

Learning Analytics on federated remote laboratories: tips and techniques

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Abstract—A remote laboratory is a software and hardware tool which enables students to use real equipment -located in an educational institution- through the Internet. This way, students can experiment as if they were using the laboratories with their own hands. And, depending on the design, instructors can later see the results of these students. During the last decade, federation protocols to share remote laboratories have emerged. The focus of these protocols is to be make remote laboratories of one institution available in other in an automated manner, through institutional contracts. And these federation protocols usually rely on existing Remote Laboratory Management Systems (RLMS), which usually provide APIs for tracking student usage. At the same time, the interest on Learning Analytics is increasing. Learning Analytics focuses on the measurement and analysis of data about learners in their context. In the particular context of federated remote laboratories, new challenges arise: on the one hand, remote laboratories must be prepared to track insightful information from the student session so as to extract patterns, and on the other hand, the usage of a federated environment requires different degrees of anonymity. This contribution describes the new Learning Analytics dashboard of WebLab-Deusto, detailing what information can be extracted and how the usage of a RLMS simplifies the development of such tools in a federated environment.

I. INTRODUCTION

An Educational Remote Laboratory is a software and hardware solution that enables students to access real equipment located in their institution, as if they were in a hands-on-lab session. There are many kinds of remote laboratories, including fields such as Physics, Electronics, Robotics or Chemistry. Once these laboratories are available through the Internet, it becomes possible to share them with other universities.

With time, several remote laboratory developers had to develop different remote labs of different nature. Instead of starting from scratch when developing these new remote laboratories, they started building software systems that could be reused among these different labs. This way, the development was splitted in two blocks: the laboratories code (e.g., the connection with the real equipment and the logic of the laboratory), and the management code (e.g., authentication, authorization, scheduling, user tracking mechanisms or administrative tools). These systems have been called Remote Laboratory Management Systems (RLMS). This way, a fair degree of shared development of remote laboratories is achieved: if one (or more than one) institution develops a RLMS, other

institutions developing their remote laboratories on top of this RLMS will not need to develop those features again and will instead use that RLMS.

Analysis of particular laboratories have been placed in the past. In [1] the particular case of the CPLD laboratory of WebLab-Deusto is presented. In this case, information such as when students were using the laboratory, if they were using the laboratory from home or from other location, the distribution of uses among students or typical session times was analyzed.

The focus of this contribution is to show how a Learning Analytics dashboard at a RLMS automates the analysis of the usage of laboratories in different contexts. For instance, WebLab-Deusto is a Remote Laboratory Management System used in universities such as the University of Deusto¹ or Slovakia Technical University², but also with secondary schools³. In some contexts, it manages the users and groups accessing those laboratories, but in other contexts it relies on external systems (such as LMSs) to do so, using federation protocols as explained in the following section. If the dashboard enables instructors to access these analytics automatically, then it will be possible to foster Learning Analytics in different contexts (e.g., different institutions, types of institutions, laboratories, etc.) by different instructors. However, several issues arise, such as what must be stored and how to guarantee certain degree of anonymity, and the dashboard must handle them properly, presented in this paper.

The paper is structured as follows: Section II introduces the concepts of remote laboratory, remote laboratory management system and remote laboratory federation. Then, Section III shows what solutions are available in the literature. Section IV describes proposed solution. Finally, Section V presents the conclusions and the future work.

II. BASIC CONCEPTS

This section introduces the concepts of Remote laboratories and Remote Laboratory Management Systems.

A. Remote Laboratories

A remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in

¹<http://www.weblab.deusto.es/weblab/>

²<http://weblab.chtf.stuba.sk/>

³<http://weblab.colegiourdaneta.com/>

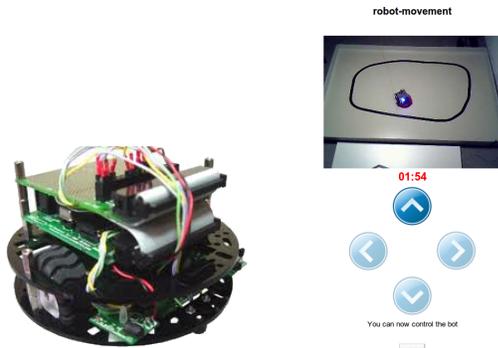


Fig. 1. Robot laboratory [2]. At the left, the mobile robot itself. At the right, the user interface once the program has been submitted.

the university. Users access this equipment as if they were in a traditional hands-on-lab session, but through the Internet. To show a clear example, Figure 1 shows a mobile low cost robot laboratory described in [2]. Students learn to program a Microchip PIC microcontroller, and they write the code at home, compile it with the proper tools, and then submit the binary file to a real robot through the Internet. Then, students can see how the robot performs with their program through the Internet (e.g., if it follows the black line according to the submitted program, etc.) in a real environment.

In this line, there are many examples and classifications in the literature [3], [4]. Indeed, remote laboratories were born nearly two decades ago [5], [6], [7], and since then they have been adopted in multiple fields: chemistry [8], [9], physics [10], [11], electronics [12], [13], robotics [14], [15] and even nuclear reactor [16].

Remote Laboratories have been considered as part of the *Five Major Shifts in 100 years of Engineering Education* in the Special Centennial Issue of the Proceedings of the IEEE [17], in respect to the influence of Information Communications and Computational Technologies.

B. Remote Laboratory Management Systems

Every remote laboratory manages at least a subset of the following features: authentication, authorization, scheduling users to ensure exclusive accesses -typically through a queue or calendar-based booking-, user tracking and administration tools. These features are common to most remote laboratories, and are actually independent of the particular remote laboratory settings. For example, an authentication and queuing system is valid both for an electronics laboratory and for a chemistry laboratory.

For this reason, Remote Laboratory Management Systems (RLMSs) arose. These systems (e.g., MIT iLabs⁴, WebLab-Deusto⁵ or Labshare Sahara⁶) provide development toolkits for developing new remote laboratories, as well as management tools and common services (authentication, authorization, scheduling mechanisms [18], mobile support [19]). The

main idea is that by adding a new feature to one of them (e.g., supporting LDAP, or LMSs [20]), all the laboratories which are developed on top of them will support this feature automatically.

One of the features that RLMSs started supporting was federating their remote laboratories [21], [22]. For example, if two universities (*University A* and *University B*) install a particular RLMS, they support federation protocols so *University A* shares a laboratory with students of *University B* without knowing these students. The key here is that the provider university does not need to register particular students, but rather groups or simply universities. It is the consumer system who defines that a set of local users can access a particular laboratory of the provider system.

Therefore, the relationship between two federated entities is the following:

- The consumer system manages the authentication and authorization of its students.
- The provider system manages the scheduling and the access to the laboratories, storing what the users did.
- The consumer system will later ask for results to the provider system.
- In every moment, the provider system does not need to know anything related to the particular students.

Through the federation protocols required for this feature, it becomes possible to build interoperability bridges that make it possible that a laboratory developed in one RLMS can automatically work in other RLMS [23], [24], or used from external systems, such as LMSs or CMSs [20].

The interest on federation of remote laboratories is growing. The Labshare project survey [25], made on all 34 Australian universities offering undergraduate engineering programs, reflects that the interviewed executives were more interested in getting involved for the pedagogic merits of the remote laboratories, and were more inclined on initially being laboratory consumers than providers.

C. Integration in LMSs through federation protocols

Federation of remote laboratories are also applied for integrating remote laboratories in Learning Management Systems such as Moodle [26], [20]. This approach considers that a LMS behaves basically like a federated node in a federation of remote laboratories: it authenticates and authorizes its own users at user level, and performs requests to the remote laboratory at organizational level. As shown in Figure 2, the LMS of University A may contact its own RLMS, which may provide its own labs or rely on an external RLMS (such as the one of University B) for federated remote laboratories. In the case of LMSs of a university, this organizational level agreement will work on a “support everything” basis (i.e., the RLMS may enable the LMS to have permission on all the laboratories).

This approach scales well and fits in the requirements of remote laboratories integration in LMS (see gateway4labs⁷), it

⁴<http://ilab.mit.edu/>

⁵<http://www.weblab.deusto.es>

⁶<http://labshare-sahara.sf.net>

⁷<http://github.com/gateway4labs/>

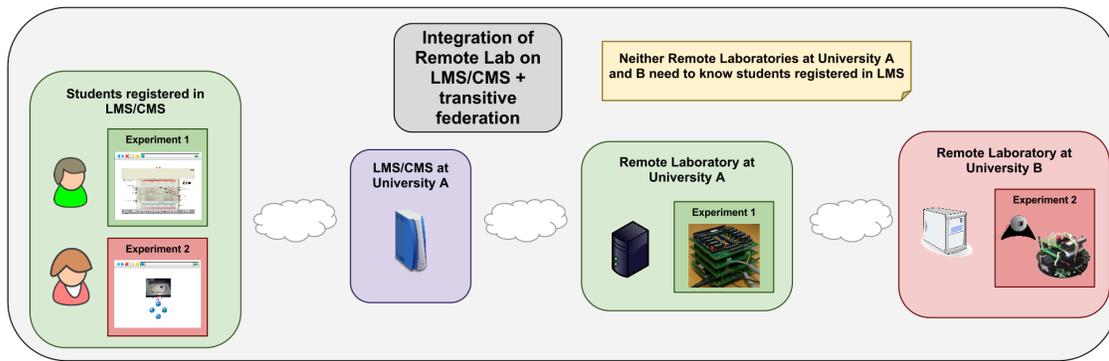


Fig. 2. Example of federated environment where two universities share laboratories with three tools [26]. Users of the LMS are not registered in the RLMSs, so developing Learning Analytics can not be handled as for regular RLMS users, but taking into account this constraint.

complicates the usage of analytics tools. Federated students are not registered in the RLMS, so while the provider RLMS (the one sharing its resources) may distinguish between different anonymized students, it can not process them as regular users. First, since students are anonymized, it may not have all the information it has of the original students, and they might not even exist in a regular users table of the database.

III. RELATED WORK

A remote laboratory, as more deeply described in II-B, is a software and hardware system that enables students to access real equipment located in universities. Different types of evaluations (related to costs, to usefulness or immersion) have been addressed in the literature [27], [28], [29], [1]. They were based on students grades, on comparisons with students in traditional hands-on-lab sessions, on dedicated surveys, or on the data recorded of the activities performed by students in the laboratories.

When using recorded activities, the remote laboratory must support some type of user tracking mechanism that enables researchers to gather an activity record and use it. There is a wide range of support degree for this features (from not supporting it at all to knowing all the fine grained interactions associated to each user and group [30], [31]). Even in the case of fine grained interactions, it is possible to aggregate data in periods of time or in teams that were working together. But real social networks (as opposed to assigned or self-assigned small teams) are easily not taken into account given the complexity of finding them in these mainly individual systems.

The goal of LA [32][33] is to discover and organize the existing information and any other additional observations within educational communities in order to extract useful knowledge during the learning and teaching process. For instance, LA might be used in analysing the interaction among students and, as a consequence, making a change or adaptation of the course material. As an additional step, LA allows faculty to establish a dynamic component in which the evolution of the course, including the corresponding changes or adaptations, can be made in order to dynamically adapt the learning process to particular features of course students and their learning ventures. The main opportunities for LA are to unveil and contextualise so far hidden data information out of educational

data and prepare it for different stakeholders (teachers, students etc.).

Several authors have analysed the importance of Social Networks Analysis in Learning Analytics. Sie et al. [34] identify four main areas in learning related SNA: network visualization, network analysis, simulation and network interventions.

In the network visualization area authors have worked both on building the networks from the sociocentric perspective using the data provided by log files and forum interactions or from the egocentric perspective constructing the social networks based on the students reported interactions. The first approach has been used by Brooks et al. [35] in the iHelp system to build undirected networks, by Chatti et al. [36] in the Plone system to build undirected networks and by Dawson [37] to build directed networks. The second approach has been used by De Laat et al. [38] using WebCT logs to build directed networks and by Martinez et al. [39] using BSCW logs to build undirected networks.

In the network analysis area authors have worked on identifying common interaction patterns that take place on the social networks, analysing the structure of the communities and identifying groups. To do this authors have used different SNA metrics. The centralities (degree, betweenness, closeness, eigenvector...) have been used by Dawson et al. [40], Capuano et al. [41] and Chatti et al. [36]. Other authors have used the density, centralisation, share and reciprocity metrics to analyse the social network like Yao [42], An et al. [43] and Martinez et al. [39].

Authors have used simulations to evaluate the outcome of new social connections [44], to predict the reactions of changes in the infrastructure [45] and to predict network behaviour [46]. Finally in the network interventions area the performed analysis have been used to improve organizational management [47], improve the social interactions between learners [48], pro-actively offer information [49] and create groups of teachers with similar interests [50].

Several authors have designed dashboards to improve the learning experience. This dashboards have been targeted to both teachers [51][52][53][54][55] and students [55][56][57][58]. An extensive review of the existing educational dashboards can be found in [59].

2013-09-20 08:07:55.796278	2013-09-20 08:07:55.824920	STATE	STATE=programming
2013-09-20 08:07:56.835209	2013-09-20 08:07:56.879640	STATE	STATE=ready
2013-09-20 08:08:00.476673	2013-09-20 08:08:00.540760	SetPulse on 0	None
2013-09-20 08:08:01.481625	2013-09-20 08:08:01.537995	SetPulse off 0	None
2013-09-20 08:08:03.715763	2013-09-20 08:08:03.779579	SetPulse on 1	None

Fig. 3. Usage information stored in WebLab-Deusto for a CPLD Laboratory (where the switches represent the interactions with the laboratory)

IV. PROPOSED SOLUTION

This section describes the limitations of applying Learning Analytics on federated remote laboratories and a dashboard that has been implemented in the WebLab-Deusto RLMS.

A. Learning Analytics Dashboard

When applying Learning Analytics to remote laboratories, one needs a set of information, such as which users were in which groups or when they accessed the laboratory. In the particular case of WebLab-Deusto, there are two models when designing laboratories: one where all the interactions are submitted through WebLab-Deusto (and stored in middle layers), and other where the communications are direct between the client and the final laboratory code. In both approaches the following information is stored:

- Basic usage information (user identifier, course identifier, laboratory identifier).
- Location information (user's IP address -so we could identify who is using it from the University-, when the students starts using it and when finishes the session).
- Additional contextual information (whether it was accessed from a mobile device, or embedded Facebook).

Additionally, for those laboratories in the first model (which are the ones in this paper), it is also stored:

- All the commands submitted by students. These are control commands (e.g., whether the system is still submitting the uploaded file to a CPLD) and user interactions (e.g., turn switch 1 on, see Figure 3), including when they were sent and the response and response time.
- All the files submitted, as well as a hash of these files is also stored, and the timestamps of the submission and response.

With this information, an administrator panel has been implemented where administrators can check the usage done by students. It includes filters to find uses in certain dates, users, origins -by IP address- or laboratory as shown in Figure 4.

In addition, with this information, it is possible to extract more advanced information, which this dashboard provides.

For instance, it is possible to provide statistics data per course as, showing where the users were using the laboratory (e.g., IP addresses of the university or outside), the time of the

User	Experiment	Start Date	End Date	Origin	Coord Address	Details
porduna	aquarium@Aquatic experiments	2013-11-05 22:48:36	2013-11-05 22:49:46	31.4.217.162	aquarium.general_laboratory@plunder	Details
porduna	submarine@Aquatic experiment			31.4.210.57	experiment_submarine.process1@plunder	Details
porduna	robot-proglist@Robot experiments			31.4.210.57	experiment_robot_proglist.process1@robot1_flgpc	Details
porduna	robot-movement@Robot experiments			31.4.210.57	experiment_robot_movement.process1@robot1_flgpc	Details
porduna	aquarium@Aquatic experiments			87.219.25.98	aquarium.general_laboratory@plunder	Details

Fig. 4. WebLab Dashboard

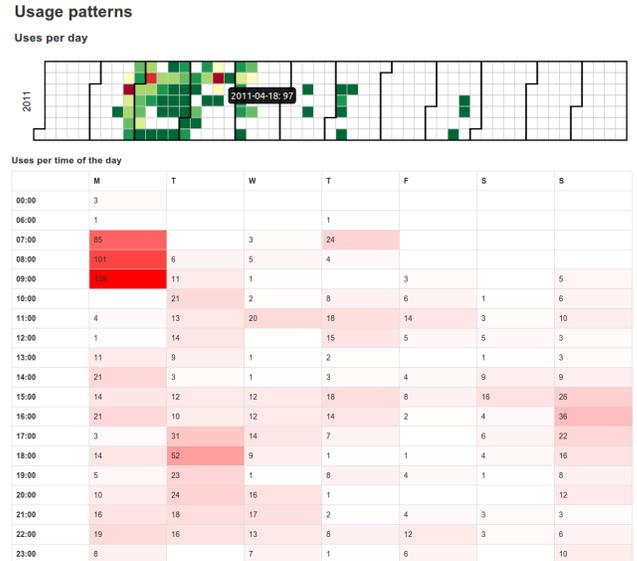


Fig. 5. Some dashboard features, including a distribution per day (top) and the distribution among the different hours of the day (bottom).

day when they were using it, or which weeks the laboratory was used. These features are represented in Figure 5.

However, there is subtle hidden information in these systems, such as implicit social networks. While most of the laboratories were not designed for collaboration, students interact outside the system. It is possible to detect if they are using the system from the same IP address in a short period of time (suggesting that they are working together at home or in a library), and, more interestingly, if they submit the same files to the system. Since they are not evaluated for their usage but later in class, they are allowed to share files and send them. Given that in some cases the submitted files include a timestamp and the filename, it can be tracked that those students submitting exactly the same file will be actually interacting outside the system. It is possible to elaborate automatically graphics such as Figure 6, where given a group it is possible to draw implicit connections among students. This analysis has been described in detail in [60].

B. Development notes

All these tools are provided by the WebLab-Deusto RLMS itself, and therefore they are available for all the laboratories, regardless what technology was used for the development of



Fig. 6. Analyzing implicit social networks. The whole drawing represents the sharing of files in a single class in one course. Each circle represents a user, and each arrow a user being the original source of the file which is used by other user.

each laboratory. For instance, a remote laboratory developed in WebLab-Deusto using Java, .NET or Python will work in WebLab-Deusto, and since the WebLab-Deusto itself is collecting all the interactions and storing it in its database, all these features are automatically available.

Different technologies were considered for the development of the detailed features, but the backend should be kept as it was for compatibility issues. WebLab-Deusto supports both SQLite, which we recommend for its use in low cost devices such as Raspberry Pi [21], and MySQL, which provides a higher performance in servers, so migrating to other database such as MongoDB was discarded. However, a big effort was placed in optimizing the database for the required queries, and several important changes had to be taken into account. For Social Analytics tasks, the NetworkX⁸ software framework was used, which calculates the different values of the nodes in the network. In the front-end, different technologies, D3.js⁹ was used for most the graphs, except for the Social Network Analytics related ones, where Sigma¹⁰ was used.

C. Limitations of Learning Analytics on federated remote laboratories

Federated remote laboratory management systems make it possible to make the analytics on the consumer side (e.g., the RLMS which processes the authentication and authorization of the particular students). However, when the RLMS is replaced by other system which is not aware of this data, this is not possible. This is the case of LMSs or CMSs integrated with federation protocols as explained in Section II-C.

In these cases, the provider RLMS, which is not aware of the list of students authorized to use the laboratory, must be

able to perform the analytics. For this, it is important to have identified the original users even if they are anonymized, and build the dashboard internally in a flexible way to support both local and federated users.

V. CONCLUSIONS AND FUTURE WORK

This contribution has summarized the information stored in the WebLab-Deusto dataset. Then it has shown the type of Learning Analytics which can be applied to it, which is extensible to other remote laboratories and remote laboratory management systems. It also shows the problems which arise when implementing Learning Analytics on a federated environment of remote laboratories, such as the case shown in gateway4labs.

Regarding future work, WebLab-Deusto will natively support the presented tools for showing different timelines and timetables, as well as SNA relations among students. This way, any laboratory developed on top of it can benefit from it and the teachers using those laboratories can obtain further information.

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⁸<http://networkx.github.io/>

⁹<http://d3js.org/>

¹⁰<http://sigmajournal.org/>

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