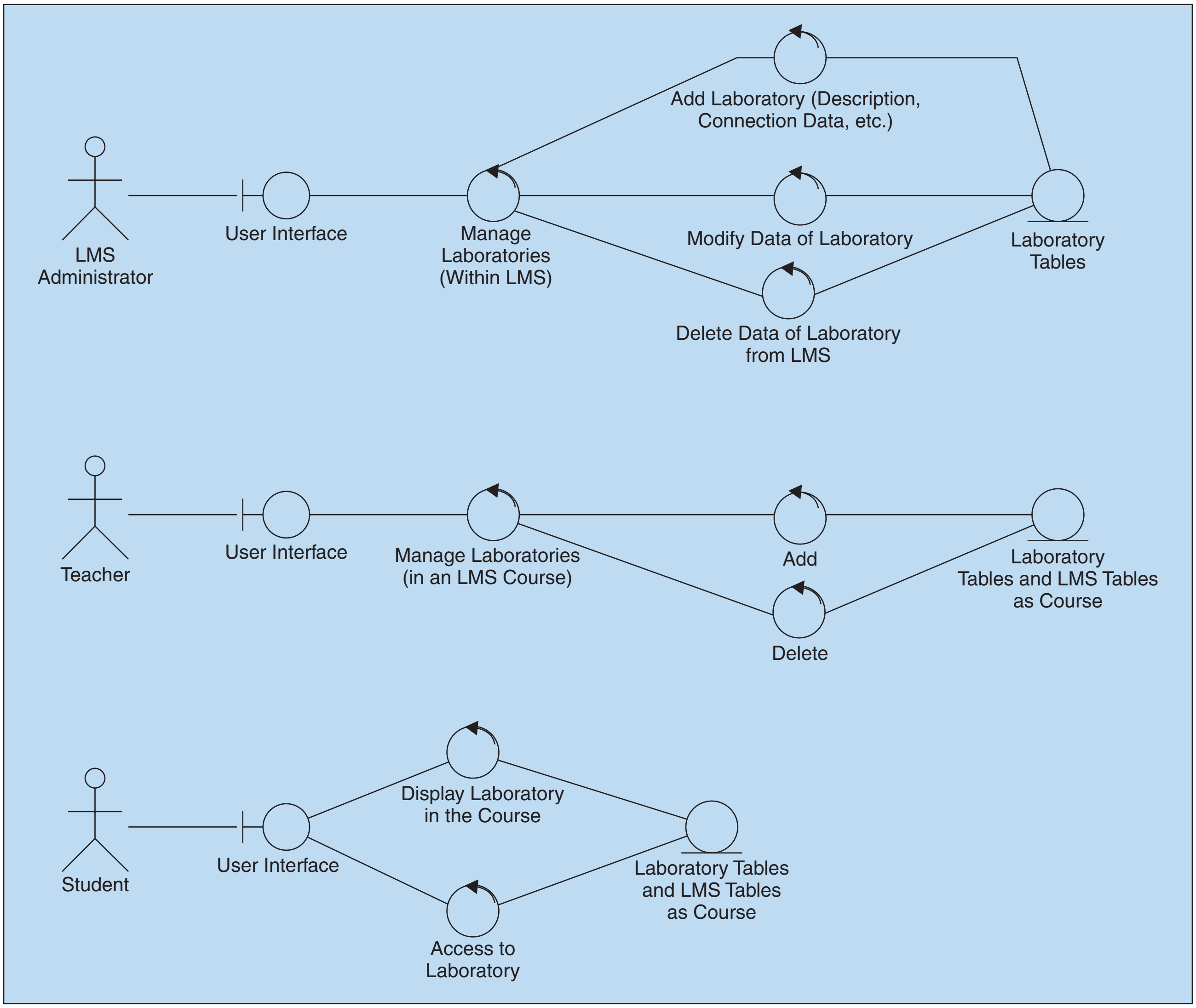

FIGURE 3 – The functionalities of each role.

entered describing and connecting the LMS with the laboratory. Currently, there are many virtual and remote labs that have been developed with different architectures and methods of connection [15], [36]. For that reason, the created open-source software is easily changed and very modular. It allows programmers to extend the system with new interfaces, functionalities, and connectors.
- Modify the description or connection data of the virtual or remote laboratory.
- Delete a virtual or remote laboratory from the LMS.

- The teacher should be able to add the LMS's learning services, such as forums, assessments, and wikis for courses, and should also be able to add or delete a virtual or remote laboratory from courses. The software must save the teacher from having to program anything. Instead, programming must be the responsibility of plug-in developers and the LMS administrator.
- Students must be able to access the remote or virtual laboratory from the LMS course.

All of these functionalities must be supported by a set of tables that will store data related to connection, laboratory description, experiments that students carried out, etc. Of course, these tables are related with other LMS tables and can be modified or extended according to the university's needs (Figure 4).

Once all functionalities, users, and tables are defined, a new service for the LMS can be created that gives access to the industrial remote environment (Figure 5). The next section will document how this proposal is implemented in two open-source LMSs: Moodle and dotLRN. This issue will show the viability of this proposal.

Cases of Studies: Implementing the Proposal in Moodle and dotLRN

Moodle and dotLRN are two well-known and widespread open-source LMSs. They are being used in many universities to support blended and distance learning. This section describes how the proposal for creating an e-learning service that

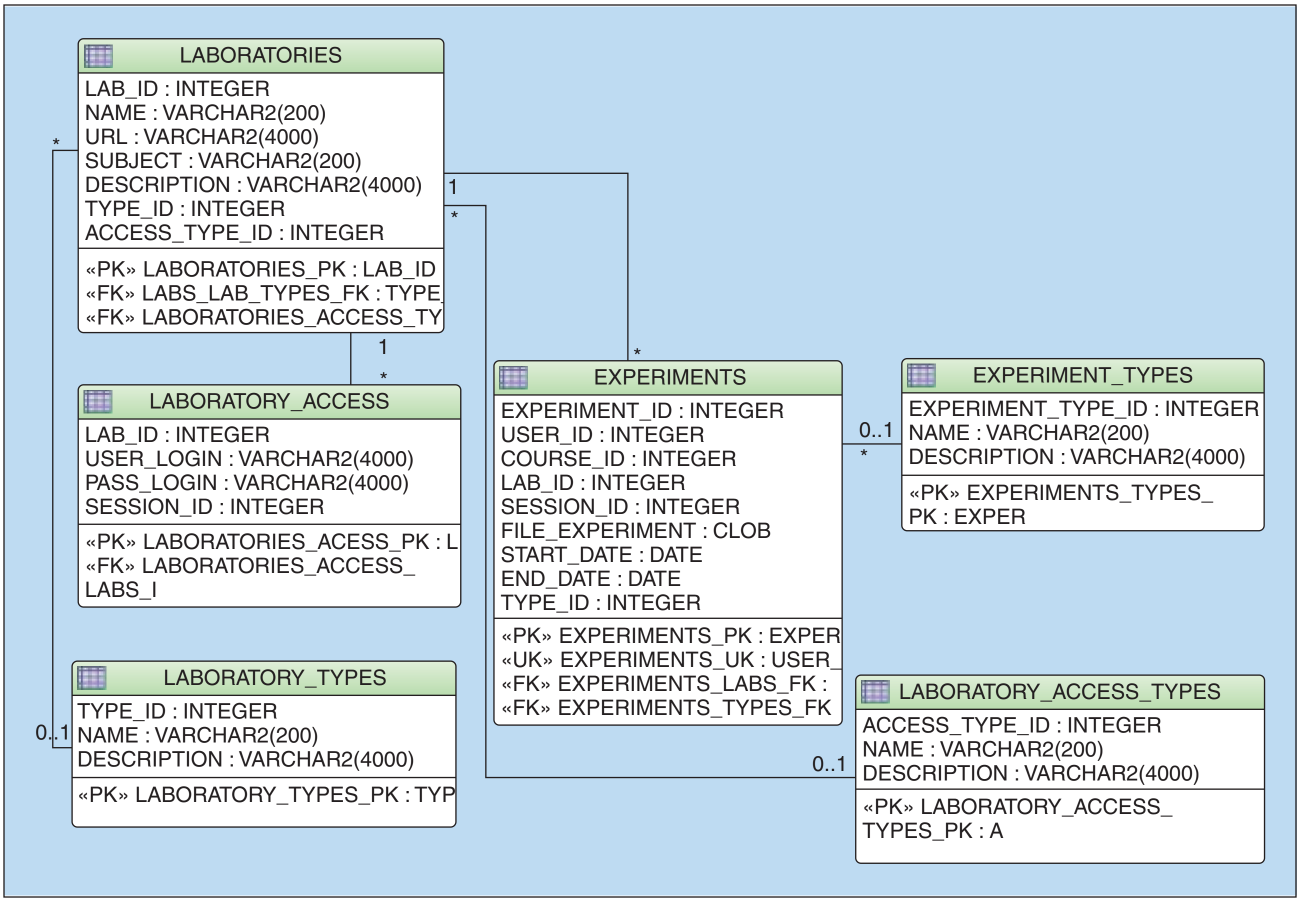

FIGURE 4 – A set of laboratory tables.

manages and shares virtual and remote laboratories in an LMS course (Figure 5) is developed on Moodle and dotLRN.

Moodle Activity

In Moodle, e-learning services such as forums and chat are called activities. These are defined as educational things to do. The new educational thing to do is to carry out an online experiment from a remote electronic laboratory. Each activity must create a set of tables and

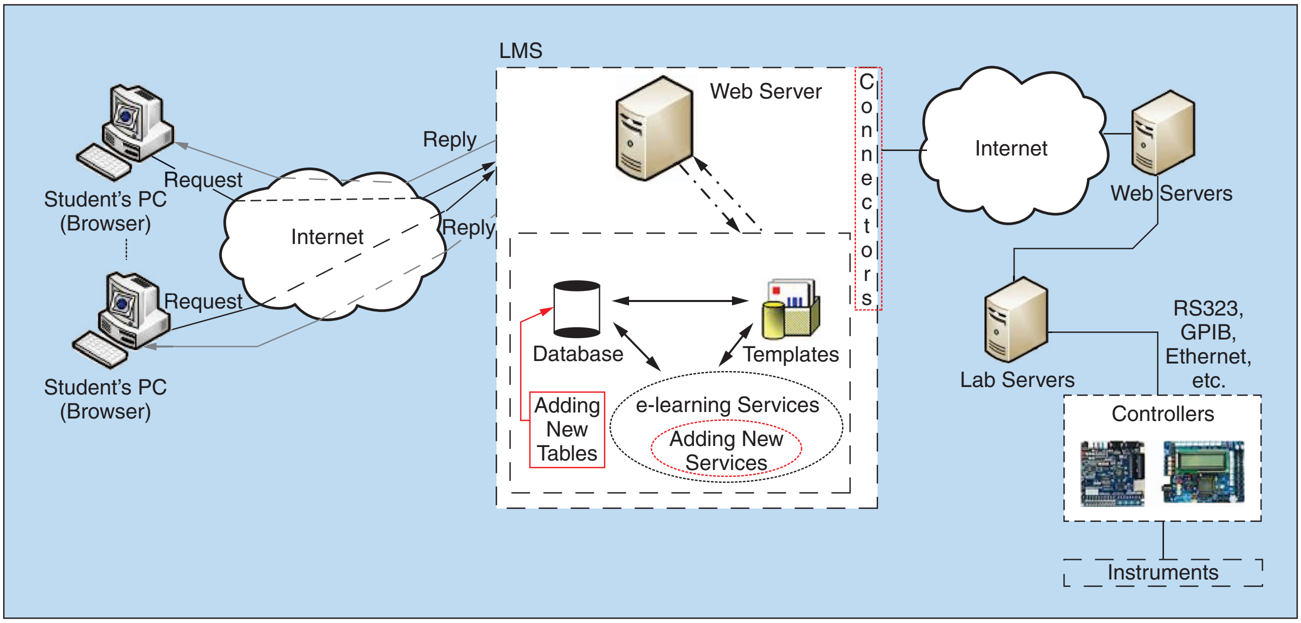

FIGURE 5 – Supporting industrial environments in LMS courses.

FIGURE 6 – The structure of a Moodle activity.

a set of functionalities that are grouped in a module with the structure shown in Figure 6. The new activity for remote labs will require these tables. The following are the important files in the module:

- *install.xml:* In this file, the set of tables (Figure 4) that the activity is going to use and also the relationships among them and other tables are described.
- *mod.html:* This file is used to add an instance of a virtual or remote laboratory in a course.
- *lib.php:* This file contains all the functions that are going to manage the activity, including the creation and deletion of instances of this activity in the LMS courses.
- *view.php:* This file contains the programming for displaying an instance of a laboratory and allowing students to access it. Furthermore, it manages the connection mechanism between the LMS and the remote or virtual laboratory (connectors, Figure 5).
- *version.php:* This file contains the version number of the activity.

As a result of these programming pages, the Moodle activity module is at the point where any teacher can add and delete virtual and remote laboratories, and students can see and access these experiments. However, the teacher should not be involved in the programming and installation process, and thus these functionalities are part of the administration module. To do this, the system administrator modifies the top.php file from moodle/admin/setting and creates several php pages to add, delete, and modify virtual and remote laboratories.

The creation of this new activity and the modification of the administration module allow a university to install and use the system easily and quickly without programming. However, if the university wants to extend the functionalities, then the programmers from that university should add code to these files.

DotLRN Package

The dotLRN package consists of a robust portal system; a comprehensive suite of

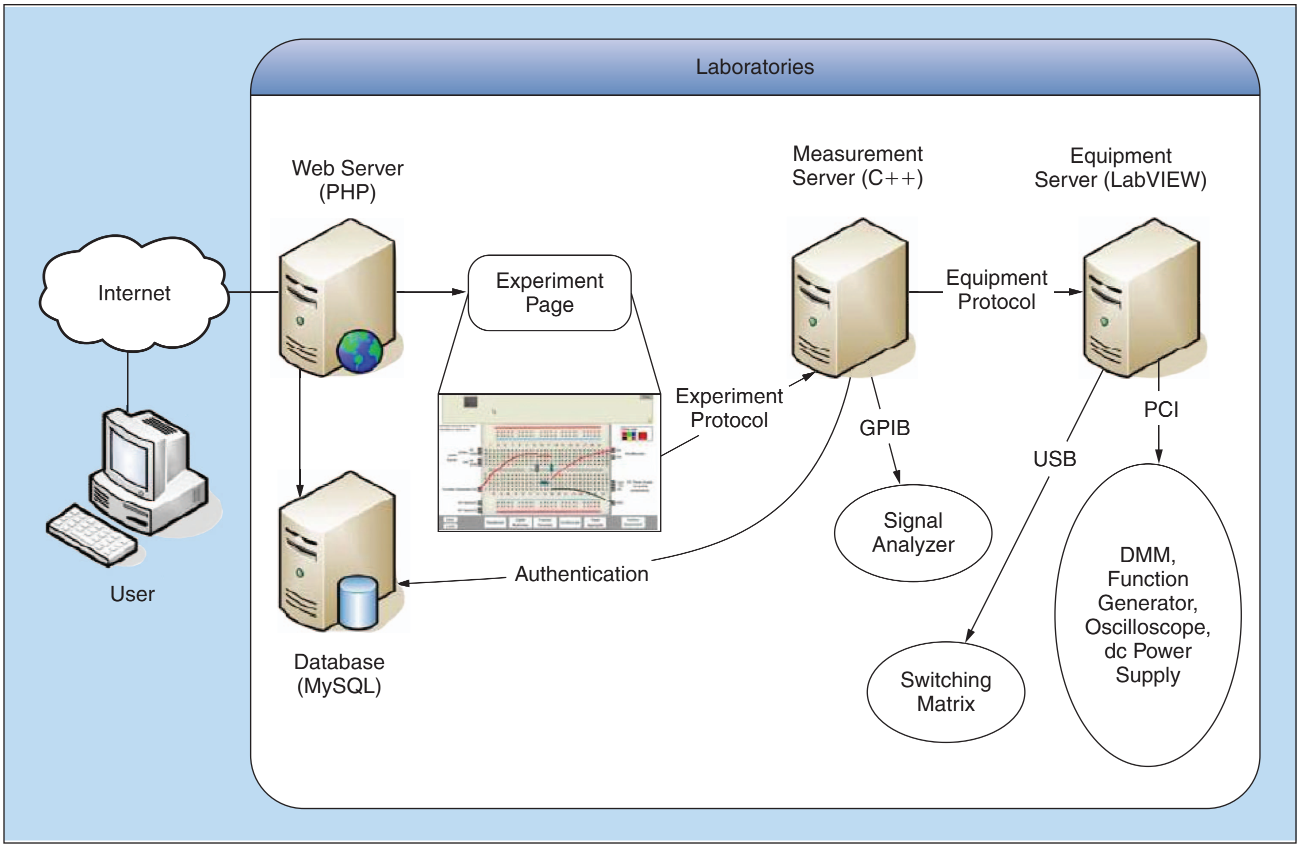

FIGURE 7 – The architecture of VISIR [21].

collaborative applications; and an enterprise infrastructure layer based on open standards ready for accessibility, usability, and education.

The implementation of virtual and remote laboratories in dotLRN comprises several steps [29], [37].

1) Create a new type of the specialized group: This creates a new subclass laboratory in the object-oriented architecture OpenACS [38]/dotLRN [with the necessary infrastructure to expand the data model: tables (Figure 4), views, and PL/SQL].
2) Add new specific properties: This extends attributes of the object type community to expand the new properties of the laboratories, such as academic term and subject (area).
3) Create new roles and relationships: New roles are created to specify the functions of persons or members in the laboratory.
4) Select tools: The types of tools such as chats, forums, and wikis that you want to include in the communities of laboratories.
5) Portal template: Adapt the configuration of the content of the group to locate the best place for tools as well as a proper color scheme for the portal template.
6) Establish a mount point: For the new instantiation of the subsite of laboratories.

The result is a laboratory experience that complies with the functionalities that are indicated in Figure 3. At this time, this model has been encapsulated within a dotLRN package, called labs, so that it is portable and can be installed on any instance of dotLRN.

The dotLRN package consists of a robust portal system, a comprehensive suite of collaborative applications, and an enterprise infrastructure layer based on open standards ready for accessibility, usability, and education.

Using Created Software in Industrial Education

Several industrial virtual and remote laboratories from different universities have been connected to Moodle and dotLRN. Examples include VISIR, CPLD, FPGA, semiconductors [39], and shareable architectures available from WebLab-Deusto. Also, a project is underway to work with the iLab project from MIT to connect all the laboratories that this shareable architecture supports (see the “Current Situation” section).

In this section, the example remote laboratories that are going to be

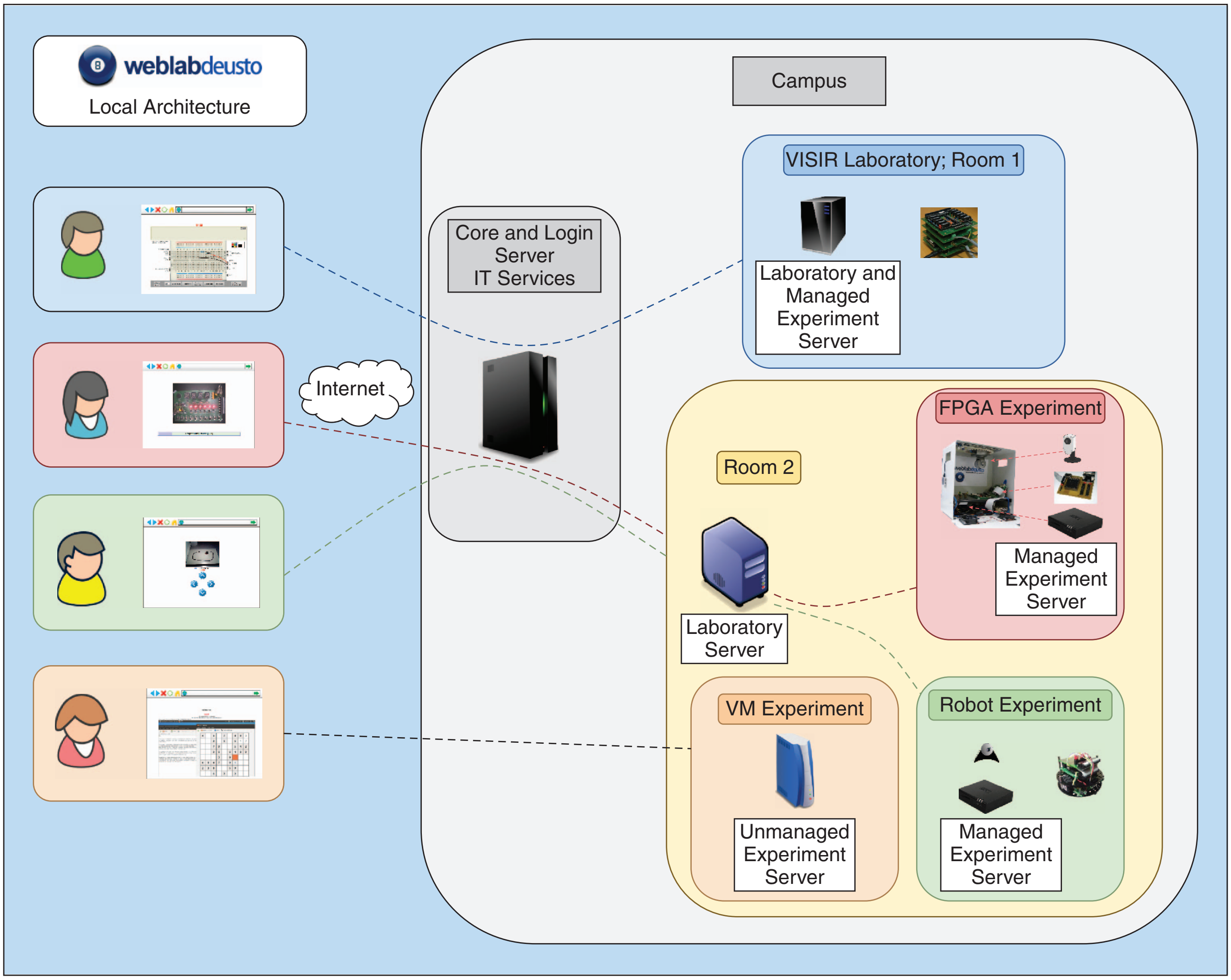

FIGURE 8 – WebLab-Deusto FPGA experiments [18], [19].

integrated as LMS activities are the VISIR project and an FPGA remote lab. Each could have been connected separately as remote laboratories. But for emphasizing the idea of reusing resources and efforts, the example connects them as shareable architecture from WebLab-Deusto (see the "Current Situation" section), where user, password, and session id are needed for establishing the connection.

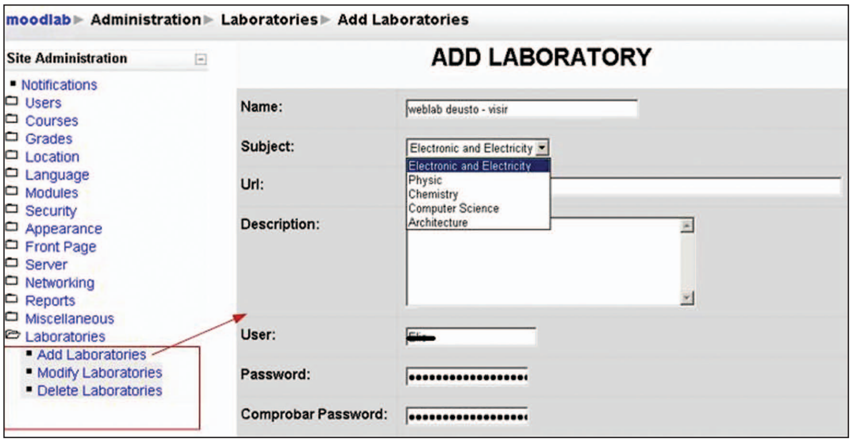

FIGURE 9 – Adding WebLab-Deusto to Moodle.

Before seeing how the process of integrating a remote laboratory into an LMS course is carried out and therefore how a complete learning environment is provided to students, a brief description of each example remote laboratory is appropriate.

1) VISIR is an open-source laboratory dedicated to remote experimentations on analog electronics. Some of the online experiments provided are function generator and oscilloscope use, dc and ac circuits, or MOS transistor characterization. To do this, it is based on the architecture shown in Figure 7.
2) WebLab-Deusto FPGA. A student sends a file, and the content is stored in the device. After that, the student can enable or disable the inputs and see the outputs. This remote lab is based on the architecture shown in Figure 8.

Adding and Using a Remote Laboratory in a Moodle Course

The process is composed of three steps. Each step outlined below demonstrates what functionalities can be undertaken by different roles (i.e., administrator, teacher).

1) Adding a remote laboratory in the LMS. This action is done by the system administrator, and to do this, the created software provides a user interface to input required data about connection, description, etc. In Figure 9, the administrator is inputting data for the use of the remote labs of WebLab-Deusto in the LMS. The file view.php contains code that describes how to use this data to connect with WebLab-Deusto, such as user name, password, and session ID.
2) Once it is added to Moodle, the teacher can not only add traditional activities such as forums, chatroom discussions, and exams but can now also add the remote laboratory from WebLab-Deusto for their different courses. Figure 10 shows the process to include the remote laboratory in the first week of a course and how it is included with a general forum and a discussion. It can be seen that the teacher does not need to know anything about programming because the configuration is all done using a menu-driven user interface.
3) Students log into the Moodle course, click on the laboratory link, and carry out the experiment (Figure 11). It is important to note that, if the remote laboratory is scheduled by queues, the students have to wait, and if they need to reserve time, they have to do it beforehand.

Adding and Using a Remote Laboratory in a DotLRN Community

This process is composed of the three same steps that were described in the "Adding and Using a Remote Laboratory in a Moodle Course" section. In each step the same roles are applicable.

- The administrator adds the remote laboratory to the LMS.
- Once it is added to dotLRN, the teacher in their community can use

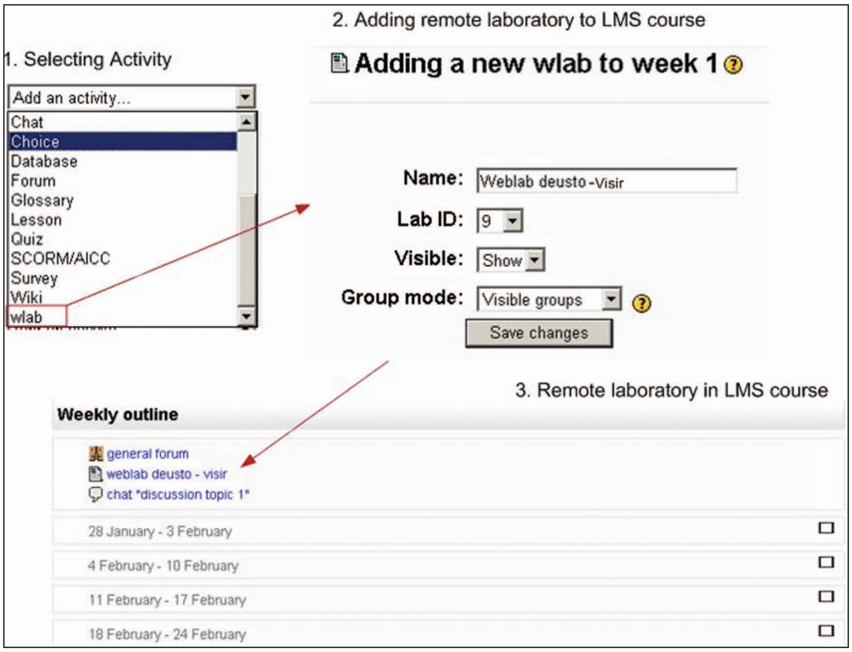

FIGURE 10 – Adding a remote laboratory to the Moodle course.

FIGURE 11 – Using VISIR through WebLab-Deusto and in a Moodle course.

FIGURE 12 – Using the FPGA online experiment from WebLab-Deusto and in a dotLRN community.

TABLE 3–ADDING RESOURCES TO REMOTE LABORATORIES WITH LMS SERVICES.

	WEBLAB-DEUSTO (REMOTE LABORATORY)			
SERVICES	VISIR (WITHOUT LMS)	VISIR (WITH LMS)	FPGA (WITHOUT LMS)	FPGA (WITH LMS)
Authentication	Yes	Yes, it is done in a transparent way through the LMS	Yes	Yes, it is done in a transparent way through the LMS
Authorization	Yes	Yes, it is done in a transparent way through the LMS	Yes	Yes, it is done in a transparent way through the LMS
User tracking	Yes	Yes, it is provided by the LMS (but a standardization for experiments results would allow a better integration)	Yes	Yes, it is provided by the LMS (but a standardization for experiments results would allow a better integration)
Scheduling	Yes	Yes (it is possible to use the calendar of LMSs)	Yes	Yes (it is possible to use the calendar of LMSs)
Assessments tools	No	Yes (it is provided by the LMS)	No	Yes (it is provided by the LMS)
Communication tools	No	Yes (it is provided by the LMS)	No	Yes (it is provided by the LMS)
e-learning content	No	Yes (it is provided by the LMS)	No	Yes (it is provided by the LMS)
File storage	Yes	Yes (it is provided by the LMS)	Yes	Yes (it is provided by the LMS)
e-learning standards	No	Yes (it is provided by the LMS)	No	Yes (it is provided by the LMS)

services such as assessments, tasks, and, of course, remote laboratories.

- Students log into the dotLRN community, click on the laboratory link, and carry out the experiment, in this case an FPGA online experiment from WebLab-Deusto (Figure 12).

Conclusions

The industrial education community desires an integration of virtual and remote laboratories into learning scenarios and learning environments that allow students to learn theory and carry out online experiments. Currently, most of the existing initiatives are ad hoc solutions for a concrete virtual or remote laboratory.

The main contribution of this work is to demonstrate that by integrating virtual and remote laboratories on LMSs, the former will benefit from the services provided by the latter. To do this, modular software has been developed. This provides an e-learning environment where students can use different e-learning services and activities, such as chat, forums, and remote laboratories, without having to move from one e-learning system to another. It also provides a set of user interfaces that allow teachers to build learning scenarios into an LMS course without having to program anything.

There is still a key challenge that must be faced, that is, the definition of a standard global connecting mechanism to connect different remote laboratories (with different authentication, scheduling systems, etc.) within the LMS and to exchange data among these systems (experiment results, tracking of users). The architecture proposed in this article claims for standardization of virtual and remote laboratories and the use of services such as single sign-on. These issues will make the reuse of virtual and remote laboratories in e-learning systems easier.

The industrial education community desires an integration of virtual and remote laboratories into learning scenarios and learning environments that allow students to learn theory and carry out online experiments.

Finally, the results of the integration of this proposal in dotLRN, Moodle, and WebLab-Deusto are as follows (see Table 3):

- *Authentication and authorization:* These services are used by LMSs and remote laboratories (see Tables 1 and 2). In this first version of the architecture, the connectors (Figure 5) are responsible for connecting both e-learning systems. This allows students to log into the LMS and access remote labs in a transparent way (without having to log into each one of the remote laboratories integrated in the LMS course). Currently, it is done with a global user, but in a future version, it will be integrated using each user name of LMSs.
- *User tracking:* The LMSs provide user tracking. For instance, when a Moodle activity is created in a course, Moodle stores information about which user clicks on the activity and at what time. However, it is necessary to establish a set of standards that allow for the exchange of data about the use of the virtual and remote laboratory and the results of the experiments. The future version of this software is working on it.
- *Scheduling:* Most remote laboratories use a scheduling service. This can be replaced or complemented with the calendars provided by the LMS.
- *Assessment tools:* The LMS provides this service to virtual and remote laboratories without having to program a code line. In

addition, it provides e-learning standards, such as IMS-QTI [28], that allow teachers to reuse questions and tests in different LMSs.

- *Communication tools:* The LMS provides this service to virtual and remote laboratories without having to program a code line.
- *e-learning content:* The LMS provides this service to virtual and remote laboratories without having to program a code line. In addition, it provides e-learning standards, such as SCORM [24], that allow teachers to reuse e-learning content in different LMSs.
- *File storage:* The LMS provides this service to virtual and remote laboratories without having to program a code line.
- *e-learning standards:* The LMSs support a set of e-learning standards, such as IMS-QTI and SCORM. This issue allows the reuse of e-learning material from one LMS to another without having to redo it once again.

As Table 3 summarizes, the studied virtual and remote laboratories benefited from the LMSs. Those laboratories integrated in the LMS automatically provide services that were not provided in the stand-alone version, such as communication tools, assessment tools, or e-learning content. Furthermore, some of the services provided by the LMS might be different from those provided by the remote laboratory. For instance, in the cases studied, the scheduling service on the LMS is a calendar, while the scheduling service provided by the remote laboratory is a queue. Both services fit, benefiting each other.

To define and promote a global architecture, the Global Online Laboratory Consortium (GOLC) (http://online-lab.org/) has been created. The GOLC is composed of universities spanning five continents, including the University of Technology Sydney, Massachusetts Institute of Technology, University of Stuttgart, Carinthia University of Applied Sciences, Spanish University for Distance Education, University of Deusto, Makere University, Polytechnic of Porto, and College of the North Atlantic Qatar.

Future challenges will focus on getting a better integration of virtual and remote laboratories in e-learning systems such as LMSs.

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