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Integration Modes Classification of Online Education Platforms with Remote, Virtual, and Hybrid Laboratories

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ABSTRACT Laboratory practices are very important resources in university teaching. In fact, laboratory work allows students to understand the reality they will face to, i.e. laboratories establish the nexus between teaching world and real world. From a technological point of view, Internet allows creating online laboratories (virtual, remote or hybrid), also known as WebLabs in case they are offered to students by web technology. In fact, distance learning (e-learning) is already a reality in modern universities for complete virtual education or as a complement to face-to-face education (blended-learning). For this, almost all educational institutions use online education platforms, known as Learning Management System (LMS) that allows managing, monitoring, controlling learning activities and courses. Over a period of time, online laboratories and LMSs have lived side by side independently. This work presents a classification of the integration modes that can be used to achieve the WebLab-LMS (Lab-LMS) symbiosis. To this end, authors have relied on the study of the relationships between online labs and LMS observed in the work of other authors and their own. The main actors involved in the integration of Lab-LMS have been identified along with their key needs and requirements. This approach allows the identification of the properties that should be satisfied in a high-level quality integration of an online laboratory. The proposed classification is based on three factors: (i) presence of communications between laboratory software used by the student and LMS; (ii) location of the laboratory software used by student with respect to the LMS; and (iii) use of e-learning standards. This work also analyzes which are the properties that could be achieved for each identified integration mode. Additionally, all identified integration modes have been tested guiding the integration of an online laboratory for tuning a controller to control the movement of a DC (Direct Current) Motor.

INDEX TERMS Educational technology, Engineering education, High Education, Learning Management System (LMS), Online Laboratories, Student experiments, Classification

I. INTRODUCTION

Practical work is very important in many higher education grades, especially in the majority of the courses of Engineering and applied science careers where students should acquire knowledge over and above the theory [1], [2]. Public and Private Institutions promote online training by Information Communication Technologies (ICT) in education [3], [4] which brings significant improvements in educational process [5], [6] and the benefits provided by the use of laboratories (Labs) [2], [7]-[10].

The use of ICTs and in particular the use of Internet has changed the way to perform practical work [11]. The steady progress of ICTs promotes the use of online laboratories, new type of laboratories where students could work via Internet [12], which are also known as WebLabs since in most cases students access them through a web browser. The use of online laboratories provide several advantages against to face-to-face laboratories [13]-[15], e.g. spatial and time slot availability, security to students but also to equipment against certain type of experiments, extension of the use of rare resources, accessibility, share with other institutions…

Students via online laboratories could interact with Real and/or Simulated systems [16]. The former is known as Remote Lab (RL) [17], however when the student works only with a simulated system is known as Virtual Lab (VL), and in a case where the student uses a real system and a simulation at the same time is known as Hybrid Lab (HL) [18]. For simplicity, the term VRL (Virtual Remote Lab) is also used to refer to any of the above-mentioned types of laboratories. Independently of the type of VRL, it is necessary the use of a software that allows interacting with real or/and simulated systems.

Fig. 1 presents a generic scenario for a VL and RL. On the one hand, the user of a VL should connect to a server and download laboratory's software, which is locally executed to interact with the simulation. It is important to remark that the simulation could be included in the previous downloaded software, or in other executed remotely. On the other hand, the RL, although looking similar as VL, at least from the user point of view, in practice, is more complex. First, users connect to a server and download the software. After that, they should execute it locally in order to interact with the real remote system through laboratory's server, which is the responsible for establishing and maintaining the connection between the real remote system and RL via Internet. In the simplest case, the laboratory's server could be the same that the users use to download the RL's software.

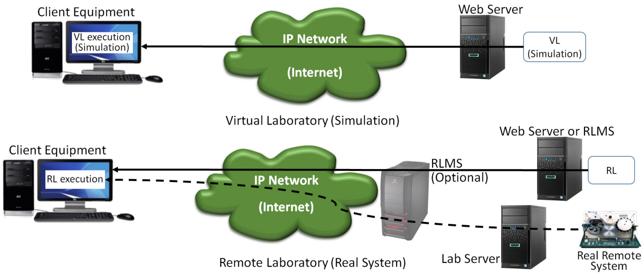

FIGURE 1. Generic scenarios of VL and RL

As discussed above, VRL have been given in engineering degrees to a greater extent than in other degrees. They have been presented in different modalities (VL [19], RL [20], HL [18]) but also implemented using multiple technologies.

Nevertheless, the biggest exposures of the use of ICTs in the high education are Virtual Learning Platform or Learning Management Systems (LMSs). Currently, the virtual teaching or e-learning has sense thanks to LMSs [21], [22]. They offer a website where students and lecturers could communicate, create, share and use learning resources, perform evaluations, find links to other external resources, inveterate external applications, etc. [23].

LMSs and online laboratories offer complementary services whose convergence is a tendency [24]. In the literature there are some works centered in integrating LMSs and VRLs [25], [26]. But, integration work has several interpretations i.e. someone could consider that integration is achieved by a link or by enclosing a laboratory in a LMS but others do not. In this work, the integration is understood as make somewhat to be part of a whole. This concept applied to online laboratories and LMSs implies that VRLs should become part of the LMS. This covers the integration caused between VRL's software, downloaded by the user, and the LMS used as learning platform, normally managed by teaching responsible. This work does not consider the specific platforms of online laboratories nor their corresponding required integration techniques. In spite of the greater complexity presented by the RL with respect to the VL (communications with real systems and possible existence of reservation systems, ...) the basic problems of integration between the program of the online laboratory that the student uses and the LMS are the same for VL and RL (VRL in the rest of the work).

There are different relevant actors involved in the creation and maintenance process, as well as, in the use of VRL, integrated in the LMS [27]. In particular there are five actors: (1) developers of the laboratories; (2) LMSs managers; (3) network communication experts; (4) teaching staff and (5) students. The relationship of each actor with the online laboratory is different so each one could understand the integration in a different way. In this way, this work identifies actors' specified requirements and makes an integration analysis of the online laboratories into LMSs. The proposed classification is based on the fulfillment of such requirements.

The rest of the paper is organized as follows. Section II details the requirements for each actor involved in VRLs. This section also presents the integration concept from each actor point of view. Section III enumerates the desired characteristics in quality Lab-LMS integration. In section IV, a classification of Lab-LMS integration modes based on compliance with previously identified requirements is presented. Section V performs an analysis of which requirements are satisfied in each integration mode. Section VI presents several technical implementation examples of the integration of an online laboratory for tuning a controller to control the movement of a DC (Direct Current) motor into a LMS using classification's integration modes (without student usage data). Finally, some conclusions are drawn in Section VII.

II. REQUIREMENTS

This section analyzes the requirements in order to guarantee laboratories integration into a LMS for actors in a university environment. As commented above, in [27] are identified five actors types; this work considers three types: (1) students; (2) teaching staff and (3) technicians that group the laboratory developers, the LMSs managers and the network communication experts.

A. STUDENTS

Nowadays, students use institutional LMS platform for learning activities via Internet. Undergraduate students use the institutional LMS to access to: theoretical contents that can study online or download; practical guidelines; communication facilities offered by the LMS such as forum, chats, email… to be in contact with their colleagues and teachers; self-assessment tools…. They use VRL as yet another resource of the learning services catalog with which should work along their career. In this sense, students could consider quality integration when they do not distinguish between the use of LMS's provided learning services and the laboratory itself, in other words, when they use VRL as another learning service offered by the LMS [28]. In a deeper analysis, they also perceive major integration if they can do the following activities: interact with other colleagues and tutors; check/validate the laboratory results and consult obtained grade. Another essential factor to be considered as an integration quality indicator is the capacity of customizing VRL execution. This allows adapting to user preferences and/or necessities e.g. displayed font size, language, the use of subtitles or sound volume. Under current legislation, this factor should be considered as essential as it provides accessibility to group of students with some kind of disability (e.g. language, vision, hearing…).

To sum up, the main requirements to consider a quality integration Lab-LMS, from students point of view, are the followings:

- VRL accessibility from the LMS.
- Identical or similar appearance of VRL as LMS.
- Customization of LMS operation to allow student with disabilities to VRL access.
- Communication capacity among colleagues and tutors.
- To have a feedback of the VRL in the LMS (consult the performed work, obtained results and final mark).

B. TEACHING STAFF

Teaching staff assesses other factors for quantifying the quality of the Lab-LMS integration. As well as those mentioned in the previous section, one of the most important is the possibility of providing identification for those students that access to VRL. This requirement is essential to tutors because it enables them to have knowledge about the work performed by students individually, but, it also offers the possibility of executing a customized VRL for each student. In other words, it enables tutors to present customized practices. Other factors also considered are: the facility to integrate a new online laboratory in the virtual learning workspace; how much related are VRLs with the rest of resources offered by LMS itself; the ease of evaluating student performed work and the final mark of each student automatically, among others.

In short, the main characteristics to be considered in order to have a quality integration of Lab-LMS from teaching staff point of view are the followings:

- Students' identification in the VRL.
- Customized execution of the VRL's practical works. This is based on students' identification.
- Facility to integrate a new online laboratory in the virtual learning workspace.
- Capacity to relate the VRL with other resources of the LMS in order to stablish learning paths.
- Automatic evaluation in the VRL.
- Accessibility to: completed works, obtained results and final marks for each student.

C. TECHNICIANS

As commented above Technicians group the rest of participants in the development, use and maintenance of a VRL integrated in a LMS (i.e. software developers, content designers, network and communication experts and LSM managers). This aggrupation is due to all of them having common interests according to quality perception, but they also have common necessities related to Lab-LMS integration.

Authors want to underline that these technicians understand integration from involved technologies point of view. In this sense, as stated in [29], there are several technological approaches for implementing VRL. Prestigious universities and educational institutions around the world promote and share their own online laboratories, developed in National and International networks such as iLab Project [30] of MIT (Massachusetts Institute of Technology), VISIR (Virtual Instrument Systems In Reality) Open Lab Platform [31], LiLa (Library of Labs) [32], UNILabs (University Network of Interactive Labs) [33], Lab2go [34], ISILab (Internet Shared Instrumentation Laboratory) [35], NetLab [36] or DCL (Distributed Control Lab) [37]. Even, there are international consortiums like GOLC (Global Online Laboratory Consortium) [38], which encourage the development, share and integration of laboratories available remotely for education purposes. Additionally there are organizations that have defined initiatives, networks, platforms, architectures and interfaces and put all of them available to other organisms in order to grant them access to experiments, create VRLs or make possible connections to physical remote devices [39], [40]. In fact, the term RLMS (Remote Laboratory Management System) refers to a system that manages remote laboratories as well as it also provides authentication, authorization and user management and registration support, as well as, APIs to develop new laboratories. Examples of including RLMSs are: ILab, Labshare Sahara and WebLab-Deusto.

The support of previous listed services implies a complex technological scheme on a VRL integrated with a LMS, especially with remote laboratories or simulated laboratories remotely managed by a RMLS or by an external LMS repository. Fig. 2 shows a scheme with the involved communications which could take place when a laboratory is integrated with a LMS. Three main situations have been taken into account according to the location of the VRL's software: (1) in the LMS; (2) in a RLMS or in external repository, and, (3) in the same server as real remote laboratory.

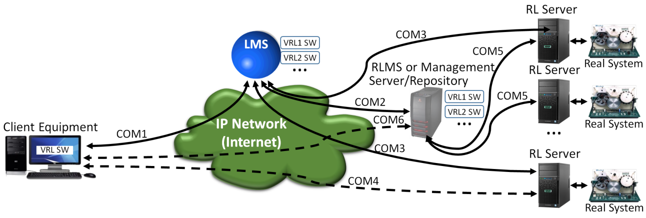

Figure 2. Communication scheme in Lab-LMS integration

Communications between the software of the VRL, used by user, and the LMS is required in all situations. This is shown as COM1 communication type in Fig.2. COM2 communication type takes place between LMSs and RLMS or online laboratory's management systems. These latter could act as final systems but also as intermediate systems between the LMS and server of the RL in remote laboratories. COM3 communication type is between the LMS and the server of RL. COM4 only makes sense in RL and it represents the communication between user VRL and server of RL. COM5 considers the communication between intermediate systems and RL servers. Finally, COM6 makes sense between the software of VRL downloaded by user and intermediated systems in which LMS is not involved.

In the literature, there are several works centered in detailing the communication technologies referred to a particular architecture, repository of RLMS [35], [37]. Nevertheless, due to the particularities of each system, the great quantity of technologies and the heterogeneity, the integration analysis of this work focuses exclusively in the interaction between the software of VRL (for the user) and the LMS as well as in the use of standards to access to their content.

Picking up on technicians' perception of integration quality, there is no unanimity in which one is the most appropriate technology, because each one invests in that which provokes the minor development and maintenance cost. Thus, this selection criterion is not impartial because technicians are influenced by the systems and technologies used in organism or working place. However, these actors agree with the use of standard technologies for developing software, communications to allow collaboration and development among systems, interoperability, and maintenance and reuse facilities. Other factor to be considered is the avoidance of changing the rules of routers or firewall to access to new resources, because this could generate security problems that should be considered.

Taking this into account, the only two requirements provided by technicians to achieve quality integration between VRL and LMS is the following:

- The use of the standards for implementing, sharing, making compatible and using laboratories at minimal cost.
- The avoidance of models that requires accessibility to LMS's external servers.

III. DESIRED PROPERTIES IN LAB-LMS INTEGRATION

The integration Lab-LMS implies an extra effort in the development of an online laboratory. For this reason it is necessary to clarify which are the benefits/advantages of this integration that make this effort worthwhile.

Before listing the properties of the online integrated laboratory, it is recommendable to take in mind these ideas:

- The LMS is key technological element in university teaching. Students use it for managing resources and required tools to perform learning activities. The teaching staff uses it to perform teaching activities.
- An online laboratory implies the necessity of VRL, a software program that, at least, presents a Graphical User Interface (GUI) used by user to interact with a real system or simulation in the case of VL.
- VRL is a learning content that from pedagogic point of view should not be presented in isolation. VRL should be coupled with other resources that provide it support and which allow improving the learning effectiveness. For example, a list or technical requirements to execute the VRL, an user guide, information about the objectives and/or competences, theory contents, practical guides, evaluation tests…

The main benefits that meet online laboratories integrated to LMS are the following ones:

1. **Identification of students**. LMSs platforms perform users' identification normally by user-password system, which offers security in different settings. The fact of integrating the laboratory as any other resource of LMS implies that the user identification is performed by LMS, freeing the laboratory of this function. The users of the laboratory only can use it if they have previously introduced their credentials. The online laboratory could be or not within the LMS. If it is in an external location, it is required to encrypt the information interchanged between laboratory and LMS. The procedure is as follows: first the online laboratory collects user's credentials; after, it stablishes a communication with the LMS to send them. Finally, the LMS performs the user identification.
2. **Execution under known environment**. Students and teaching staff are used to use any resource of the LMS. Having online laboratory integrated in the LMS implies that users can use it as any other LMS resource.
3. **To present online laboratory close to other resource of LMS.** As commented above, there are several studies in the literature which promote to present online laboratories jointly with other learning resources avoiding presenting them in isolation [41], [42]. Every LMS platform provides resources to implement learning objects that could be very useful to the execution of an online laboratory. In such way, an online laboratory could be presented jointly with the following elements:

a. *Content resources*. They are files with platform proprietary format or any other standard format such as PDF or SCORM (Shared Content Object Reference Model) [43]. These resources are very useful. Hereafter there are presented some examples: (i) the inclusion of explanations about technical or training requirements to access to online laboratory; (ii) the ad of final remarks about objectives, working principle and/or software; (iii) the incorporation of required theoretical concepts and practical user guides, which could be used even by non-technical users, despite the great effort involved.
b. *Evaluation tools*. They are evaluation tests that allow checking the knowledge before and after performing the laboratory. These tools are very useful to check if the laboratory helps or not to improve students' knowledge.
c. *Communication tools*. They allow students and teaching staff to stablish communication. For instance, students and tutors to online tutoring or communication between students to coordinate the performance of the laboratory. There are two types of communication tools: (i) asynchronous that does not require coincidence in time between communication's participants e.g. email; (ii) synchronous that requires the coincidence in time between communication participants e.g. chats, video-conferences or VoIP.
d. *Other multimedia tools*. For example Videos, podcasts that could be used with same purposes as content resources
e. *Interviews and feedback tools*. They make possible to obtain the students opinion before, during and after the execution of the learning proposal.
f. *Content editing tools*. They offer students the possibility to add information about the performed work. These tools can vary from one platform to other e.g. text, graphics, wiki…

4. **Establishment of learning paths.** Previous commented resources that can be associated with an online laboratory, could be presented isolated with each other's. But on the opposite, teaching staff can define learning plan or path by linking them. Learning sequences could be self-regulated by the student himself without restrictions [44]. They also can be defined using the LMSs provided sequencing control specific facilities. In this case, it needs to configure the access control of each resource in the sequence. The access can be controlled by timing, use and/or the overcoming of other resources. When the online laboratory is located in the LMS, it can be used and controlled as any other resource in the sequence. If communication possibility between VRL-LMS is missing, the learning sequence finishes in the access of the VRL (Pre-VRL learning sequences). On the other side, if VRL-LMS communicate with each other, the learning sequences can include the control of the state and passing of each student (Post-VRL learning sequences).
5. **Training adapted to students**. When the online laboratory can communicate with the LMS to obtain the identifications of logged students, then it could also be adapted to them. This enables performing customized experiments.
6. **Customized online laboratory execution**. When the online laboratory can communicate with the LMS, it could also store user preferences as language, subtitles, volume, execution speed… This allows executing the VRL according to users' tastes and needs.
7. **The follow-up of the work produced by students**. This characteristic requires Lab-LMS communication facilities that allow VRL to send information related to its use and the overcoming of fixed experiments. They also allow LMS to register and present the received information properly. In this case, this information is immediately available to students and teaching staff.
8. **The storage of marks and results**. This characteristic is feasible only if lab performs an automated assessment [45] and the LMS provides facilities to monitor performed work. This implies storage of the using and overcoming results which can be exported from LMS in order to be imported during the grade's calculation process.
9. **The use of content and communication standards**. As stated in [46] the use of standards provides facilities to all actors involved in the education process. For instance, the use of learning standards to create a laboratory allows its reuse in other heterogeneous systems.
10. **The Lab-LMS communication**. The data interchange between laboratory and LMS contributes towards improving the students and teaching staff experience. This is mandatory to achieve other characteristics commented above.

Today, students can access to online laboratories from a great variability of devices such as PCs, laptops, tablets, and even intelligent mobile phones. Hence, it is desirable that the technology used for developing the VRL being in line with the responsive design principles. In this manner, the type of device used by students to access to the online laboratory does not condition the access. This does not mean that all laboratories can be used in the same way from all devices; it will depend on the interface designed for each laboratory [47], the laboratory itself and the characteristics of the device used by the student. But this accessibility is independent of the classification's Lab-LMS integration modes, for this reason it has not been included in the desired properties.

IV. PROPOSED LAB-LMS INTEGRATION CLASSIFICATION

The proposed classification is based on the study of integrations performed by other works and authors personal experience. The followed criteria for the classification have been the use of standards, the location of VRL with respect to the LMS and the whether or not there are communications between VRL and LMS. The communication is understood as the data interchange between the VRL's software and the Data Base that is managed by the LMS. In fact, the existence or not of the communication between VRL and LMS defines a category of the classification's integration modes: Advanced if there is and Basic if there is not communication. Hence, the other two criteria, the use of standards and the location of the VRL with respect to the LMS, have been taken into account for identifying the integration modes in each category/level.

Before describing the different possibilities of Lab-LMS integration, Fig. 3 shows a scenario in which there is no Lab-LMS integration (NIM: No Integration Mode), Although the laboratory and the LMS are available on the web, there is no relationship between them. Not even a link of one to the other neither communications. There are many examples of works based on this scheme [18]-[18], [31].

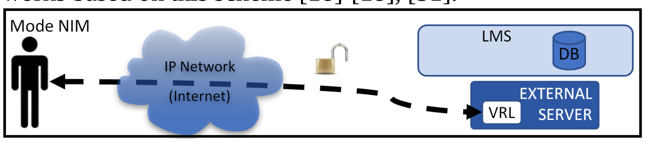

Figure 3. Scheme of scenery without Lab-LMS integration

Following subsections detail the identified integration modes for each classification integration level (without communications or with communications).

A. INTEGRATION MODES WITHOUT LAB-LMS COMMUNICATIONS

In the integration modes that are going to be shown in this subsection, no data exchange is established between the VRL and the Data Base of the LMS.

MIMIMAL INTEGRATION MODES (MIM)

In this integration mode the VRL is located in other external placement than the LMS is. Apparently, the unique relation between laboratory and LMS is a link. Hence, the VRL takes part of the subject's virtual space through a link located in the LMS. The link can be a native link element of the LMS (Fig. 4, integration mode MIM1) or it could be included in an element or object (Obj.) located in the LMS (Fig. 5, integration mode MIM2), in the latter case, Obj. may be a standard content object supported by LMS or a native LMS resource (it could even need an LMS plugin to work).

The orange boxes with R letter represent other LMS's resources with which the link (in MIM1) or object containing a link (in MIM2) could be related. [26], [28] and [46] are some examples of work based in these modes.

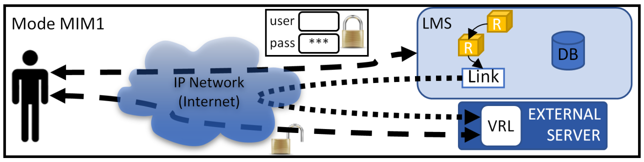

Figure 4. Scheme of the MIM1 Lab-LMS integration mode

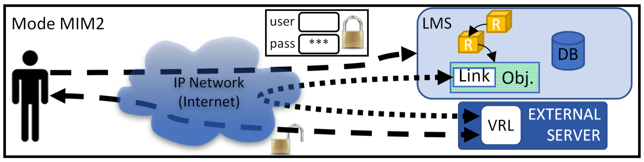

Figure 5. Scheme of the MIM2 Lab-LMS integration mode

BASIC INTEGRATION MODES (BIM)

In these integration modes the VRL is located in the LMS but they do not communicate with each other. There are two options; the laboratory could be added in the LMS thanks to a LMS specific plugin (Fig. 6, BIM1) or it could be included embedded in an LMS supported object (Obj.) which could be based on a LMS-native format or in any learning standard such as SCORM (Fig. 7, BIM2).

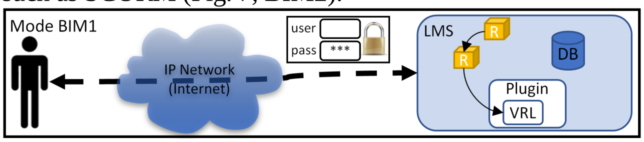

Figure 6. Scheme of the BIM1 Lab-LMS integration mode

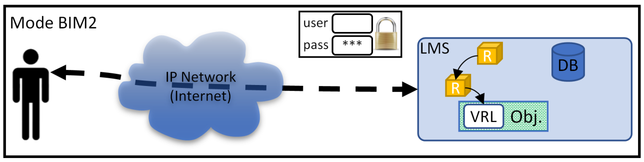

Figure 7. Scheme of the BIM2 Lab-LMS integration mode

[46] and [49] are some examples of works based in BIM modes.

B. INTEGRATION MODES WITH LAB-LMS COMMUNICATIONS

In the advanced integration, communication between laboratory and LMS is able. Besides, the VRL could be located in the LMS platform or in other external platform. This latter requires a LMS object to support external accessibility. Advanced integration can be achieved by different modes; this work identifies four, which are detailed below.

AIM1. The VRL is in a location external to the LMS, however in the LMS a specific LMS plugin is being used to create objects (Obj.) that embed the VRL. Additionally, the VRL can interact with the LMS database (DB) allowing bidirectional communications based on the plugin specific development. Fig. 8 shows a diagram of this integration mode that can be found in several works [42], [50], [51].

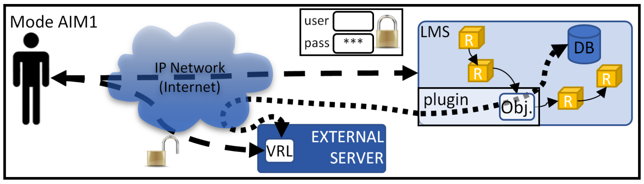

Figure 8. Scheme of the AIM1 Lab-LMS integration mode

AIM2. The VRL is located in the LMS and the communications are stablished with a VRL type specific plugin. This software must be installed in the LMS platform to allow it to manage the VRL as any other resource. For example, the plugin of [53] lets add any Java or JavaScript (JS) application created with Easy Java (script) Simulations (EJS) [54] to Moodle [55], using these tools have been performed several labs [56]-[58]. Fig. 9 presents the scenario for this integration mode.

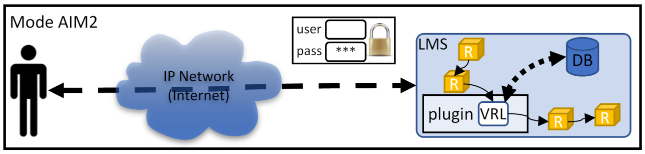

Figure 9. Scheme of the AIM2 Lab-LMS integration mode

AIM3. The VRL is located in other server than the LMS is. The communication between them is possible only if the LMS supports external interoperability standards such as Learning Tool Interoperability (LTI) [56] [60] or experience API (xAPI) [61]. As Fig. 10 shows, the LMS manages a resource (Obj.), compliant to an external interoperability standard, which allows setting communications and launching the laboratory from the LMS platform. First, students access to LMS an open this resource (Obj.), and, later, the LMS starts the communication in a standard way with the external server to launch the VRL which will be accessible to students.

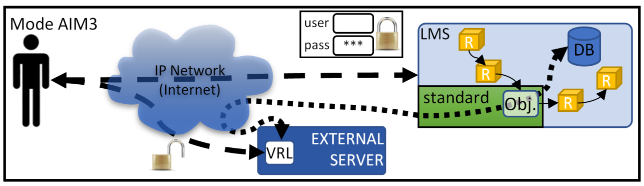

Figure 10. Scheme of the AIM3 Lab-LMS integration mode

There are several works based on the AIM3 mode [62]-[64].

AIM4. The VRL is located in the LMS and it has been developed using e-learning standards as SCORM. In this case, the LMS must support such e-learning standard thanks to which it stablishes communications and stores data related with the work performed by students (i.e. the score) in the Data Base of the LMS. Fig. 11 illustrates the scheme of this integration mode.

Some examples of this integration mode, based on SCORM standard, can be found [27], [65], [66].

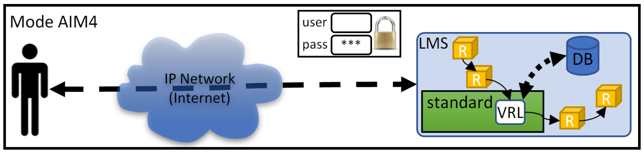

Figure 11. Scheme of the AIM4 Lab-LMS integration mode

V. ANALYSIS OF THE PROPOSED INTEGRATION MODES

This section performs a deep analysis of which properties and requirements are supported for each integration mode (see Table I). The characteristics supported for each integration level is incremental. Note, the fact that one laboratory belonging to a determined mode guarantees the support of this mode's properties. Nevertheless, the satisfaction of other modes properties cannot be guaranteed.

Hence, in **NIM** as the integration is missing, the fulfillment of none can be guaranteed. Consequently, the support of any of identified actors' requirements neither.

TABLE I. Properties of the Lab-LMS Integration Modes

Properties	Integration Modes			
	NIM	MIM	BIM	AIM
1. Identification	No	No[a]	Yes	Yes
2. Environment	No	Yes	Yes	Yes
3. Other LMS Resources	No	Yes	Yes	Yes
4. Learning Paths (LMS)	No	Pre-Lab	Pre-Lab	Pre/Post Lab
5. Customized Experiments	No[b]	No[b]	No[b]	Yes[c]
6. Customized Running	No[b]	No[b]	No[b]	Yes[c]
7. Learning Tracing (LMS)	No	No	No	Yes[c]
8. Final marks (LMS)	No	No	No	Yes[c]
9. Standard	No	MIM2	BIM2	Optional
10. VRL-LMS Comms	No	No	No	Yes
11.LMS-Ext Comms	No	Yes	No	AIM1,3

[a]LMS identifies users logging to obtain the VRL link but does not identify users who truly use the laboratory.
[b]It is possible when the VRL software identifies the user by itself and it is programmed to achieve this characteristic using this identification.
[c]It is possible when the VRL software is programmed to achieve this characteristic.

The **MIM** modes assure the performance of three of the properties identified in section II (see Table I). As commented above, the VRL is integrated in LMS by a link. Since this link is located on the LMS platform, it can be presented close to other LMS resources with which VRL can be related. Event though, if the LMS supports the resource sequencing, the learning paths definition is enabled, but only until the link (pre-Lab). Hence, in this integration mode they could be stabilized only till laboratory access but not during or after its execution. This is because in MIM modes the communication between laboratory and LMS is not supported. Besides, by default these modes do not support the customized laboratory execution, if needed; this must be performed by VRL. The results of the laboratory's execution are lost from one time to the next. Notwithstanding, the VRL could not use the user identification resource, because the LMS uses it only for giving or not the access of the laboratory link to students. Nevertheless, if students get this link without accessing to the LMS, the VRL execution will be the same. The LMS-external server communications could suppose network problems (firewall and routers reconfigurations).

BIM modes support the same properties as MIM modes. The only difference between MIM and BIM is that the former integrates the VRL with a link, and the latter include the VRL itself. The appearance for students in both cases is the same, but the security access does not. Hence, BIM modes offer more secure access to VRL, due to only previously logged users can use the online laboratory.

Finally, all **Advanced Integration Modes** support previous integration modes properties but they also give support to the Lab-LMS communication. This enables the establishment of full learning paths, i.e. pre and post VRL. With communication facilities, the LMS can store the student's laboratory current overcoming level. Hence, according to this level, it is possible to define post-VRL learning paths. The Lab-LMS communication provides facilities to develop adapted training of the students; customized online laboratory executions; following-up activities as well as marks and results storage. Furthermore, the VRL must be programed to perform these functionalities as well as the communications. Finally, the existence of LMS-external server communications in AIM1 and AIM3 modes could suppose network problems (network devices reconfigurations).

The work cost in time of the staff that implements the integration of the VRL-LMS increases in each integration mode identified in the proposed classification. For this reason, if it is the first time that staff integrates VRL-LMS should be start by minimal integration models and as he/she progresses could try achieve integration in advance modes. Furthermore, it is important to remark that those integration modes that make use of LMS's plugins can be much more complex. Plugins are software code that only can be used in a particular type of LMS and with a specific VRL. They cannot be used in LMSs they were not conceived for, nor with VRLs were they not considered in their creation. For this reason, the use of integration modes with plugin is only recommended if such plugins are available and compatible with the VRL to be used. If the plugin is not available, it is necessary to develop and this is very difficult.

VI. CASE STUDY: A LAB-LMS INTEGRATION IN THE PROPOSED MODES

This section presents technical implementations examples of an online lab that could be used as guidelines for achieving a Lab-LMS integration in the modes identified in the proposed classification. Not all of these examples have been presented to students (there are no usage data). In particular, the goal of the selected laboratory is the control of the movement (angular position/ velocity) of a DC Motor by the PID (Proportional, Integral Derivative) controller tuning, very useful to engineering degrees students. The dynamic of such Motor, which represents the variation of the angular position/velocity according to voltage, has been defined as a transfer function. Additionally, this online laboratory is settled for each student due to the transfer function of the DC motor's behavior varies according to him/her ID credentials. It has been developed with JS technology in EJsS [65]. Fig. 12 shows the GUI of the software used by the students. Authors have used the UJA institutional LMS (ILIAS) and Moodle to integrate above commented online laboratory.

In order to not be exhaustive, in those integration modes that present the same properties, only one mode is detailed (MIM1/MIM2 and BIM1/BIM2). Additionally, as AIM1 requires a concrete plugin which is not available, and which implementation implies a great cost is neither detailed.

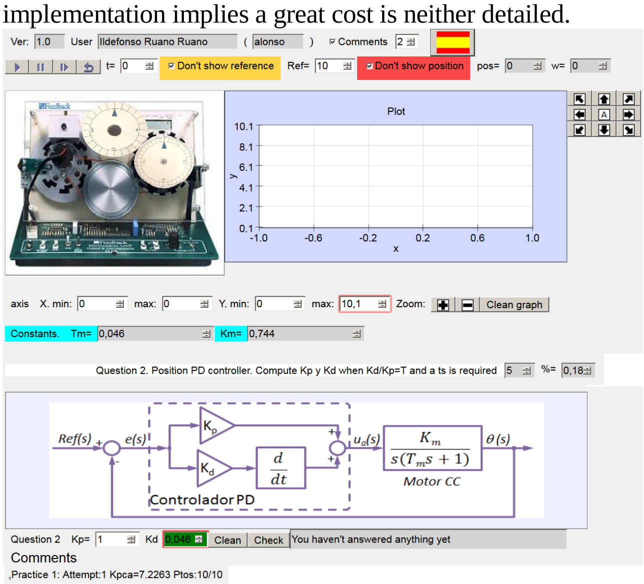

Figure 12. VRL software GUI of the PID DC Motor

NIM. The institutional LMS of UJA is ILIAS and it has been used for achieving NIM integration mode. The developed VRL software has been located in a public access web server[1].

EJS allows exporting designed VRL in a compressed file that includes a folder structure and a web page which embeds the JS of the laboratory. This integration mode only requires decompressing this file and uploading the resulting ones to the public access web server. The teaching staff is the responsible to pass students the link of the online laboratory. The VRL includes ID field that in this case must be filled by the student before performing the customized experiments.

MIM1. In this integration mode, the tutor should have created a web link resource in the LMS course's virtual space. This link is configured with the URL of the VRL that could be the same which was used with NIM[1].

[1] https://weblab.ujaen.es/access/NIM-MIM/PID2018js.xhtml

UJA students, after logging to course's virtual space in LMS, know the link of the virtual laboratory in a folder. In this folder other laboratory's related resources that allow configuring pre-lab learning paths have been also included. In this case, as communication between laboratory and ILIAS platform is missing, the ID field must be filled by the student before performing the customized experiments.

BIM2. In this integration mode example, SCORM e-learning standard has been used. The VRL is the same as the one used in previous integration modes. In concrete, the used SCORM structure is formed by a unique webpage (SCO) that contains the JavaScript function with the VRL. The structure of this SCORM packages has been compressed to a zip file, which has been uploaded in ILIAS's folder. As previous example, this folder includes resources for pre-lab learning paths.

AIM2. The UNILabs website [32], offered by UNED, has been used for achieving this integration mode. UNILabs is an enriched Moodle LMS with a set of plugins developed specifically to achieve the integration with virtual and remote laboratories [56], [57]. Among these plugins there is the EJSApp, which allows adding Java or JavaScript developed by EJsS in a Moodle's course [53]. Hence, a new EJSApp activity has been created. In its configuration page, several fields need to be filled, including those ones that allow importing the compressed file of the JS laboratory, previously exported from EJsS, variables customization, registration of user followed actions in the laboratory and its final mark. Variables customization allows offering automatically different experiment to each student without the requirement of a previous identification.

AIM3.This is based on LTI standard where the ILIAS, UJA's institutional LMS platform, acts as consumer and launches an external tool (in this case, the DC motor control online laboratory) located in a tool server (the same external server that used in NIM and MIN integration modes). Hence, following LTI tool Provider library PHP [67] and LTI Sample Tool Provider PHP [68] authors have been enriched the VRL as a tool provided by the tool server, a Linux system in which an Apache server with PHP and MySQL is installed. Besides, In ILIAS a new LTI element, configured with the URL and other properties of the LTI tool provider, has been added. Fig.13 shows the action's sequence: (1) The student opens the LMS object within LTI external content; (2) ILIAS stablishes a communication with the tool server (weblab.ujan.es). In fact, in this communication ILIAS send data related to student's session in which the identification information is included. (3) Student executes the VRL, as a tool provided by the server. Thanks to ILIAS facilitated data, the laboratory can perform a customized execution. Finally, (4) the online laboratory sends the final mark to ILIAS allowing it to act accordingly.

AIM4. This example uses SCORM e-learning standard and the communication possibilities. Those LMSs that support SCORM are obligated to support communication between their SCO, following the SCORM RTE communication standard, [69] and managing and maintaining a SCORM model data base. Initial JS of the laboratory has been enriched with *uja_scorm_rte.js* in order to maximize the use of communications in the SCORM data model [66]. This has been done in EJsS and, after, it has been exported to a ZIP file that contains the SCORM package compressed. This package has been modified to obtain a 4-page SCORM module. In this structure there are resources associates to the laboratory, which is embedded in the SCORM-page 3.

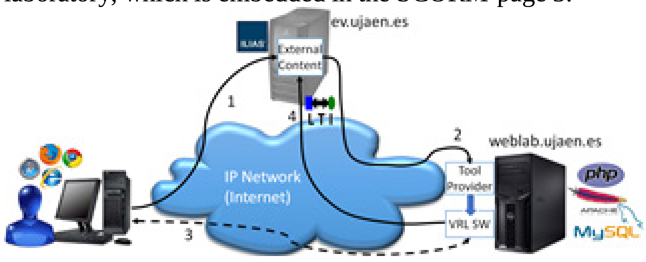

Figure 13. Action's sequence of Advanced Integration Mode based on LTI

Finally, after compressing the new structure, the resulting file has been uploaded in ILIAS folder jointly with other resources used to create a learning path (see Fig. 14). The result of this example is an interactive VRL that, once obtained the student's credentials from ILIAS, can storage even partial results in the LMS. The unique restriction of this integration example is that the data interchange must be based to SCORM model. As far as authors know, this standard does not offer facilities to store data in other formats such as graphics.

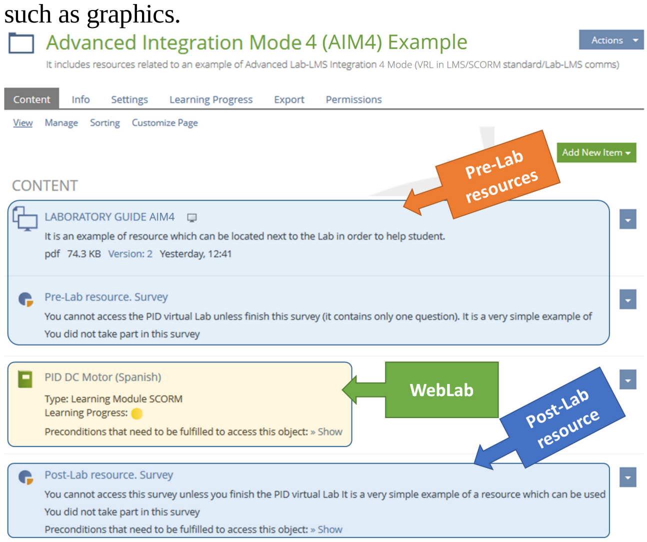

Figure 14. LMS folder including the Lab and related resources.

The MIM1, BIM2, AIM2, AIM3 and AIM4 integrations modes examples are available through the ILIAS institutional platform of the UJA[2].

[2] https://dv.ujaen.es/goto_docencia_fold_900099.html

Table II summarizes the characteristics of the different integration modes used to integrate DC motor control online laboratory.

TABLE II. Properties of the specific examples of the PID control Lab, fulfilling the Lab-LMS integration modes

Properties	Integration Mode					
	NIM	MIM1	BIM2	AIM2	AIM3	AIM4
1. Identification	No	No[a]	Yes	Yes	Yes	Yes
2. Environment	No	Yes	Yes	Yes	Yes	Yes
3. Other LMS Resources	No	Yes	Yes	Yes	Yes	Yes
4. Learning Paths (LMS)	No	Pre-Lab	Pre-Lab	Pre/Post Lab	Pre/Post Lab	Pre/Post Lab
5. Customized Experiments	Yes[b]	Yes[b]	Yes[b]	Yes	Yes	Yes
6. Customized Running	No	No	No	No	No	Yes
7. Learning Tracing (LMS)	No	No	No	Yes	No	Yes
8. Final mark (LMS)	No	No	No	Yes	Yes	Yes
9. Standard	No	No	SCORM	No	LTI	SCORM
10. VRL-LMS Comms	No	No	Yes[c]	Yes	Yes	Yes
11.LMS-Ext. Comms	No	Yes	No	No	Yes	No

[a]LMS identifies users logging to obtain the VRL link but does not identify users who truly use the laboratory.
[b]The VRL software shows an editable field where students identify themselves. This identification is used by VRL to customize the DC motor constants.
[c]There are minimal communications required by SCORM to launch/close the web page that integrate the SCORM package but these data interchanges are not related to the lab.

VII. CONCLUSIONS

The LMSs and online laboratories offer complementary services whose convergence is a tendency that offers several advantages. This work emphasizes mainly in the following three ones:

1. Authors identified the main actors which are closely related with the design, development, use and maintenance of the online laboratories integrated in LMSs. The requirements and necessities which depend on the Lab-LMS integration have been also identified. They allow extract two main conclusions: (i) identification of the properties to be satisfied in the high quality integration of the online laboratory in a LMS; and (ii) which are the most beneficed actors of this integration: students and teaching staff.
2. The proposed classification is based of several integration modes to integrate an online laboratory with a LMS. This analysis has allowed obtaining the generic properties which adds each integration mode and knowing when they cover the identified necessities.
3. A case study based on VRL basic which includes de tuning of a controller to manage the movement of a CC motor. In fact, this laboratory has been integrated in a LMS following the classification proposed some of the integration modes. The achieved properties in every integration mode have been checked. Besides, it has been also demonstrated that the cost increases according to the order in which integration modes have been presented (being MIM the less cost models and AIM modes the higher cost models). Finally, the cost difference among AIM modes depends on the knowhow and experience with the used technology that the staff responsible of the implementation has.

It is advisable that those people whose tries the integration of an online laboratory with its LMS, analyzes the different integration modes proposed by the classification. It is recommendable follow the proposed order, due to the required complexity increases from MIM to AIM (avoiding those modes that require the use of plugins when there are not available for the LMS and the VRL to be integrated to).
Authors conclude that AIM integration modes, which allow the communication between online laboratories and LMS, offer a major quantity of quality properties. But, they require edit the original VRL and a great effort and development time to achieve this integration. Hence, advances integration modes at least for technicians are more complex than MIM integration modes. Nevertheless, authors consider AIM integration modes the best solution due to the offer the major quantity of quality properties to students and teaching staff. However, those technicians without knowhow nor experience to address AIM integrations, they should start with MIM integration modes.
As future line, the authors intend to carry out the evaluation of every integration mode of the proposed case study by students and teaching staff.

APPENDIX A. ABBREVIATIONS & ACRONYMS

AIM: Advanced Integration Mode
API: Application Program interface
BIM: Basic Integration Mode
Comms: Communications (in Table I and II)
DB: Data Base (in some figures)
DCL: Distributed Control Lab
EjsS: Easy Java/JavaScript Simulations
GOLC: Global Online Laboratory Consortium
GUI: Graphical User interface
HL: Hybrid laboratory
ICT: Information Communication Technologies
ID: Identification
ILIAS: Integriertes Lern-, Informations- und Arbeitskooperations-System (German for “Integrated Learning, Information and Work Cooperation System”)
ISILab: Internet Shared Instrumentation Laboratory
JS: JavaScript
Lab: Laboratory
LiLa: Library of Labs
LMS: Learning Management System
LTI: Learning Tool Interoperability
MIT: Massachusetts institute of Technology

MIM: Minimal Integration Mode
NIM: No Integration Mode
Obj.: Object (in some figures)
PDF: Portable Document Format
PHP: Hypertext Pre-processor
PID: Proportional Integral Derivative
R: Resource (in some figures)
RL: Remote Laboratory
RLMS: Remote Laboratory Management System
SCORM: Shared Content Object Reference Model
UJA: University of Jaén
UNILabs: University Network of Interactive Labs
URL: Uniform resource Locator
VISIR: Virtual Instrument Systems In Reality
VL: Virtual Laboratory
VoIP: Voice over Internet Protocol
VRL: Virtual and/or Remote Laboratory
WebLab: Web Laboratory
xAPI: Experience API

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