xAPI-Based Model for Tracking On-line Laboratory Applications

Luis Felipe Zapata-Rivera
Department of Computer & Electrical Engineering
& Computer Science
Florida Atlantic University
Boca Raton, FL, USA
Email: L.F.ZapataRivera@ieee.org

Maria M. Larrondo Petrie
Department of Computer & Electrical Engineering
& Computer Science
Florida Atlantic University
Boca Raton, FL, USA
Email: petrie@fau.edu

***Abstract*—Online laboratories can exhibit smarter behavior when information about the user and his/her context is given as an input to the lab. Part of this data can be gathered from a virtual learning environment (VLE) or any other educational system that contains information about the user. Information provided for these systems include: the type of user (student, teacher, administrator), user current level of experience (amount of time performing lab experiments, background knowledge) and results obtained in previous lab experiences. Additional context information can be provided by the user device, such as the geographical location, device type, bandwidth, date and time, among others. With this information, the online laboratory system can offer different variations of laboratories to each user and customize the experiment interfaces and activities in terms of task difficulty level, situational context and support information. The user interactions and administrative information can be collected and stored in the Learner Record Store (LRS) in the form of xAPI statements, ready to be accessed by the VLE to update the current state of the user information and extract/perform learning analytics. This paper presents the design and implementation of a model to integrate xAPI technology with online laboratories demonstrations that includes the VLE integration and user context information as part of the online lab experience.**

***Index Terms*—xAPI, Online Laboratory Architecture, Metadata, Educational Laboratory Roles, Digital Design, E-Books**

I. Introduction

In the evolution of online laboratories there is still a need of capturing and tracking the user interactions and experiences, information useful to enhance the lab experience. Current systems normally report information about the hardware and software through the System Log Reports, only used by administrators when some problem occurs. The problem of lack of integration and tracing capabilities is a problem that has been identified not only in the online laboratory systems but also in the tools used for content generation and integration for e-learning. The Education Society of the Institute of Electrical and Electronic Engineers (IEEE) has formed the P1876 Working Group (Standard for Networked Smart Learning Objects for Online Laboratories). During the last 3 years this working group has been developing the standard that defines the architectures and the standard implementation processes of online laboratories for education. [1].

This research looks at implementations that use xAPI for tracking user experiences. We compare these approaches and propose a model for the integration of xAPI for use with our Smart Adaptive Remote Laboratories system (SARL) [2]. We include a classification of xAPI statements, the first type includes xAPI statements for technical aspects of the lab experiments and the second type includes statements related with the user interactions, supporting educational roles to support pedagogical aspects and data necessary for learning analytics.

The paper is organized as following: Section II discusses online laboratories and xAPI context, Section III presents related works of xAPI applied to online laboratories, Section IV compares the xAPI implementation models, Section V defines the proposed integration of xAPI with online laboratories, finally, the conclusions and future work are stated.

II. Online Laboratories and xAPI Context

A. Online Laboratories

Online laboratories are defined as online access to a laboratory experience that uses either virtual or remote experiments. The former are based on simulations and computer programs that mimic the behaviour of the actual physical phenomena, and the latter refers to online controlling of real experiments equipped with different elements such as: sensors, actuators and controllers adapted to be manipulated remotely, normally they require the use of cameras to monitor the experiment during its use.

This technology has been applied in industry, medical, science research and educational laboratories. During a remote laboratory experience it is crucial to track and report in a timely fashion: the laboratory experiment data, information about the sessions, activities, experiment results, status of the equipment, among others. The integration of more innovative ways to support this process will make the online laboratories more robust, reliable, interoperable and adaptable to user needs and yield results that can be utilized to yield learning analytics.

B. xAPI Context

Tin Can API, also called xAPI or Experience API, has evolved rapidly during the last years and is now being im-

978-1-5386-1174-6/18/$31.00

plemented, not only in the educational context, but also in other types of systems. This technology allows the collection of experiences in the form of statements stored in a Learner Record Store (LRS).

xAPI [4] was proposed by The Advanced Distributed Learning group (ADL). A previous definition from ADL was the Shareable Content Object Reference Meta-data (SCORM) [7] specification that defined the structure of an educational content package that can be deployed in any Learning Management System (LMS) that supports SCORM. In version 2014 and later revisions, SCORM implemented a content object-to-run-time environment communication, and the possibility to define the sequences of the content in an adaptive manner. This permits capturing and reporting information about the use of the content such as: results, time expended, clicks made, etc. This information could be visible or used across the same or other content objects at the course level or even at the LMS level.

xAPI is not considered an improvement of SCORM, it is by itself a different definition, innovating in the information management process, allowing the collection, distribution and retrieval of information about a user's experiences either offline or online. This technology makes possible the integration of applications by accessing a common repository of information. xAPI can be used by different types of systems through the use of a simple common vocabulary. xAPI provides flexibility and interoperability.

Activities are recorded in the form of a triplet: Noun, Verb, Object to a Learning Record Store (LRS). The syntax used is a JavaScript Object Notation (JSON) [8] that can record and share statements with other LRSs. Additionally, the LRS can exist on its own, or inside a Learning Management System (LMS).

ADL has defined the "freedoms of the Experience API": In terms of the xAPI statements, allowing the storage of almost anything through the use of the structure of noun, verb and object. In terms of the history, the LRSs have the ability to communicate to each other, through forwarding functions. In this way, users can take their experiences to other institutions or organizations. In terms of devices, it enables any type of device to send xAPI statements with the advantage of not needing a permanent internet connection. Finally, in terms of workflow, xAPI allows tracing activities that occur in different application and locations [4].

xAPI libraries are available for a wide range of web technologies, either running on the client side or on the server side. The most commonly used xAPI packages are: the JavaScript xAPI library and the PHP: Hypertext Preprocessor (PHP) Library.

The LRS can be implemented following the definition from ADL, however, there are some cloud platforms that offer the possibility to create an LRS and provide the tools to connect the applications that are going to send xAPI statements. They also offer possibilities to retrieve information from the LRS in order to send information to the LMS or any other platform. The most common services available to create LRS instances are SCORM Cloud [5] and Learning Locker [6].

III. Related works of xAPI applied to Online Laboratories

In this section we describe and compare four different existing models that incorporate xAPI with online laboratories.

A. Saliah-Hassane and Reuzeau c-MOOLs Model

In 2014 Saliah-Hassane and Reuzeau [9] developed the concept of Mobile Open Online Laboratories (c-MOOLs), this type of labs are possible with the integration of miniaturized electronic devices and cloud computing technologies.

xAPI was used as a tool for monitoring experiments. Each action results in sending an xAPI Statement to the LRS. This feature provides to teachers the possibility of accessing the student list of performed actions synchronously or asynchronously. Teachers can then see the evolution and progress of each student, allowing them to detect student's conceptual weaknesses during the learning process and guide them to choose specific exercises to deepen the concepts that were difficult for the students.

As part of their work, authors defined xAPI data process work-flows as shown in figure 3. They Describe the process of data collected by sensor and geographical information, formatting into xAPI statements, storage in the LRS and later retrieval through a Web App displaying in map.

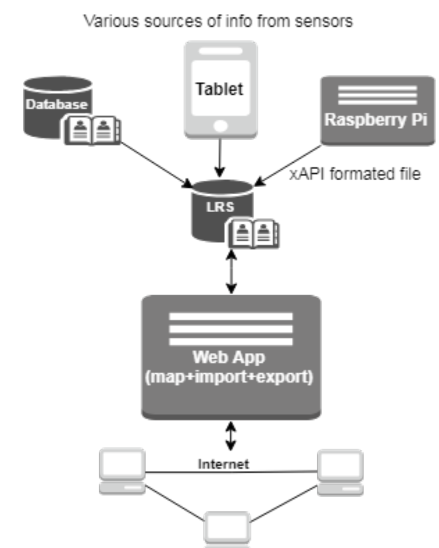

Fig. 1. xAPI integration with MOOLs (Adapted from [9])

B. ForgeBox Model

In 2014 the Forge Project, as part of their components, defined the ForgeBox [10]. This element includes interactive content with the possibility to be instantiated, collecting and sharing xAPI statements with the LRS to generate learning analytics. Figure 2 presents the model of the ForgeBox. While the user interacts with the course content, or with the remote laboratory (testbeds), xAPI statements are generated and sent to the LRS. ForgeBoxes make use of testbeds laboratories from

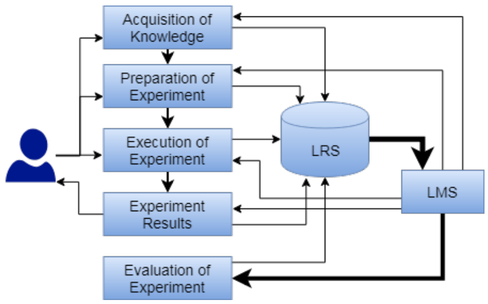

Fig. 3. xAPI integration to support the generation of learning analytics (Adapted from [11])

the project: Future Internet Research and Experiment (FIRE), these testbeds can also generate and send xAPI statements to the ForgeBox LRS.

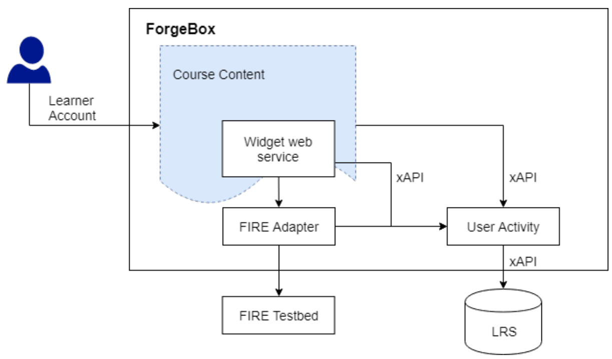

Fig. 2. ForgeBox Model with xAPI integration (Adapted from [10])

C. Learning Analytics in Online Remote Labs

In 2015 Wutke, Haman and Henke [11] presented an a alternative to connect an online laboratory with analytics tools to get learning relevant data during the students interaction with the remote laboratory. The data analysis had the goal of informing about higher order thinking skills, based on "Blooms Taxonomy" [12].

Figure 3 shows the xAPI statements generated and reported to the LRS during the whole process of learning. The authors stated a learning process including the following stages: Acquisition of knowledge, preparation of the experiment, execution of the experiment, Experiment results and finally the evaluation of the experiment. From each of the first four stages, xAPI statements are generated and sent to the LRS. In the last stage the LMS receives all the information collected in the LRS to feed the evaluation of experiment stage.

An additional software tool, Weka [13], is used to process the data and extract relevant information for the students and teachers

D. Lab@Home based xAPI architecture

In 2017 the model for mobile laboratories integrating xAPI was implemented as a proof of concept of a low-cost configuration of labs [14]. This model included the concept of Lab@Home proposed in 2011 [15]. The mobile laboratory includes the use of a Lab Gateway located between the "Lab@Home" module that includes the user interface, and the Smart Device module, that includes the lab server. The actions and outcomes during the experimentation process were stored in a LRS using xAPI statements. They defined two actors: the smart device and the lab user. The vocabulary defined for the statements include verbs such as: display, require, present, connect, disconnect and share. Figure 4 shows the integration proposed.

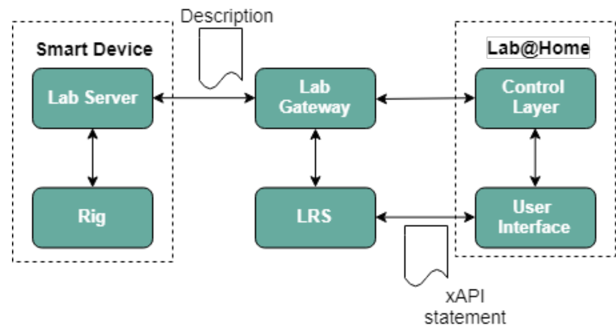

Fig. 4. Lab@Home Model with xAPI integration (Adapted from [14])

E. xAPI Framework

In 2017 Paredes, Barragan et. al [16] defined a framework to describe learning interactions reported using xAPI statements. Their objective was to capture the interactions between student and instructor, or between the lab and either the student or the instructor, reporting the status of the system during those interactions, see figure 5.

The xAPI statements were also used to report problems with some component of the lab. The vocabulary implemented included either verbs defined by ADL (Launched, Initialized, Abandoned), and other verbs defined for this specific domain (Increased, Decreased, Rotated, Set and Queried). In terms of objects, they defined specific objects such as: experiment, sensor or actuator. They included a new optional field for their messages called Context. This field could include contextual information of the experiences, for instance if the experience reported was part of a team-base activity. Context concepts include: Lab-info, Observer and Mode.

Additionally, the authors defined three different granularity levels for the xAPI statements. Level 1, related to experiment meta-data, Level 2, related to operational components, such as sensor and actuators. Level 3, for the higher-level elements, for instance all the statements generated by the interaction between lab and user.

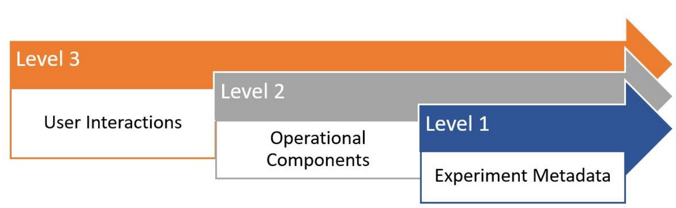

Fig. 5. Granularity levels Model with xAPI integration

IV. Comparison of the xAPI implementation models

This section presents an analysis of the strengths and shortcomings of the five related works taken into consideration when we developed our model. Table I compares the xAPI implementation presented in the related works section in terms of features and support provided.

TABLE I
Comparison of existing xAPI approaches

Feature \ Tool	**c-MOOLs Model**	**Forge Box Model**	**Lab@-Home based xAPI architecture**	**xAPI Interaction Framework**	**Learning Analytics (TU Ilmenau)**
Reporting user experiences	YES	YES	YES	YES	YES
Reporting system information	*	*	YES	YES	*
Classification of the xAPI statements	YES	*	YES	YES	*
Origin of the xAPI statements	*	*	Client	Client and Experiment	Client and Experiment
Use of ADL vocabulary or from other contributor	ADL + Other	*	ADL + Other	ADL + Other	Other
Use of optional fields in the xAPI statement	YES	YES	YES	YES	*

* the feature was not implemented or was not reported by the author in the paper reviewed.

Features such as: xAPI statement forwarding, implementation of security, or use of the xAPI statement for adapting user interfaces, were not implemented or not reported in those works. The proposed model develops some of these features as part of its core.

V. Proposed Integration of xAPI with Online laboratories

The model of xAPI integration proposed includes a new definition of the actors taking into account different roles important in the laboratory educational context. The identified roles are: students, teachers, lab administrators and SARL administrator. Additional actors are the laboratory experiment and the SARL system. They can report xAPI statements about the system information or about the state of the lab components. Their reports can help the system to auto-adjust lab experiments parameters to increase the availability of the labs. The xAPI statements can also help in the distribution of users over the lab stations.

A. Overall Model of Smart Adaptive Remote Laboratories (SARL)

The goal of “Smart Adaptive Remote Laboratories” [2] is to provide to each student an “individualized experience” of the lab activities. The individualized student experience is created based on the “Online Laboratory Learning Objects” [17] that include lab activities, assessment information, student information, and information about the access to the remote laboratory experiments. These LLOs are managed by the Remote Laboratory Management System (RLMS), part of the SARL system, and can be integrated to a VLE. The SARL system can adapt the interface of the “Lab Learning Objects”. The SARL model is presented in figure 6.

B. Model of xAPI integrated to Remote Laboratory Management System

The proposed integration model of xAPI is not only to report the status of the laboratories or to collect assessment data, but to integrate the LMS and RLMS systems and give real-time feedback to all the actors involved in the learning process.

The xAPI statements proposed in this integration model are classified in two different categories:

- Technical administrative information about the labs operation (Availability, streaming quality, controls responsiveness, controllers, sensors and actuators)
- Educational information (lab activities results, time expended, attempts made, and other traces of each user interaction)

The following list presents different xAPI statements according to the type of actor reporting information to the LRS, where Role X represents a type of actor.

- Role X reporting information about events occurred in the SARL (reports about login, logout, access lab gallery, lab schedule, networking configurations, adaptability of user interface, etc)
- Role X reporting information about events occurred in lab experiment (availability, streaming quality, controls responsiveness, controllers, sensors and actuators, communication with SARL, etc)
- Role X reporting information about educational administrative activities (design of lab activities, lab assessment, lab curriculum design, parameter definition for adaptive user interfaces, etc)
- Role X reporting information about the educational outcomes (lab activities results, lab grades, time expended, attempts made, performance measurements, etc)

The vocabulary defined for the proposed xAPI integration module uses the available verbs in the ADL repository [18] and additional verbs defined by other contributors of the xAPI community [19] that fit accurately with this model.

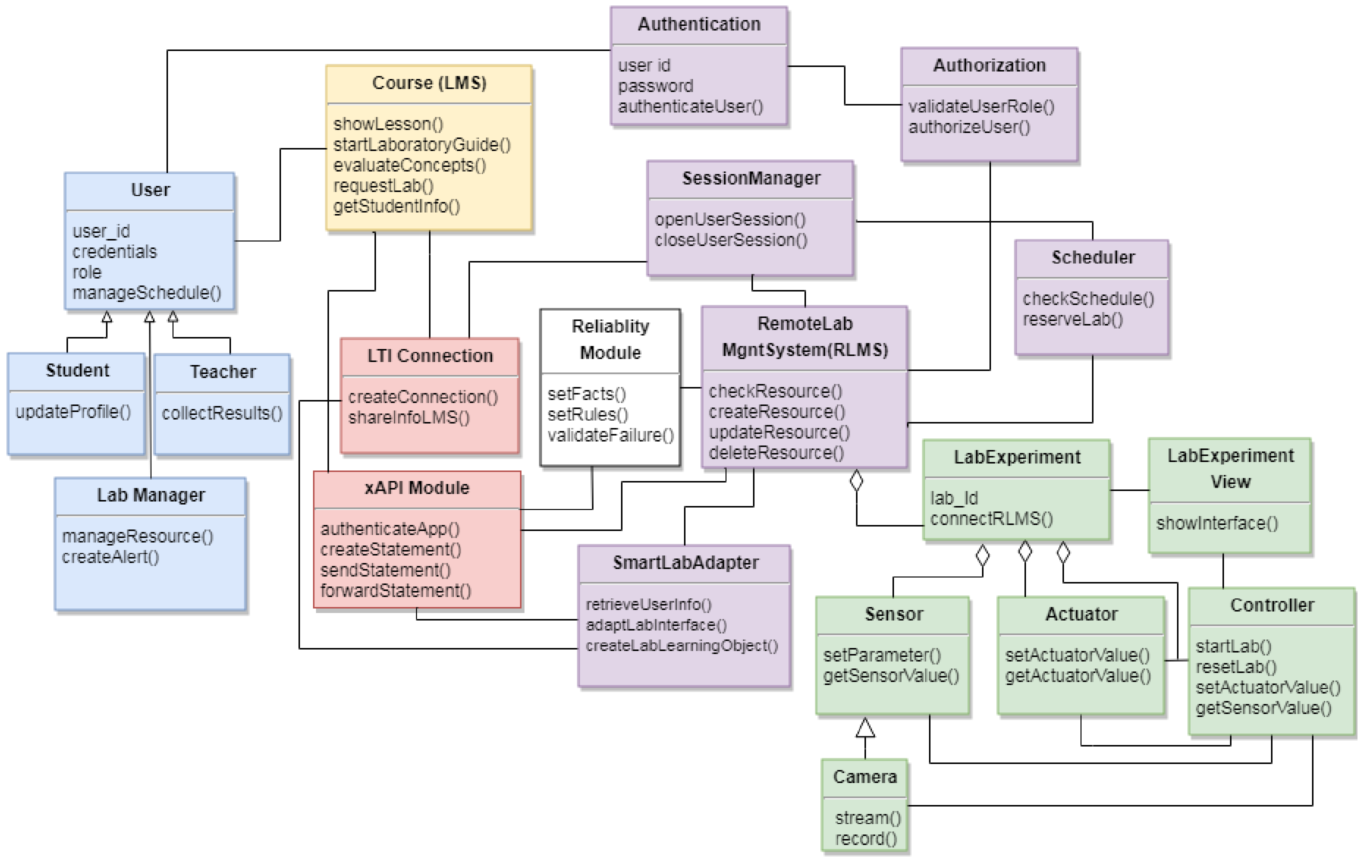

Fig. 6. Smart Adaptive Remote Laboratories for Education (UML - Class Diagram) [2]

Actors based on the roles defined in the model include those roles related to the educational context:

- Student
- Teacher
- Lab Administrator
- SARL Manager
- Lab experiment (System)
- SARL (System)

It is common to see that, in some cases, an entity can be the Actor or the Object in the xAPI statement. For example: (Student X, Used, Lab experiment A) and (Lab experiment A, Disconnected, Server X"). The proposed model include all the hardware and software components of the Lab experiment and server. The following list presents some of the entities that are reported in the xAPI statements and can change according to the context or domain of the event:

- Lab experiment
- Lab activities
- Lab experiment component
- Lab session
- Lab schedule
- Lab user interface

The model also makes use of four of the additional fields included in the original xAPI statement definition [20]:

- Context (to include some contextual information)
- Result (provides an option to report some measured outcome)
- Authority (used to report the entity who certify the validity of the statement)
- Time stamp (describe when the statement occurred, can be different to the sending date)

Figure 7 presents an UML sequence diagram indicating how and when the xAPI statements are generated and sent. These statements can be generated from different modules of the system and are sent immediately after an event occurs. After each action is completed, an xAPI statement is generated and sent to the LRS. All of these communications are controlled by the xAPI Module (LRS) which is part of the SARL architecture presented in the figure 6 .

Figures 8 to 14 present the verbs proposed in our model to be used according to the role involved in the recorded action. Some verbs are used for more than one type of role.

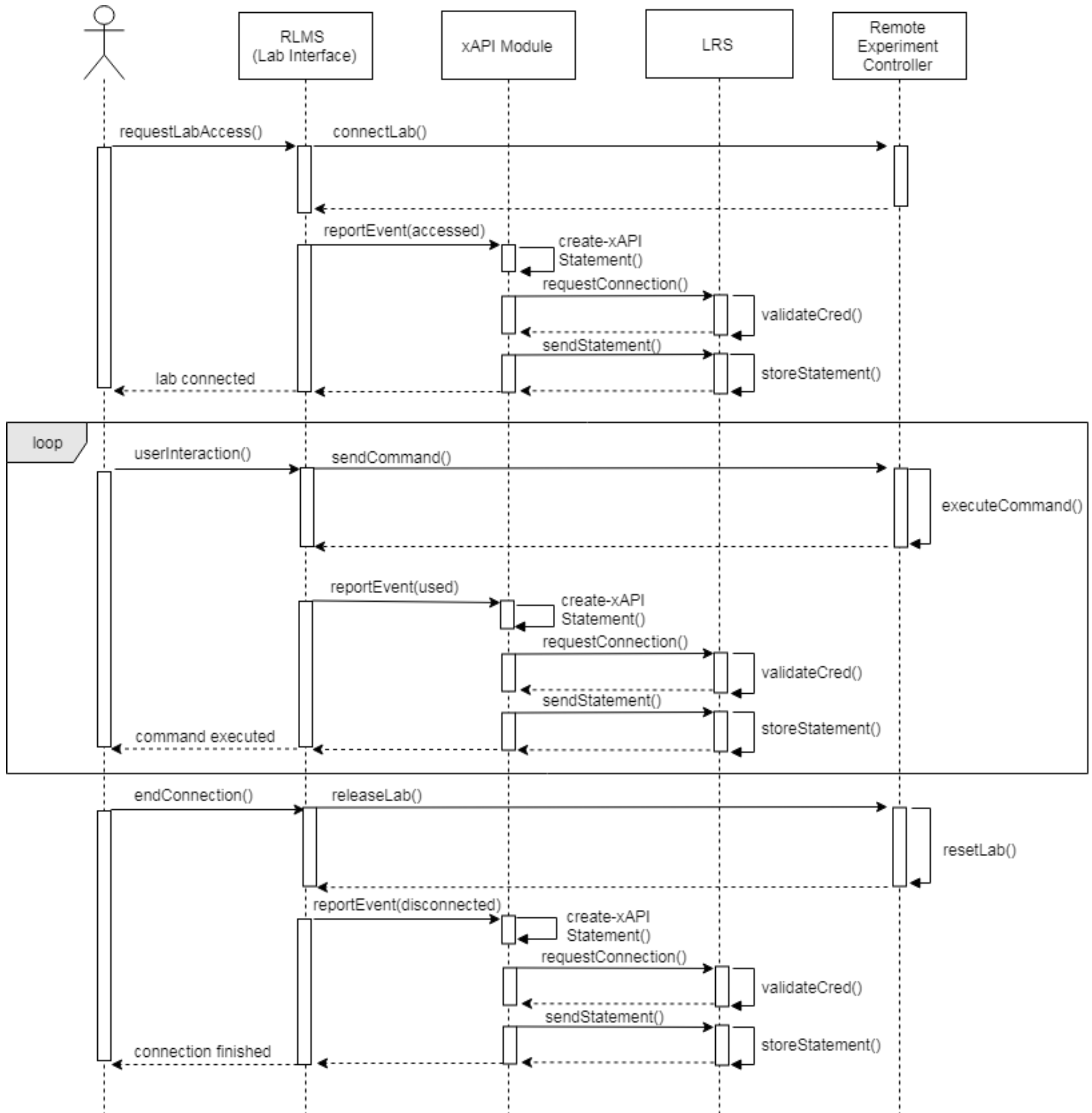

Fig. 7. xAPI Statements reporting (UML - Sequence Diagram)

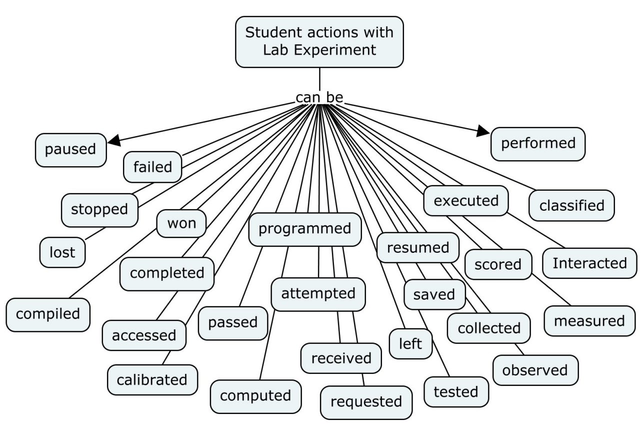

Fig. 8. Student Role xAPI verbs used to report interactions with the Lab

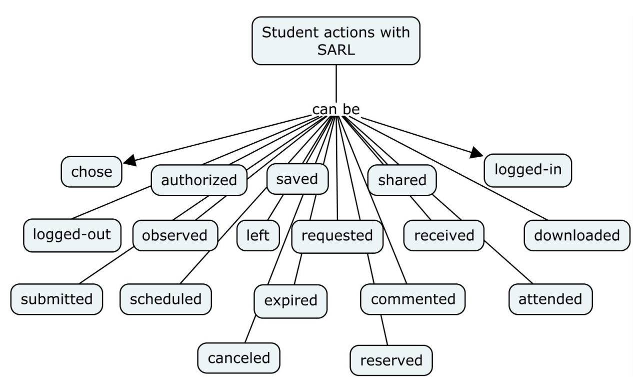

Fig. 9. Student Role xAPI verbs used to report interactions with the SARL System

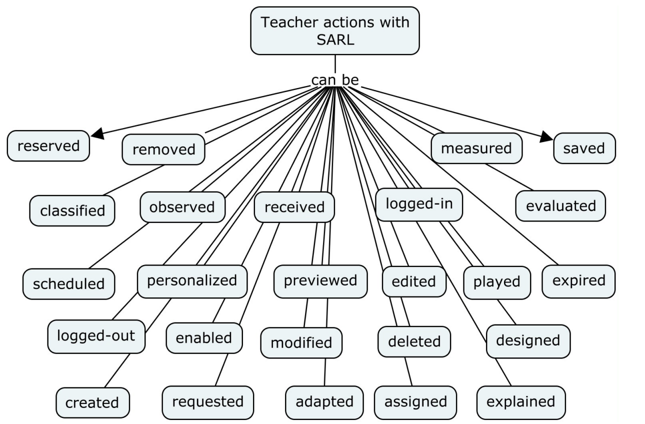

Fig. 10. Teacher Role xAPI verbs used to report interactions with the SARL System

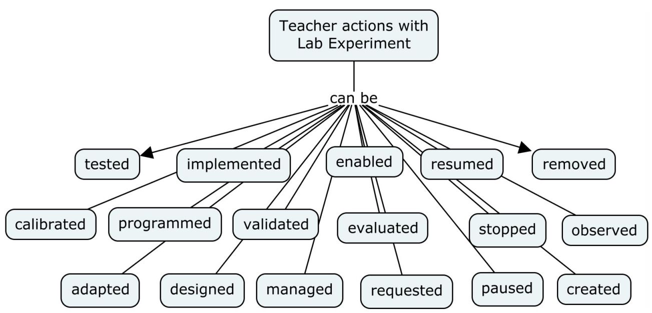

Fig. 11. Teacher Role xAPI verbs used used to report interactions with the Lab

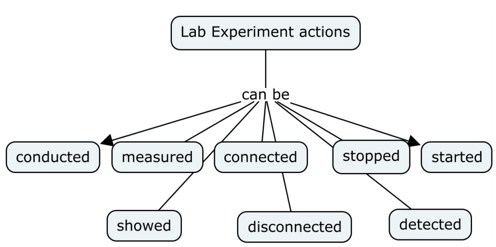

Fig. 12. Lab Experiment Role xAPI verbs

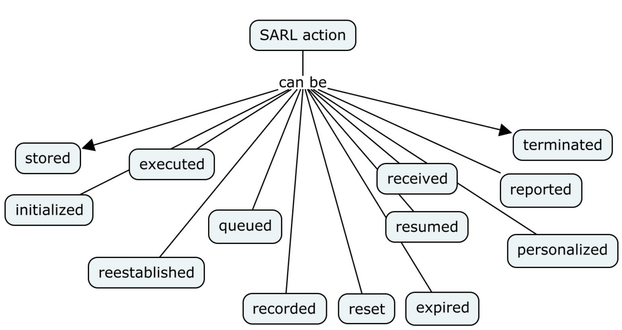

Fig. 13. SARL Role xAPI verbs

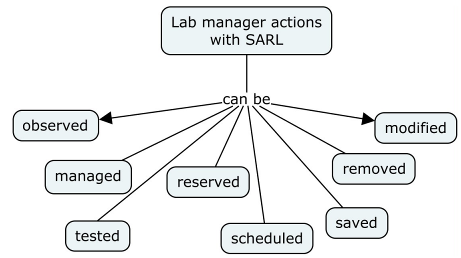

Fig. 14. Lab Manager Role xAPI verbs

The xAPI model proposed in this paper, has been successfully integrated with the IEEE Industry Connections Actionable Data Book (ADB) [21], this e-book has been implemented as a demonstration of the capabilities of using xAPI as a centralized repository of collection of data generated by the users of the e-book. The demo book presents different interactive materials, including the interfaces of our demo remote lab. The demo lab sends information to the LRS. Once the LRS receives the information, it is immediately forwarded to the e-book LRS.

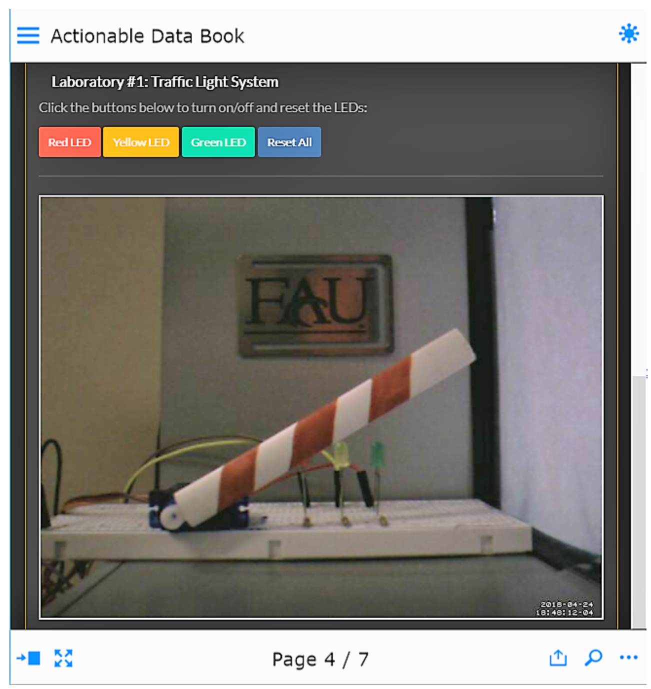

Fig. 15. ADB E-Book Remote Laboratory Integration

Figures 16 and 17 present screen captures of the statements that are sent from the SARL system to the LRS. The first one, figure 16, is a general view of the xAPI statements received in the LRS. Figure 17 shows the xAPI statement created and sent when the student executes a command in the remote lab experiment. The student received 100 points out of a 100 possible in the activity. In this case, the additional field ”results” is used in the xAPI statement to report the grade of the student.

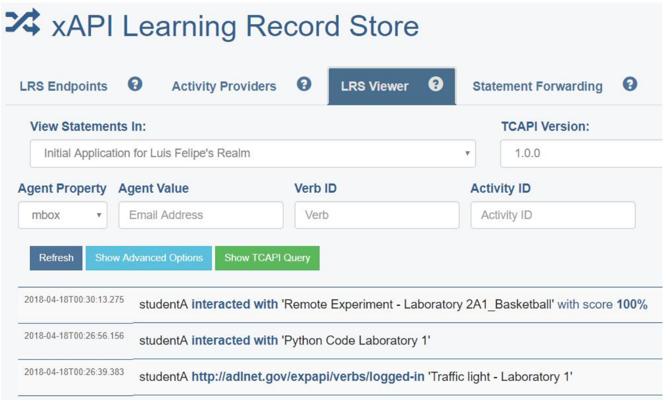

Fig. 16. LRS xAPI statements view (SCORM Cloud Platform)

Fig. 17. xAPI statement content (JSON structure)

VI. Conclusion

Having a more robust tracking system, allow the integration between laboratory and VLE. Giving more flexibility to the user and making possible a learning process independent of the place or the platform. Learning can start in one place and continue in another no matter the geographical location, the system used or what type of device the user owns.

xAPI statements adhering to predefined vocabulary can be used to capture user experiences at different granularity levels, Allowing learning analytics to extrapolate information that support the different roles of remote laboratory users.

More work is needed to provide standards and best practices to facilitate the use of online laboratories. During the last 3 years the IEEE working group P1876 has been developing the standard that defines the architectures and the standard implementation processes of online laboratories for education. In parallel until 2017, IEEE industry connection ADB working group accomplished innovative results integrating multimedia and interactive software and hardware to e-books. Recently the project IEEE Industry Consortium on Learning Engineering (ICICLE) has started promoting the use of xAPI in different applications in the educational context. Educational roles and adaptability approaches of SARL model are expected to be added as part of the definition and best practices recommendations of the P1876 standard definition.

Future Work includes the development of a learning record consumer systems to retrieve information from the LRS and send it back to the SARL system and to the LMS/VLE. Using this information to give feedback to users in the different roles.

The students can receive a periodical or on-demand reports, giving them information about his/her performance during the sessions labs. The teacher can use this information to create the grade reports and to follow the process of learning of his students. The SARL system can use the processed information from the LRS to auto-adjust the laboratory experiments and to fix problems generated during the user experimentation sessions. Finally the LMS can use the information to update the user profiles and enable or disable content according with the student results in the lab sessions.

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