

# Models of Remote Laboratories and Collaborative Roles for Learning Environments

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**Abstract**— One of the main concerns in development of remote laboratories in academic settings has been the lack of standardization in terms of technology, processes, operation and aspects related to their integration with formal educational environments.

Remote laboratories are used in a variety of educational situations, for instance, when the equipment is not available in the physical laboratory, when physically laboratory space available is not sufficient to either set up the experiments or permit access to all students in the course, or when the teacher wants to provide laboratory experiences to students taking courses via distance education. Centers have been forming platforms that provide remote access to a collection of physical experiments that provide alternatives to educational institutions to reduce budgets of not only equipment purchases but also in other expenses such as: people, space, maintenance, and electricity consumption.

This paper explains the different types of laboratories and hybrid combinations, and presents Unified Modeling Language (UML) models for remote laboratories in the educational context incorporating learning environments, as well as a model of the user roles that defines user interactions with remote laboratories.

**Keywords**—*Collaboration, Models, Remote Laboratories, STEM Education, UML, Virtual Laboratories.*

## I. INTRODUCTION

Remote laboratories have been under development for more than 15 years. In 2002 Hamza et al [1] evaluated alternatives to physical laboratories used in engineering education, including simulation and remote laboratories. Since then, research laboratories and companies have improved the quality of the experience with remote laboratories, by increasing infrastructure technology available to build remote experiments. The bandwidth, processing capacity, video codification algorithms, new and more versatile controllers and hardware devices [2], and repositories [3] and portals to access the remote experiments are some of the elements that have been improved drastically in a relatively short period of time.

Providing Laboratory as a service (LaaS) [4,5] has been proposed as an approach which companies, research and laboratories centers will start to use, providing services of remote laboratories, accordingly to the demands of the user. But without standards and models for implementation of remote laboratories to guarantee of minimum levels of quality, reliability, safety, security, etc. then these services will be implemented without interoperability considerations.

Within the educational context, there is an important demand for these types of services. Remote laboratories play an important role in academic areas like Physics, Chemistry, Biology, Medicine, and Engineering. There are two main elements in the educational context that remote laboratories providers need to take in account. A first consideration is the roles of the users: the users can be teachers, administrators or students, every one of them will use the services in a different way. Secondly, the integration and interoperability are important when it is desired to combine and integrate these services with educational platforms. Due to the need of integration, contextualization and interoperability, IEEE Education Society has formed the IEEE-SA P1876 Working Group (Standard on Networked Smart Learning Objects for Online Laboratories) [6] to develop the standard that will define the architectures and implementation processes.

This paper focuses on proposing models for laboratory classification and roles of collaboration using remote laboratories that can be useful in understanding how the standards works, and also provide a documentation of reference for developers and users in the academic context.

## II. REMOTE LABORATORIES BACKGROUND

Remote laboratories are part of a bigger category called online laboratories, which includes also virtual laboratories. Remote laboratories use real physical laboratories which are capable of being accessed through a network. The instruments can be accessed, monitored and controlled at distance. Instead virtual laboratories are basically simulations which mimic the behaviors of real laboratory artifacts. The results of the

experimentation process should be similar to those obtained in a real laboratory, but results are mostly based on calculations and mathematical formulas. Most advanced virtual laboratories include in the data processing information of previous experimentations made in real laboratories, that creates a more realistic and reliability environment that takes into account behavior of real components.

Figure 1 illustrates the interface for an existent remote laboratory at North American Network of Science Labs Online (NANSLO) [7] with the capacity of using 4 cameras each having 6 pre-configured positions to get a sense of the environment, as well as focus on the display of each instrument. Notice also the controls on the interface for remote adjustments of variables such as: panning and zooming the cameras and setting current and voltage. This interface additionally has on the top left an indicator showing temperature of the equipment. In this particular experiment a heater must be turned on and the instruments must reach certain temperature for the instrumentation to operate optimally. A pop-up interface allows the user to request access to viewing the instruments and one student to control the instrumentation.

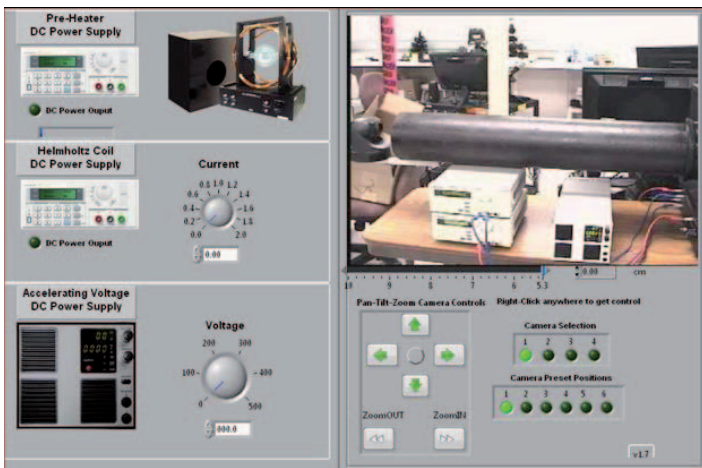


Figure 1. Remote laboratory from Consortium for healthcare Education Online [7].

### III. PROPOSED UML MODEL FOR DIFFERENT TYPES OF REMOTE LABS

Physical laboratories are commonly part of government institutions, companies and/or educational institutions. There exist two types of physical laboratories, on site traditional laboratories, sometimes called real laboratories, constructed in a fixed physical place, and mobile laboratories, which are hosted on vehicles, such as boats, airplanes, cars (for climate monitoring, surface sensing as example). The mobile type of laboratories use additional important variables, such as the current geographical position and time stamp as part of each experimental data result. Figure 2 presents a classification of remote laboratories [3], based on the location of the experiment and the location of the experimenter.

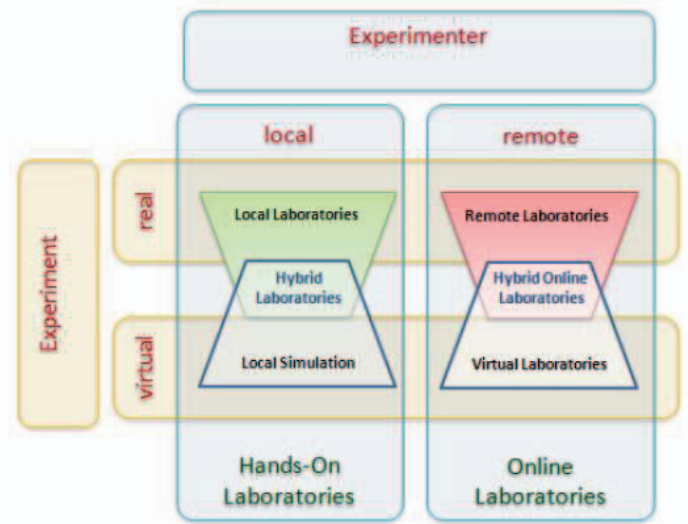


Figure 2. Types of Remote laboratories depending on location. Source: [3].

In Figure 3, the proposed model uses Unified Modeling Language (UML) notation [8] to classify possibly types of laboratories, and illustrating the types of relations that can be done among these. Laboratories can be Physical, On-line or Hybrid. The Physical Lab can be On-Site or Mobile, while the On-line Lab can be Remote or Virtual. Hybrid laboratory can be composed of combination of physical laboratories (e.g., an on-site and a mobile laboratory), or a combination of on-line laboratories (e.g., a remote and a virtual laboratory), or a combination of a physical and an online laboratory. Some possible set of combination are described with examples in the next section.

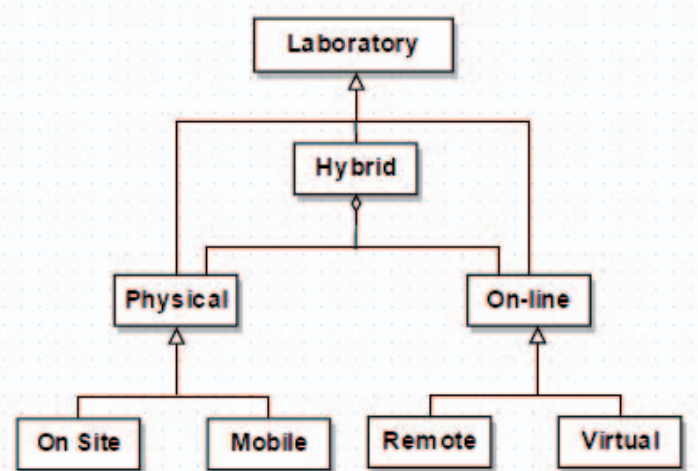


Figure 3. Proposed UML Model of laboratory taxonomy.

#### IV. CONFIGURATIONS OF HYBRID LABORATORIES

Hybrid laboratories are created by combining physical and/or online laboratories. The following are some possible configurations and examples of these laboratories.

1. **Local access to real laboratory (on site) with online access to a virtual laboratory.** In this configuration the users work on equipment in a physical facility but also simulate some processes using virtual laboratories available externally. An example of this is: a group of students working the topic of energy in the physics lab, and at the same time, using an open educational resource (OER) [9] virtual laboratory available in the University of Colorado's PhET platform [10] to simulate the kinetic and potential energy in the movement of a skate board, as shown in Fig. 4.



Figure 4. Online virtual laboratory in physics from PHET web platform [10].

2. **Local access to real laboratory (on site) with local access to a virtual laboratory.** This is very similar situation to the previous one, but in this case the virtual laboratory is available locally. An example of this is: a group of students working in the construction of an aerodynamic vehicle. Previously to construct it physically, they decide to create a simulation on their laptop to know exactly the effect of the wind in a particular design of the vehicle.
3. **Local access to mobile laboratory and online access to a virtual laboratory.** In this configuration the users work in a mobile laboratory but also simulate some processes using virtual laboratories available via the internet. An example of this is: a group of meteorologists measuring climate variables in a mobile laboratory vehicle and also at the same time, running a climate prediction model available in the server (Fig. 5).

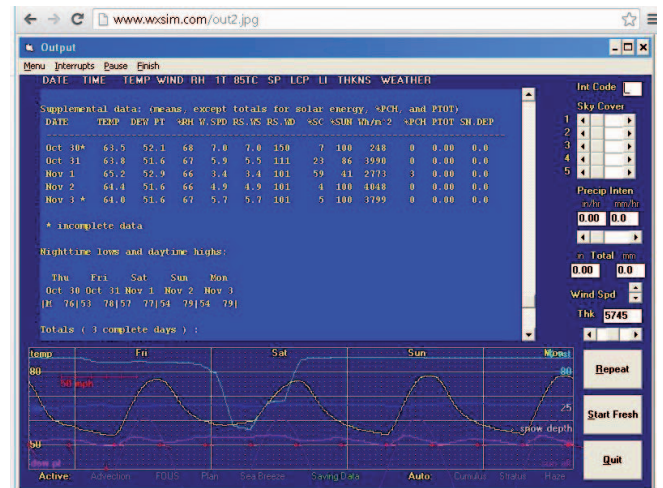


Figure 5. Virtual Laboratory of weather from WxSim [11].

4. **Local access to mobile laboratory with local access to a virtual laboratory.** This is very similar situation to the previous one, but in this case the virtual laboratory is also local. Referencing the previous example the only difference is that the meteorologist would run the climate simulation model from a local program installed in the computer.
5. **Remote access to mobile and online access to a virtual laboratory.** This particular configuration is commonly used when is not easy for people to be inside the mobile laboratory, for example if the mobile laboratory is created to perform experiments inside the ocean, it is very possible that it has to be accessed remotely, additionally the user can have the support of simulations available external on the boat to be completely sure of some instructions given to the instruments in the mobile laboratory.
6. **Remote access to mobile and local access to a virtual laboratory.** This is very similar situation to the previous one, but in this case the simulations are locally stored.
7. **Remote access to real laboratory (on site) and remote access to a virtual laboratory.** In this configuration the users work in a remote laboratory and also simulate some processes using virtual laboratories available externally. An example of this is: the design process of circuit, the students decided first to simulate the circuit using Partsim web platform [12] to verify the maximum power supported by the circuit, with this data students can determine the type of components such as capacitor and resistances are needed for the real circuit in the remote laboratory session, see Figure 6.
8. **Remote access to real laboratory (on site) and local access to a virtual laboratory.** This is very similar situation to the previous one, but in this case the virtual laboratory is also local; for instance, if the students of

the previous situation use the stand alone software OrCAD [13] instead of using Partsim, see Figs. 6 and 7.

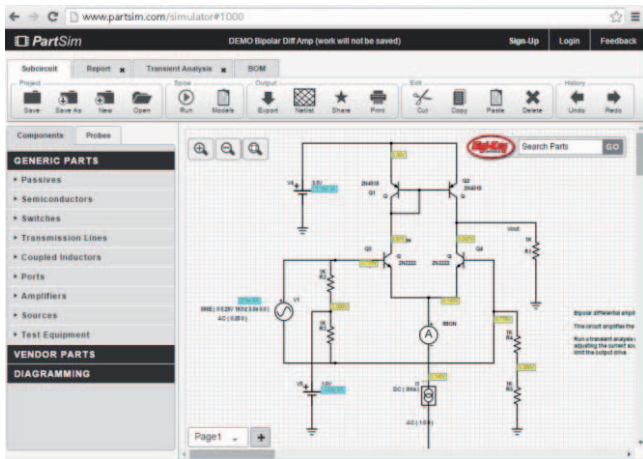


Fig 6. Virtual Laboratory for circuits' simulation from PartSim web platform [12].

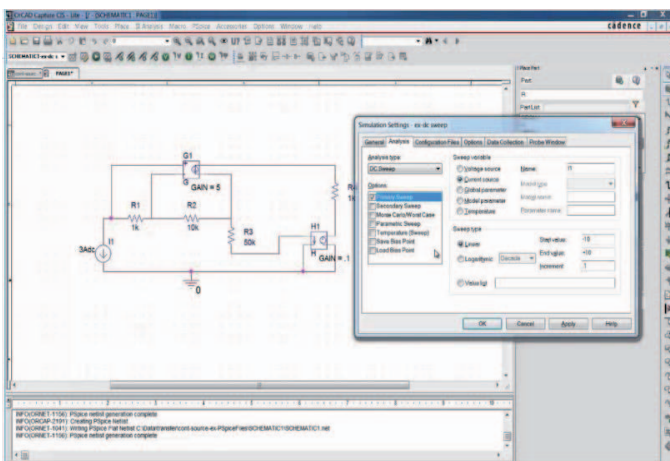


Fig 7. Virtual Laboratory for circuit simulation from local platform OrCAD [13].

## V. MODEL OF REMOTE LABORATORIES

This section develops a model of the typical architecture of distributed remote laboratory based on the work of Tawfik, Salzmann, Gillet and Lowe who proposed delivering remote labs using Laboratory as a Service (LaaS) approach [14].

The proposed model for the Remote Lab, shown in Figure 8, has three layers. The first, the Client Layer, which provides the user an interface to request and interact with remote lab experiments by communicating with the second layer, Remote Lab Server Layer. This layer provides the Client layer access to a remote laboratory using three modules: Access Manager, responsible for validating the identity and authorization rights of the user. The second module, the Scheduler, provides the services related with the management of the user appointments

and the validation of the availability of a specific experiment (resource). The Scheduler works with the third module, called Resources, which implements the searching service over the indexed list of resources using the metadata associated to each resource. Once the Scheduler has identified resource availability, the server sends a confirmation and access token to the user. The Third layer is related to the Physical Laboratory, which implements a centralized administration module responsible for the communications with the remote Lab server and is also responsible of performing administrative activities, such as: update the new resources, report changes of schedules originating at the physical site (for maintenance, etc.), and activate alerts when security or safety constraints occur in the use of the equipment.

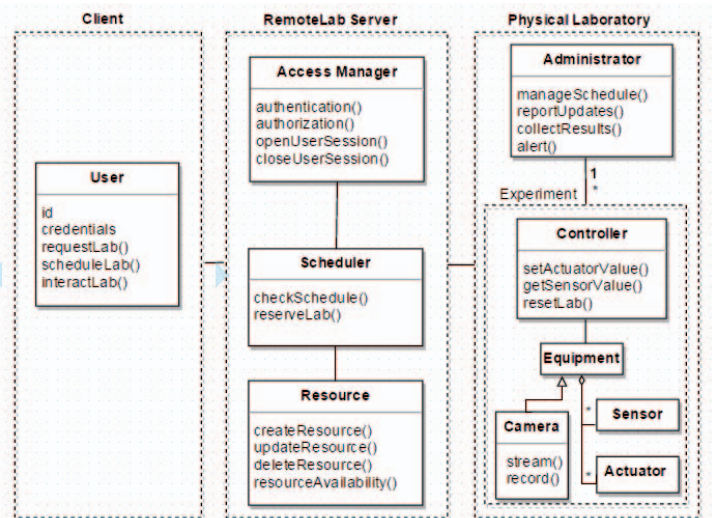


Fig 8. Model of a Remote Laboratory

## VI. MODELS OF COLLABORATIVE ROLES IN REMOTE LABORATORY

During the last 10 years companies have developed very interesting products to provide experimental environments to companies, universities and schools in topics such as: physics, chemistry, electronic systems among others, but most of them are limited to provide remote access to a physical resources, and are not concerned about user feedback nor how the information generated about user interactions could be useful to teachers and students in the learning processes.

On the other hand, other common problem of remote laboratories include that users cannot use the same resource at the same time, for instance in the case of laboratories related with Control systems, commonly students need to schedule a turn to use the control infrastructure remotely in an individual mode, because the actuators cannot execute actions from different users at the same time. The case of sensor is different because reading a specific sensor can be broadcast to a group of concurrent users.

Collaborative remote laboratories allow a specific laboratory to be simultaneously used by a group of users. Callaghan, Harkin, McGinnity and Maguire in 2007 [15] proposed a technological architecture to support collaboration in remote labs.

In a collaborative scheme, users must have specific roles which identify the type of activities that each user can do, for example, only one of the members of the group can give instructions to the actuators, another member will have the job of monitoring the sensors, etc. Due to the risks that this scheme can generate for the security and safety of the laboratory equipment and facilities, it is important to generate mechanisms to automate the assignment of roles and restrict the activities according to each role.

Schumacher, Fernandez-Buglioni, Hybertson, Buschmann and Sommerlad have published a book of Security Patterns [16], software design patterns that have been validated and standardized for implementing security. Their patterns includes one for Role Based Access Control (RBAC) which defines the structure of roles for accessing a protected object, as seen in the UML diagram shown in Figure 9. The administrator defines a set of standard roles and their rights to protected objects. The role is then assigned to users and according to the role, the user is granted the rights to access a set of activities to interact with the protected objects inside the system.

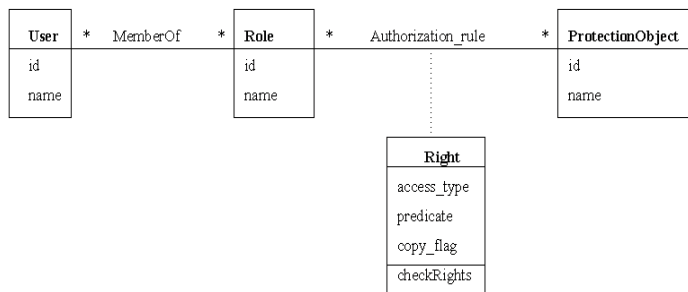


Fig 9. UML model of the Role Based Access Control Pattern [16]

In the education context, the roles may vary depending of the structure of the institution, commonly defined roles are teacher, student, grader, lab assistant and administrator. It is also possible to give more than one role to one user, for example the teacher of the course can act as a teacher and/or as an administrator of the laboratory, as seen in Figure 10. The **Administrator** determine which experiments the students in the course sessions will be assigned remotely. The **Teacher** requests access to the lab for the student on their class list. The **Teacher** role can made more specific to include the **Instructor** role, who monitors the progress of the students, grants extensions and determines final grade, and the **Coordinator**, who is the grader or lab assistant assigned to the Instructor to record student participation and lab completion and handle

student questions regarding the remote lab experiments or access. The **Student** role reflects the constraint that the equipment of the laboratory can only be manipulated by one user at a time by defining more specific roles for students, such as:

- **Leader** - responsible for coordinating all the request and use of the experiment (resources, security, time, control, etc.)
- **Implementer**: responsible for codifying the instructions in the software platform
- **Executer**: responsible for sending the instructions to the equipment, and
- **Recorder**: responsible for monitoring and recording the results of the experiment.

Other roles can be defined according to the specific type of laboratory.

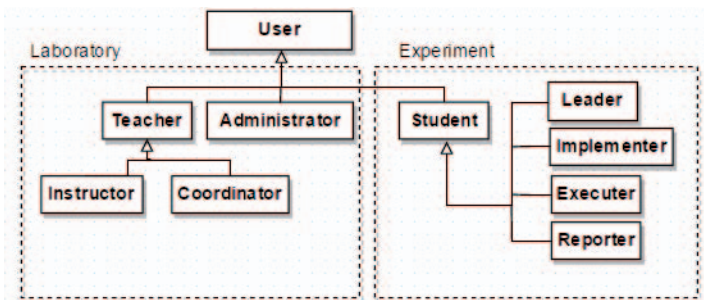


Fig 10. Hierarchy of roles

## VII. PROPOSED MODEL OF REMOTE LABORATORY INTEGRATED WITH LEARNING ENVIRONMENT

This section proposes a UML model integrating the remote laboratory with a learning environment that uses a Learning Management Systems (LMS) [17, 18] and educational standard [19] to communicate the remote laboratory servers and the learning environment. In this architecture it is important to describe two important standards, the first is Learning tools Interoperability (LTI) [20], a standard created by the IMS Global Learning Consortium [21], with the primary purpose of connecting learning systems, such as a LMS, with external service tools in a standard way across learning systems. This standard uses XML language to allow the interoperability between both systems. The second standard is experience API (xAPI) [22], also known as the Tin Can API, an e-learning software specification that allows learning systems to communicate each other in order to record and track learning experiences.

Figure 11 shows the proposed UML model illustrating how a learning environment, such as LMS, could be integrated to the remote laboratories infrastructure.

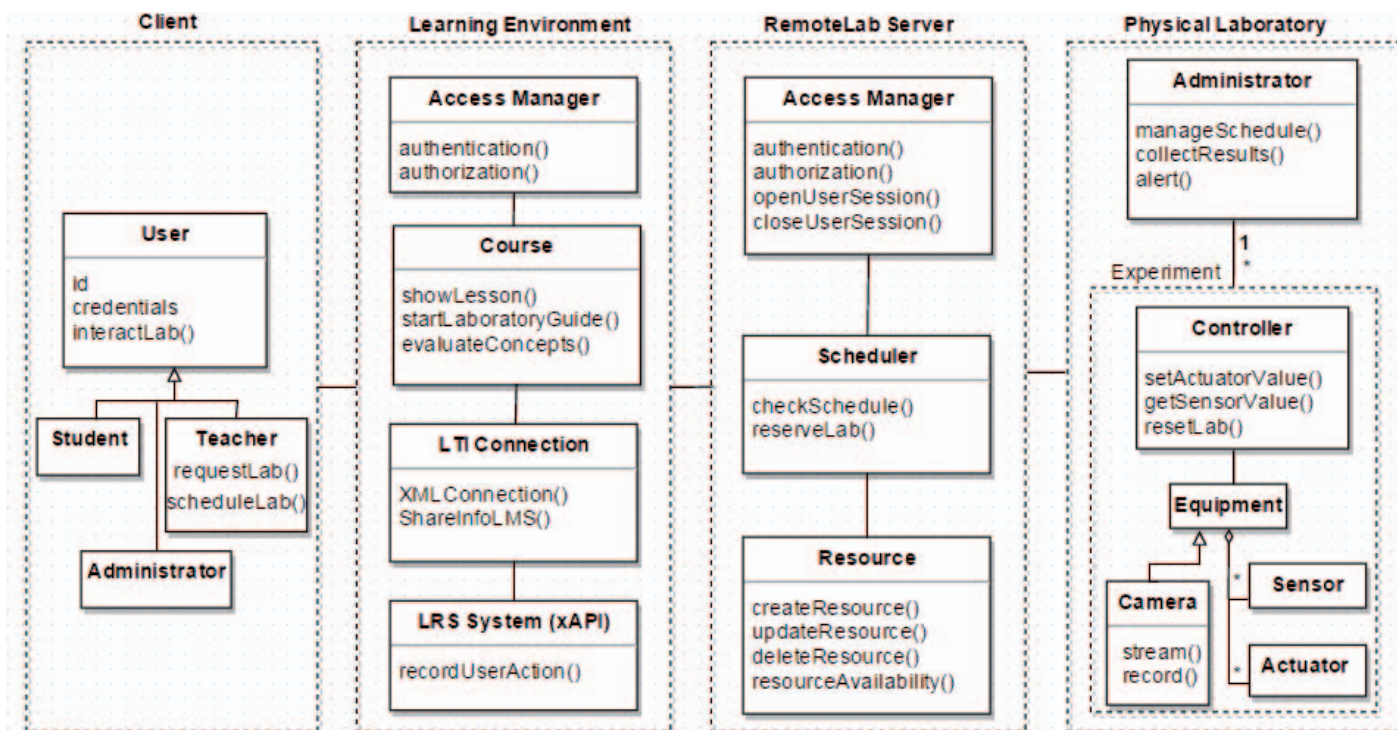


Fig 11. Remote laboratory integrated to a learning environment using educational standards.

In this model the access control is implemented using RBAC having two main roles: teacher and student, in the case the teacher, they are responsible of the administration of the course, and is the only one that has the possibility to request and schedule resources (experiments), and to enable resource access to the students. Teachers also can assign different roles to every member of a group of students to use one remote laboratory in a collaborative way within the scheduled class time.

The students will have available the laboratory access inside a learning unit for their course within the LMS using LTI, and in this case, within a scheduled class meeting. Access to the laboratory experiments should be configured previously by the teacher for students in the course. During the session of experimentation with the laboratory all important interactions (from the point of view of the teacher), will be stored in the Learner Record Store (LRS) system. Students also can find in the same learning environment, the guide with instructions to perform the experiment and to make the report with the results of the experimentation process.

In another variation with additional methods and details, the model can be extended to allow the teacher to assign the lab experiment and a range of time within which it must be completed, and also allow the student to request the scheduling of the exact time of their lab experience. This variation would be more appropriate in a distance learning environment that is asynchronous.

## VIII. CONCLUSIONS AND FUTURE WORK

This paper presented the need for establishing standards and model for educational use of remote laboratories that are compatible for established learning environments and LMS. Various efforts toward standardization, such as the IEEE Education Society e-learning standards under developed, and the proposed Laboratories as a Service approach, would benefit from development of detailed models and design patterns that could be used to describe the requirements to developers and users, and would allow composing more complex collaborative interactions with remote laboratories, and more interoperable architectures that would better support the learning process and requirements.

This paper proposed a UML model classifying the different types of laboratories, presented examples of hybrid configurations that the model would support. Extended the model to include a learning environment, and proposed a model for remote laboratory access roles that have the flexibility of supporting synchronous and asynchronous formats.

Future work planned includes the development of a pattern language, patterns with static and dynamic models and variations that detail in depth the scenarios of interactions possible with remote laboratories, especially in the context of education.

New developments in technology makes possible a new ways to interact with and use remote labs, it is important to develop new standards, not only to define technological

aspects, but also include the context and the pedagogical aspects.

Security aspects are important in the implementation of remote laboratories, risks could be generated due bad use of the laboratory, intrusion of viruses or malware, impersonation of users remotely, and many other threats inherent to systems distributed through any type of network. Safety concerns because of the possibility of exceeding operational requirements of the equipment need to be addressed. Reliability of the remote laboratories can be improved through more complex scheduling algorithms that take into account the mean-time-to-failure and maintenance requirements such as battery or materials replacement. Patterns showing how to integrate security, safety and other non-functional concerns need to be developed

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