Modelling Remote Laboratories integrations in e-Learning tools through Remote Laboratories federation protocols

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Abstract—An educational remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university as if they were in a hands-on-lab session. Federations of remote laboratories have existed for years: they are based on enabling two universities to exchange remote laboratories directly, without registering students of the latter on the former university. Integration of remote laboratories on Learning Management Systems (LMS) or Content Management Systems (CMS) have also been addressed in the past, enabling institutions to delegate the authentication or authorization of the experiments to the LMS/CMS. However, these integrations are usually achieved in an ad hoc way, integrating each particular laboratory to a LMS/CMS. This contribution studies the use of federation models to integrate remote laboratory management systems in LMS/CMSs, since both approaches (integrating a laboratory on an a external electronic learning tool, and integrating a laboratory on other laboratory) are essentially equivalent. The contribution defines two case studies to evaluate this approach, showing how this integration is achieved on a LMS (Moodle) and on a CMS (Joomla).

I. INTRODUCTION

An educational remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university, as if they were in a hands-on-lab session. Federations of these remote laboratories have existed for years, as well as integrations of remote laboratories in Learning Management Systems (LMS), developed to integrate the remote laboratories on institutional platforms. However, these integrations were mostly done in an ad hoc way, binding a particular laboratory to an LMS and focusing on the integration itself.

The contribution of this paper is to model and evaluate how a general federation model for remote laboratories can be used to support third party consumer systems such as LMSs, CMSs or e-learning tools. Since the discussed federation model is focused on simple rules (priorities, access) for third-party agents consuming laboratories -regardless they are remote laboratories or other kind of software- it becomes reusable for the integration of other e-learning tools. With this approach, the remote laboratory will still establish particular rules for each system and for each external institution. Furthermore, the provider university can establish high level rules (e.g. University A grants 10,000 accesses on Laboratory 1 to University B) and the consumer university can decide to let their users consume it through different technologies (e.g. different LMSs or remote laboratories) without notifying the provider.

In order to evaluate this contribution, a federation model is defined and implemented on an existing open source remote laboratory called WebLab-Deusto [1], enabling two universities to share laboratories through this remote laboratory. The federation protocol has been implemented in an LMS (Moodle), so users can consume the laboratories and educators can select which users can access which laboratories. Finally, the federation protocol has been incorporated to a CMS (Joomla) through an extension. The feasibility of this approach to support heterogeneous web environments is described detailing the differences over existing e-learning integration approaches.

This paper is structured as follows: section II explains the federation model, section III describes the existing integration of remote laboratories in LMS/CMS, section IV discusses the approach proposed, and section V describes case studies, focusing on Joomla (CMS) and Moodle (LMS). Finally, section VI sums up the conclusions and draw the future work.

II. FEDERATION OF REMOTE LABORATORIES

This section details what is a federation of remote laboratories and its relevance.

[1] http://www.weblab.deusto.es/

Fig. 1. Remote laboratory

A. Remote laboratories

A remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university. Figure 1 represents the essentials of a remote laboratory: a student connects -normally through a web browser- to a physical, real laboratory deployed in the university. There are a wide range of remote laboratories in the literature for different engineering and sciences fields: robotics, electronics, chemistry....

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. However, most remote laboratories are developed aiming a particular setting (a laboratory for robots based on PIC18, an electronics). So the focus is usually achieving that the particular setting is available through the internet.

B. Remote Laboratory Management Systems

As many features of remote laboratories are common among them, Remote Laboratory Management Systems (RLMS) arised. RLMSs were focused on providing the required common tools for remote laboratories, and managing the common features. Examples of these systems are: MIT iLabs[2] [1], Labshare Sahara[3] [2], VLCAP [3] and WebLab-Deusto [4]. Each RLMS can manage different concurrent experiments. They provide tools for establishing which users can access which experiments, tools for reporting teachers which students did what and when, and other administrative tools. For instance, if a RLMS supports a new feature, such as LDAP (a directory protocol used to authenticate and authorize users), automatically all the experiments developed with that RLMS will support it.

In order to do so, RLMSs usually provide some guidelines or even APIs that allow experiment developers to create new experiments. For instance, WebLab-Deusto provides an web service interface for experiment developers and working libraries for a wide range of software technologies, both for server (Python, Java, .NET, LabVIEW, C++, C) and client side (JavaScript, Flash, Java).

The advantage of using these RLMSs is that they speed up the development process of remote laboratories. Teachers aiming to create a remote laboratory do not need to work on scheduling, authentication, authorization, etc. but focus on making the experiment available through the Internet. If a new version of one of these RLMSs is released and comes with

[2]http://ilab.mit.edu/wiki/
[3]http://www.labshare.edu.au

more features, the developed experiment will automatically include them.

C. Federating remote laboratories

A unique characteristic of remote laboratories when compared to traditional laboratories is that the distance of the student to the real equipment is not an issue, so remote laboratories can be shared with other institutions. This sharing can be managed in a direct, simple way: the *provider university* (the one where a remote laboratory is located) creates accounts of users of the *consumer university* (the one interested in using the provider university's equipment for their students). Students of the consumer university directly access in the provider university and the provider university does all the work: it authenticates the user, authorizes him to use the laboratory and provides the laboratory.

There are multiple problems with this solution. First, the provider university must create and manage the user accounts of all the interested consumer universities. In a complex scenario, where a wide variety of consumers exist -such as foreign universities and even secondary schools that simply do not speak the provider university's language-, this approach does not scale. Second, the management of this approach is cumbersome: consumer universities would need to notify providers every change, and local databases or protocols such as LDAP would not be available. Third, the consumer university cannot carry a proper accounting of the uses performed: it must trust the provider university. If both institutions come to an agreement where users of the consumer university can access up to 10,000 times, there will be no way for the consumer university to audit this if the provider university at some point says "you have already the limit".

In order to handle these and other problems, a two-side model is required (see figure 2), where both universities have the same RLMS that manages this sharing. The consumer university can authenticate and authorize local students, and once authorized, the local RLMS will contact the provider university and request a slot. This way, the provider university does not need to manage students and courses of the consumer university, and the consumer university can track all the requests performed to the provider university, being able to track students and audit the overall use.

In this sense, MIT iLabs have been effectively sharing remote laboratories around the world for years [1][5]. Different universities can use the MIT iLabs RLMS to develop, maintain and share their remote laboratories with other universities. In the federation model defined by the iLabs Shared Architecture (ISA), two types of remote laboratories can be shared: batch laboratories (using queues) and interactive laboratories (using a calendar-based booking system).

However, this mature architecture lacks a feature relevant to this contribution, which is *transitive federation*. Transitive federation refers to the capability of re-sharing a remote laboratory to a third university. For instance, one university could share 10,000 accesses to other university, and this other university could split these 10,000 accesses on two: the
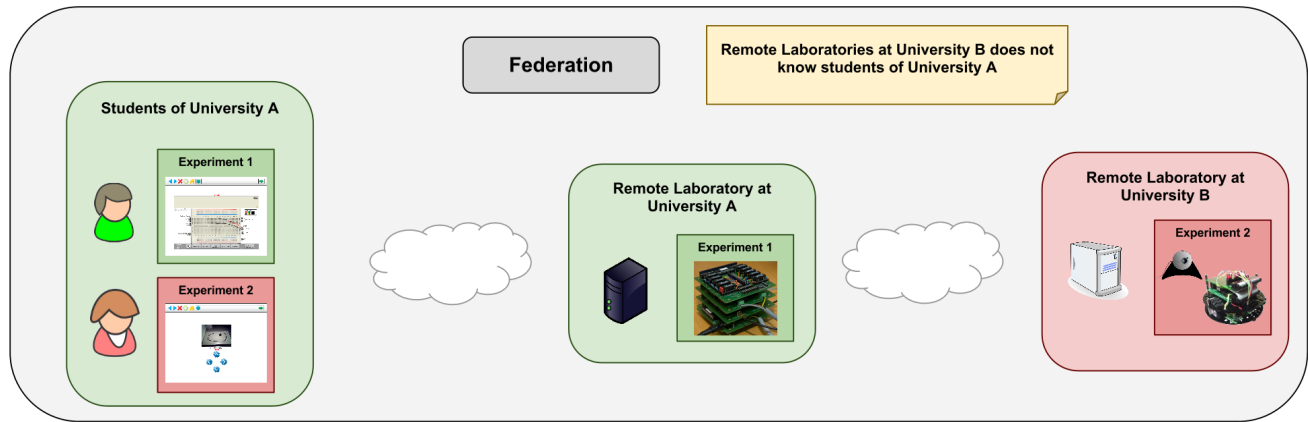
Fig. 2. Federation of remote labs. Students registered in the federation

first 7,000 being exclusive for their students and the other 3,000 might be re-shared to a third university interested in consuming that laboratory. This would work in the same way a real market works, where prices adapt to the offer, demand and required quality of service. The RLMS used in this contribution (WebLab-Deusto) defines a federation model which supports transitive federation, as well as load balance among different copies of the same experiment distributed through the federated universities.

D. Relevance

The federation of remote laboratories has a major role on engineering and sciences education. It makes possible for students of one university to access hands-on-lab sessions of other universities through an institutional RLMS and through agreements among the institutions involved. Furthermore, secondary schools connected to local universities can transitively access laboratories of federated institutions.

Indeed, the interest on federation of remote laboratories is growing. The Labshare project survey [6], made on all 34 Australian universities offering undergraduate engineering programs, reflects that 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. Indeed, the European Union Commission will invest 60 million euro in research actions, projects and network of excellences in Technology-Enhanced Learning (TEL), under the objective ICT-2011.8.1 of the call FP7-ICT-2011-8. One of the target outcomes is precisely supporting a European-wide federation and use of remote laboratories and virtual experimentations for learning and teaching purposes.

III. EXISTING INTEGRATION OF REMOTE LABORATORIES IN LEARNING / CONTENT MANAGEMENT SYSTEMS

Proper integration of remote laboratories on LMSs is an active field of research. The relevance of this field is that, as detailed in [7], there are several services duplicated between remote laboratories and learning management systems. The

administration and user experience would increase if they were merged. Both systems usually support user authentication, authorization, group management, administrative tools, user tracking, and even scheduling. Some integration approaches suggest to delegate all these services to the LMS, but some of these services will still be at least shared, such as scheduling (especially when federation systems arise) or user tracking (since some interactions with the remote laboratory might occur outside the scope of the web browser).

In order to integrate remote laboratories and LMSs, [8] discusses the usage of SCORM and [9] implements an architecture around it. This technology is designed to be supported by different LMSs and indeed multiple LMSs have implemented different versions. However, since it is a client-side technology and therefore it cannot contain any server code, it does not support a secure way to exchange credentials, ensure reservations or return results to the LMS.

Other approach is to develop an ad-hoc plug-in to include a particular remote laboratory on a LMS[10]. This approach is common in the literature, and sometimes it is implemented by just copying or exchanging the users among both systems. Within the field of integrating remote laboratories on electronic tools appears the integration of remote laboratories on CMSs. In [11], the remote laboratory relies on Joomla to perform all the administrative tasks. This approach is interesting since it does not duplicates all the tasks refered in [7]. However, it is an example of an ad-hoc integration which does not support the integration of other remote laboratories neither the integration on other CMSs.

IV. DISCUSSION

Most integrations among remote laboratories and LMSs or CMSs are ad hoc integrations of one particular LMS/CMS to a particular remote laboratory. The target of these integrations is to delegate the tasks for authentication, authorization, user tracking and scheduling to the LMS/CMS. This delegation is the same delegation described in section II as the target of federation models: the consumer remote laboratory will manage the authentication, authorization and user tracking,
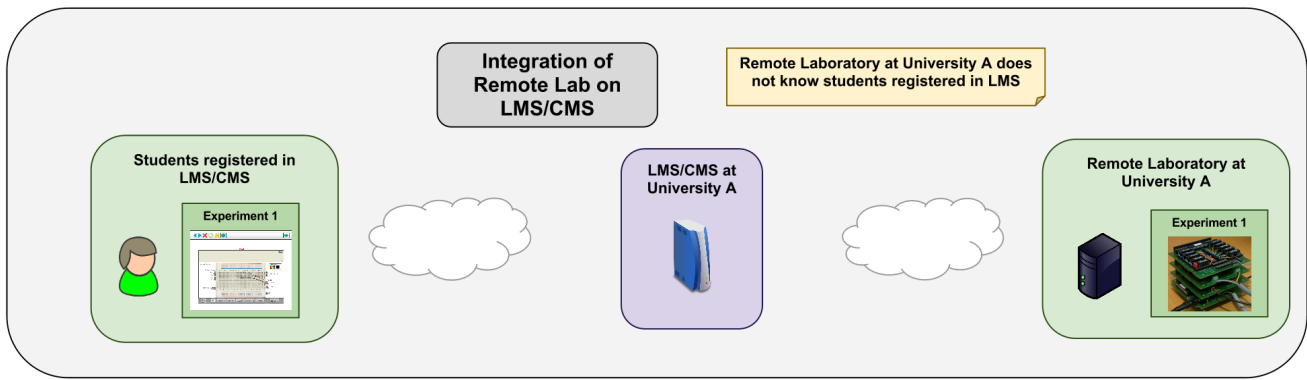
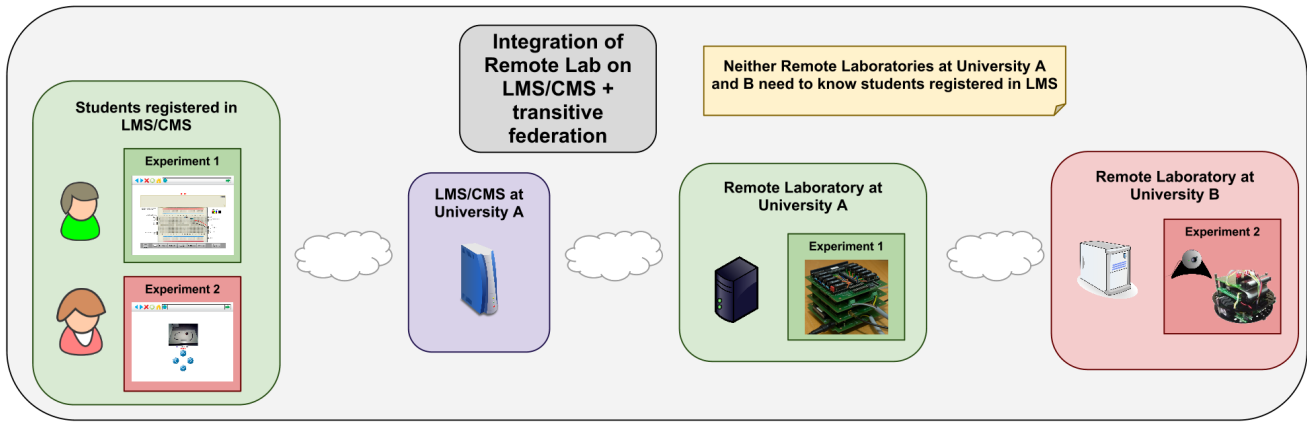Fig. 3. A LMS/CMS can act as a federated node consuming the federation protocol

Fig. 4. If the federation is transitive, the LMS/CMS will still be able to consume remote laboratories in other universities

while the provider remove laboratory will be in charge of enabling the interaction of the user with the experiment.

The key concept introduced in this contribution is that the remote laboratory integration on LMS/CMSs is essentially equivalent to the integration of two federated remote laboratories. Thus, a LMS/CMS could be considered an external consumer of the federation protocol of a RLMS. As described in figure 3 and compared to figure 2, the LMS/CMS acts as a federated node, even if it is in the same university as the remote laboratory. This way, the student in the figure will access through the LMS/CMS to the remote laboratory.

The relevance of this concept is that it simplifies notably the integration of both systems. Under this approach, the LMS would not need to exchange user information, or use standards such as OAuth or Single Sign On protocols to effectively perform reservations in the remote system. If the protocol is simple enough, different systems can adopt it, since the interface only needs to provide three actions:

- Listing of possible experiments (so administrators of the LMS/CMS can choose who has access to what)
- Reserving the remote experiment
- Usage retrieval (to be stored in the LMS/CMS database)

It is worth mentioning that if the federation model does not

support transitivity, the LMS will not be able to consume remote laboratories on other universities through the institutional remote laboratory. This means that in the example of figure 3, students registered in the LMS will be able to use experiments located in University A. But, if no transitivity is supported, and if the remote laboratory of University A was federated with one of University B, students registered in the LMS would not be able to use them. The only way to achieve this would be registering also the LMS in University B. However, given the transitivity property of the federation model supported in WebLab-Deusto, figure 4 becomes possible without expliciting all the contracts and subcontracts.

V. CASE STUDIES

For the sake of clarity and evaluation, two case studies are presented. They describe sample integrations in a LMS (Moodle) and a CMS (Joomla) of the remote laboratory WebLab-Deusto. WebLab-Deusto is a remote laboratory used for the latest 8 years by over 1,000 students in 12 different courses in the University of Deusto. WebLab-Deusto supports federation with other instances of WebLab-Deusto in a transitive way, and this federation protocol is indeed being used with local
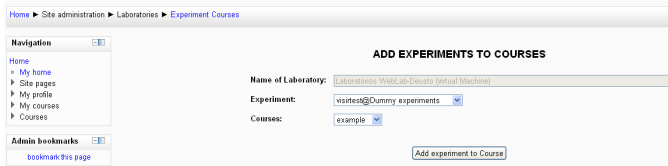
Fig. 5. Admin granting permissions of an experiment on a course

Fig. 6. Teacher adding a remote lab as an activity for a course

Fig. 7. Student running an experiment

secondary schools [4].

While both Moodle and Joomla use the same technology (PHP) and therefore some code is reused (the federation protocol client), the same code has been implemented in other kinds of systems. WebLab-Deusto experiments can be consumed from iLab systems through the federation protocol of WebLab-Deusto: iLab acts as a federated node that interacts with WebLab-Deusto. As part of the european *e-pragmatic* project, a commercial LMS is also integrating WebLab-Deusto using .NET and it will be used in the context of the project.

The federation protocol of WebLab-Deusto requires a web service with the following methods:

- System authentication → The consumer system will call the *login* method to authenticate the institution, providing the institution ID and password.
- Available experiments retrieval → The consumer system will call the *list_experiments* method to retrieve the list of experiments available for the consumer system. The provider university can choose through a permissions system to what experiments the consumer system will be able to access.
- Reserve an experiment → The consumer system will call the *reserve_method* to request a reservation and start on a queue.
- Check the state of a reservation → The consumer system will call the *get_reservation_status* to know the current state of the reservation requested, such as the position in the queue or if it has already been assigned. The consumer system is free to cancel the reservation at any point if a similar resource was found during this process in other university. Finally, it will provide a URL that the user will be able to use to consume the laboratory.
- Usage retrieval → The consumer system will call the *get_experiment_uses* to get what messages were exchanged among the user and the final remote laboratory. The system may respond that the final user cancelled the request or that it is still running so the consumer must request again some minutes later.

A. Moodle

A Moodle plug-in using the federation protocol has been developed. In the Moodle system, different RLMSs can be registered. The connection data will include the URL of the remote system, and a single username and password, identifying the university. Three roles are defined:
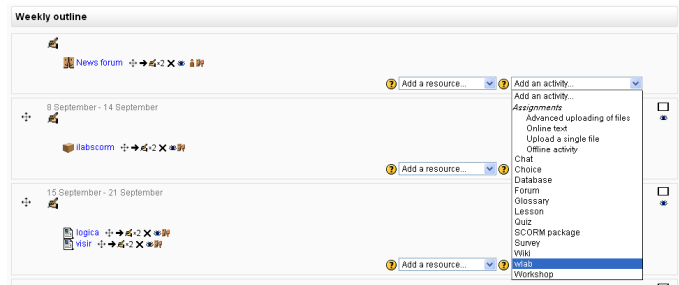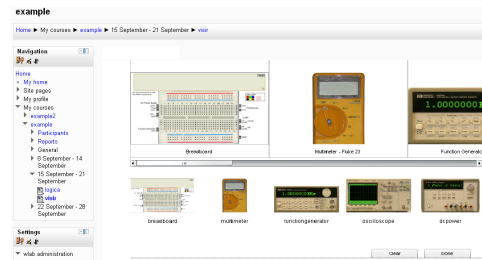
- *Administrators:* Administrators can associate courses to experiments. As shown in figure 5, they can define that the course "Electronics IV, Electronics Engineering can access the VISIR experiment in University A". In order to do this, the plug-in use the *list_experiments* method detailed above.
- *Teachers:* Teachers of courses with associated experiments are automatically allowed to add accesses to laboratories as Moodle activities to the course. In the menu shown in figure 6, in the second step they will choose among the associated laboratories. They can add, remove or hide the activity as any other Moodle activity.
- *Students:* Students of courses with associated experiments can automatically use the experiments (see figure 7), once teachers have created the activities. Whenever a student requests an access, the plug-in will perform the request in the name of the student, using the university credentials.

Only moodle administrators can define which courses have access to each external remote lab. The management becomes simple: every teacher added to a course through the Moodle administrative tools can automatically manage the associated laboratories. Every student enrolled in a course can use the laboratory. Remote laboratories do not need to exchange any user information (credentials, full name, etc.) with the LMS.

B. Joomla

A plug-in for Joomla using the federation protocol has been developed (live demo [5]). The schema used for this integration was simpler, with only two roles involved:

- *Administrators:* they will manage which groups have access to what remote experiments. This is done through

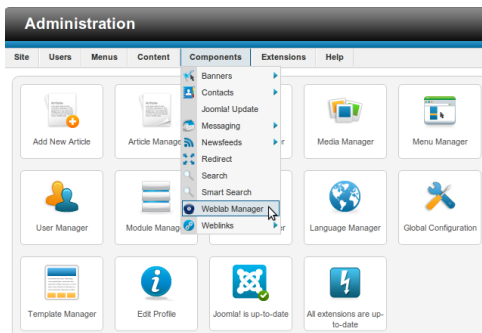Fig. 8. List of experiments available for current user

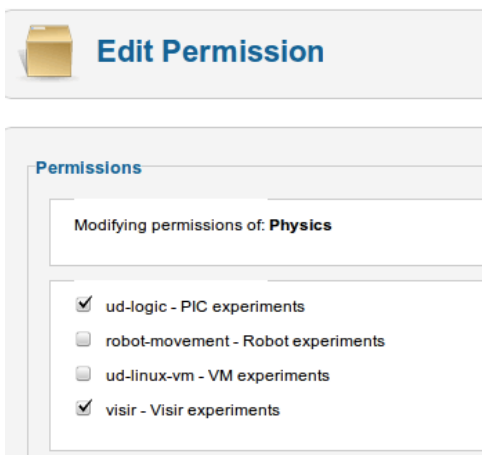Fig. 9. WebLab-Deusto manager in the Joomla Administration panel

Fig. 10. Permissions editor for each group

the standard Joomla's administration site (see figures 9 and 10).

- *Users:* there is a link where every user can see what experiments can be run. This way, users who are members of groups with associated experiments will see those experiments and they will be able to start using any of them (see figure 8).

As in the Moodle case, users and administrators of Joomla use the standard tools provided by the framework. In this case, authentication and group membership is managed with the standard tools. The plug-in only needs to define which groups can access which laboratories, as well as provide a small component to start the reservations. The remote laboratory does not need to exchange credentials or register students.

VI. Conclusions and Future Work

This contribution shows a novel approach for integrating remote laboratories on LMS/CMS, using the federation model of remote laboratories. The impact of this contribution is not restricted to the users of those remote laboratories that support federation -especially to those that support a transitive federation model-, but to every remote laboratory which aims to be integrated into a LMS/CMS. This is so since this feature will automatically be available for laboratories integrated in a Remote Laboratory Management System (RLMS) that supports this federation model. For instance, the integration of VISIR on WebLab-Deusto [4] makes VISIR benefit from this integration, as seen on figure 7. Furthermore, the integration model proposed does not need to exchange information related to particular students, neither it requires to constantly synchronize this information, becoming a simple approach to be implemented. Indeed, the contribution details the integration of a LMS (Moodle) and a CMS (Joomla), showing how the integration of other LMS/CMS could be done.

Regarding future work, the Moodle plug-in is expected to be used with students of the University of Deusto during the next course, and support for other LMS -in particular, the ".LRN" LMS, used in UNED- is under development. At the time of this writing, it still misses the retrieval of usage data. It would be desirable that other RLMSs provided new or supported existing federation interfaces to evaluate the proposed integration approach with more remote laboratory systems.

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