

IEEE Standard for Networked Smart Learning Objects for Online Laboratories

IEEE Education Society

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Standards Committee

IEEE
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New York, NY 10016-5997
USA

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IEEE Standard for Networked Smart Learning Objects for Online Laboratories

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Abstract: Methods for storing, retrieving, and accessing online laboratories as smart and interactive learning objects are defined in this standard. For this purpose, the first level of the standard offers any online laboratory (lab) as a service (Lab as a Service or LaaS). The standard also defines methods for integrating online laboratories as smart learning objects in learning environments and learning object repositories.

Keywords: IEEE 1876™, Lab as a Service (LaaS), learning environment, learning object repository, metadata for learning resources, mobile laboratory, mobile learning, networked learning environments, online distributed simulations, Open Educational Resources (OER), online laboratory, online laboratory architecture, online laboratory brokerage, open laboratory, remote laboratory, Science, Technology, Engineering, and Mathematics (STEM) Education, smart device, virtual laboratory

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Avron Barr	Randall Groves	Stephen Schwarm
Shelly Blake-Plock	Werner Hoelzl	Steven Smith
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Introduction

This introduction is not part of IEEE Std 1876-2019, IEEE Standard for Networked Smart Learning Objects for Online Laboratories.

Laboratory activities in support of Science, Technology, Engineering, and Mathematics (STEM) Education aim at attaining pedagogical goals and developing engineering skills. Laboratory activities can nowadays be carried out online, thanks to information and communication technologies (ICT). Such online laboratory activities rely on networked electronic devices such as personal devices (desktop computer, laptops, digital tablets, or smartphones), as well as Internet of Things devices (such as connected sensors and actuators).

Online laboratories for STEM education are educational ICT systems. They are becoming more and more popular. In many cases, an online laboratory experiment consists only in remotely interacting with devices over computer networks without necessarily reflecting the educational objectives that underlie the activities. This standard establishes the relationship between all the components (hardware, software, and learning environments) in order to ease the design and implementation of pedagogically driven online laboratory activities. This standard is designed to ease the design, the implementation, and the usage of pedagogically-oriented online laboratories as smart learning objects and their integration in learning environments and learning object repositories.

Figure 1 illustrates the implementation layers of online labs as smart learning objects that are considered hereafter for standardization. The first layer standardizes an online Lab as a Service (LaaS), which can be personalized at the second layer. The second layer describes an online Lab as a Learning Object (LO), which can be integrated in various learning environments, including massive open online courses (MOOCs), learning management systems (LMSs), learning resource repositories, and mobile applications.

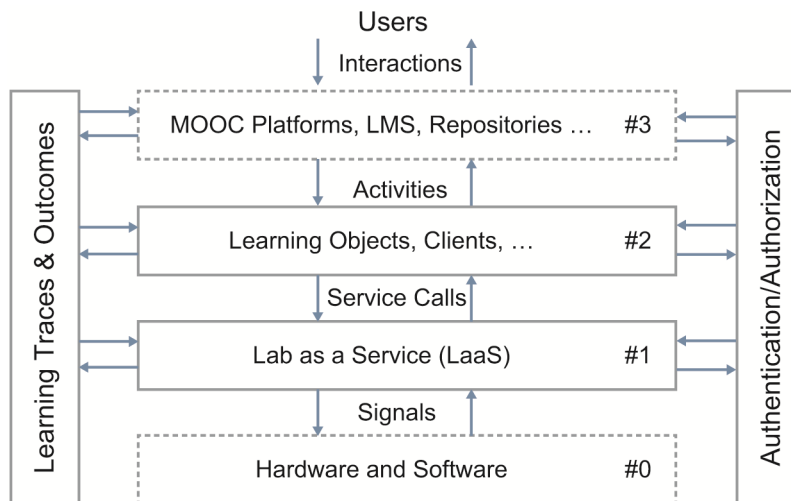


Figure 1—Conceptual layers and normative information

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IEEE Standard for Networked Smart Learning Objects for Online Laboratories

1. Overview

1.1 Scope

This standard defines methods for storing, retrieving, and accessing online laboratories and associated data as smart and interactive learning objects. For this purpose, the standard does so within the context of defining an online laboratory (lab) as a Lab as a Service (LaaS). The standard also defines methods for integrating online laboratories as smart learning objects in learning environments and learning object repositories. Finally, this standard demonstrates, through use cases, how adhering to the methods defined herein can satisfy pedagogical objectives.

Within the context of this standard, LaaS is defined as a set of interface requirements to be met to satisfy the first level of standardization. This provides a standard interface. Once this interface is established, an online laboratory should fit within learning frameworks as a Learning Object to provide pedagogical value. This capability, however, is not something that can be guaranteed. Therefore, the second level of standardization is defined as a set of recommended practices.

1.2 Purpose

The purpose of this standard is to ease the design, implementation and use of online laboratories for education. It is understood that laboratory activities are required in Engineering, Science, and Technology Education. Laboratory activities aim at fulfilling pedagogical objectives and developing experimental skills. Laboratory activities can nowadays rely on digital education solutions. Such solutions generally integrate networked electronic devices such as computers (desktops, laptops, tablets, and smartphones) as well as networked measuring instruments or electromechanical devices. Online laboratories for education are technology enhanced learning resources. They are becoming more and more popular. This standard defines and establishes the relationship between all the components required to carry out pedagogically sound experiments using laboratories (equipment, software, hardware, and services). The standard aims at facilitating the work of lab owners when setting up and sharing online laboratories; the work of platform managers when offering and enabling the exploiting of online laboratories as learning objects; the work of teachers when integrating and implementing an online laboratory in their pedagogical scenarios; and the work of learners when interacting and learning with online laboratories.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1484.12.1™-2002, IEEE Standard for Learning Object Metadata.^{1, 2}

3. Definitions, acronyms, and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.³

client: An entity that enables the user to access/exploit centralized services and resources, in this context, the online lab.

NOTE—When live interaction is supported, the client interface enables an *interactive experimentation* mode where the results are collected in real time; otherwise the client interface enables a *batch experimentation* mode where the results are collected at a later time.

experiment: A scientific procedure to make a discovery, test a hypothesis, or demonstrate a known fact. In the context of this standard, it consists of a sequence of service calls to LaaS, followed by internal LaaS activities, and its corresponding responses to the client.

laboratory: A set of hardware or software (or both) components that are integrated to perform scientific experiments in an educational context. *Syn. lab.*

learning activity: An ordered set of tasks for a learner or a group of learners to acquire some knowledge or skills resulting in *learning outcomes*.

learning object (LO): Any entity, digital or non-digital, that can be used for learning, education, or training. (IEEE Std 1484.12.1-2002.)

NOTE—This document addresses how online labs can be exploited as a learning object. The online lab could be either remote or virtual, especially designed for individual or collaborative, synchronous or asynchronous learning activities. Examples include distance learning, personal learning, blended learning, or Massive Open Online Courses (MOOCs).

online laboratory: A laboratory that is accessible via computer networks, such as the Internet. An online lab can either be virtual, remote, or hybrid of the two.

remote laboratory: A set of network-connected physical devices that can be observed and controlled at distance.

NOTE—The assumption is that the underlying connecting network is the Internet. The physical devices are mainly sensors and actuators that respectively sense and change the physical environment they are sitting in. A remote lab is hosted in a physical space (e.g., building, nature...) and is provided and/or managed by lab providers (e.g., person, institution, organization, or

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company). A remote lab could support two modes of interaction: real-time and batch. In the real-time mode, the user experiments and collects data live, while in the batch mode the user submits the experimental commands and collects the results at a later time.

server: An entity that manages/provides access to centralized resources or services.

NOTE—In the context of this standard, an LaaS server.

virtual laboratory: An interactive simulation of physical phenomena supported by mathematical models or experimental datasets.

NOTE—The simulations are provided as software applications, which allow the learners to assimilate some knowledge regarding some scientific theories and physical phenomena, otherwise impossible in a real physical space (e.g., generation of nuclear power). The simulations run on physical and remote application servers. A virtual lab is provided and/or maintained by the same or different entities (person, institution, organization, or company).

3.2 Acronyms and abbreviations

ADB	actionable data book
ADL	advanced distributed learning
API	Application Programming interface
CSS	cascading style sheets
DAQ	data acquisition
FIM	Federated Identity Management
GDPR	General Data Protection Regulation
GPIO	general-purpose input output
HTTP	hypertext transfer protocol
IaaS	Infrastructure as a Service
IdAM	Identity and Access Management
IMS	Instructional Management System
I/O	input/output
IP	Internet protocol
IRI	Internationalized Resource Identifier
LaaS	Lab as a Service
LED	light emitting diode
LMS	learning management system
LO	learning object

LOM	Learning Object Metadata
LRS	learning record store
LTi	Learning Tools Interoperability
MIME	Multipurpose Internet Mail Extensions
MOOC	Massive Open Online Course
OAuth	Open Authorization
OEL	Open Educational Lab
OL	online laboratories
RDF	Resource Description Framework
REST	Representational State Transfer
RFC	Request for Comments
RPi3	Raspberry Pi 3
SAML	Security Assertion Markup Language
SARL	Smart Adaptive Remote Laboratories
SOAP	Simple Object Access protocol
SSO	single sign-on
TLA	Training and Learning Architecture
UI	user interface
URI	uniform resource identifier
URL	uniform resource locator
USB	universal serial bus
VLAN	Virtual Local Area Network
VLE	virtual learning environments
VRML	Virtual Reality Markup Language
WebIOPi	Web Input Output control for Raspberry Pi
WS-Federation	Web Services Federation
WSDL	Web Service Description Language
xAPI	Experience Application Programming Interface

4. First layer of standardization: Lab as a Service (LaaS)

LaaS is a term derived from the XaaS series of terms, where “X” means anything and “aaS” refers to “as a Service.” In this paradigm, the assumption is that anything “X” is offered as a service over the Internet rather than at a physical space. LaaS refers to Laboratory as a Service, where a lab is abstracted and made remotely available through Internet as a service. In this clause, paradigm of LaaS is introduced, followed by the proposal for abstracting it as a lab as a service.

4.1 Introduction

An online lab standardized as Lab as a Service (LaaS) provides services and integrates functionalities. A service represents, for instance, a sensor or an actuator that is made available to the outside world (i.e., the client) through Application Programming Interfaces (APIs). Services are fully described and documented so that an interfacing client application can use them without additional explanation. A functionality is an internal behavior provided by the online lab. There may be communication between functionalities and the client interface through services but not necessarily. While the required services are fully described through APIs, the functionalities are only recommended, and best practice guidelines are provided. For example, there can be an actuator service that enables the client application to set the voltage of a motor connected to the server, and a functionality that checks that the maximum voltage is not exceeded (and corrects it if needed). The actuator service is well described by the LaaS metadata, on the other hand the internal validation mechanism is left to the lab owner’s discretion since it will be mainly ad-hoc. Still, such a mechanism must be implemented to help ensure that client applications will not break the server and the connected equipment.

To summarize, a LaaS consists of a set of well-defined services that enable interoperability with external applications and internal functionalities.

4.2 Metadata

The metadata are at the core of the support for interoperability provided by the LaaS. On one hand, they provide a general description of the online lab, which is useful for publishing them into a lab repository. On the other hand, the metadata provide technical details about the online lab. This technical detail constitutes all the elements necessary to fully describe the lab as an API, and hence supports the claimed interoperability features of a LaaS. So, the metadata can be used to automatically generate user interfaces. The full metadata shall consist of the following elements, which are further described in the next subclauses:

- a) General information on the online lab, including its name, description or contact information
- b) List of APIs describing the services (i.e., sensor and actuator services). The services are fully described in [4.3](#)
- c) Authorization mechanisms allowing the access to the services, as described in [4.2.3](#)
- d) Concurrent access mechanisms managing possible multiple access requests simultaneously to a same resource, as described in [4.2.4](#)

The general metadata document for an LaaS provider should include one element from each of previous points, a) through d).

4.2.1 General metadata

The general metadata shall provide information about the online lab, such as the name, a short description, the terms of service, a contact person, and licensing information as defined in [Table 1](#).

Table 1—General metadata fields

Name	Type	Description
title	String	General title of the online lab.
description	String	Extended description of the online lab, features, etc.
termsOfServiceURL	URI	Link to the terms of service of online lab.
contact	Internet Message Format, e-mail	The e-mail of the contact person.
license	String	The license of use of the online lab (CC, Apache 2.0, GNU, etc.)
licenseUrl	URI	Link to the terms of the license specified in the “license” field.

4.2.2 Binding metadata

The binding metadata shall list all API endpoints or available services, as defined in [Table 2](#) through [Table 6](#). In this subclause, the general fields are included. The other fields are discussed in the subclauses specific to each service.

[Table 2](#) identifies and describes the basic binding metadata fields, i.e., *basePath*, *apis*, and *models*.

Table 2—Binding metadata fields

Name	Type	Description
basePath	URI	The root URL path of the service
apis	Set[ServiceDescription]	Set of Service Description elements
models	Set[Models]	Set of Models used in Service Description elements

The service description fields provide the description of the service, as shown in [Table 3](#).

Table 3—Service description metadata fields

Name	Type	Description
identifier	URI	Parameter to reach the service
protocol	Vocabulary	Communication protocol used by the services
produces	Data Type	Encoded data type of requests and responses
operations	Set[Operation]	Set of Operation elements

Referring to [Table 3](#), the *identifier* field provides information on how a service is reached. It is formatted accordingly to the communication protocol used by the lab. For instance, if REST is the communication protocol, the identifier would be of type URL. The *protocol* field designates which communication protocol is adopted by the lab. The *produces* element specifies the data type in which the data communicated with a client application are used. The *operations* field contains parameters that describe in detail the representation of a service; these parameters are detailed in [Table 4](#).

Table 4—Operations metadata fields

Name	Type	Description
method	Vocabulary	Method used in the communication for this operation
nickname	String	Service title
summary	String	Short description of the service
notes	String	Detailed description of the service
type	String	Model used to represent the service
parameters	Set[Parameters]	Set of Parameter elements used in the operation
responseMessages	String	Response message corresponding to different responses

Referring to [Table 4](#), the *method* field specifies the communication protocol method used for the service. It corresponds to one of the possible method values for the used communication protocol. The *nickname* field is necessary to include in every request in order to identify the required service. The *summary* and *notes* fields, respectively, provide a short and detailed description of the service in order to provide a better understanding of the expected behavior. The *type* field then specifies the *model* according to which the response is formatted. The *parameters* field is an array of arguments to be passed in the request. [Table 5](#) details its elements. The *responseMessages* field provides for any needed reply to a request.

Table 5—Parameters metadata fields

Name	Type	Description
name	String	Name of the parameter
description	String	Description of the parameter
required	Boolean	If required or not
paramType	Integer	Numerical type of the parameter

The last element of the binding metadata is *models*. The *models* provide a description of the requests and responses exchanged between the client application and the LaaS server. They are necessary to allow the parsing of requests and responses on both sides. [Table 6](#) details the fields that make up a *model*.

Table 6—Models metadata fields

Name	Type	Description
id	String	Name of the model
required	Set[String]	Lists all fields of the ‘properties’ field that must be provided in any instance of that model
properties	Set[Property]	Set of properties for this model

4.2.3 Authorization metadata

The authorization metadata allow the definition of a security scheme that can be used by the online laboratories to allow third party users to access the services and shall be defined as shown in [Table 7](#) and [Table 8](#).

Table 7—Authorization metadata fields

Name	Type	Description
authorizationType	Vocabulary	Authorization type
keyName	String	Holds the authentication credentials
authServiceUrl	URI	Refers to the location of the authentication service

Supported schemes are basic authentication, an API key (either as a header or as a query parameter), and OAuth2's common flows (implicit, password, application, and access code), as shown in [Table 8](#).

Table 8—authorizationType vocabulary

Name	Values
authorizationType	basic
	apiKey
	SSO protocol

4.2.4 Concurrent access metadata

The concurrent access metadata help to define the concurrency of the models of online labs, so client applications can handle the different mechanisms appropriately. Different concurrency mechanisms exist, and it is up to the online lab owner to decide on the appropriate scheme for his or her lab. Concurrent access metadata shall be defined in accordance with [Table 9](#) through [Table 13](#).

Table 9—Concurrent access metadata fields

Name	Type	Description
interactionMode	Vocabulary	Synchronous or asynchronous
concurrencyScheme	Vocabulary	The concurrency scheme for the online lab
roles	Set[Role]	Set with the described roles

The interaction with an online lab can be in a synchronous or asynchronous mode. If the mode is synchronous, the users are interacting directly with the lab. If there are other people using the lab concurrently, the user is aware of their actions, if supported by the lab owner. If the mode is asynchronous, the user typically prepares an experiment, submits it to the lab, and waits to get results back. Users are not aware of other users' activity in this case. For this reason, the field “interactionMode” may take one of the two values from the vocabulary as shown in [Table 10](#).

Table 10—interactionMode vocabulary

Name	Values
interactionMode	synchronous
	asynchronous

The rest of these metadata are for synchronous online labs, since asynchronous labs can internally deal with concurrency issues. There are typically two possible concurrency schemes ‘concurrent’ and ‘roles’ (modeled in the ‘concurrencyScheme’ field). Either the online lab allows users to operate the experiment at the same time, or provides different user roles to control access to the experiment, as shown in [Table 11](#).

Table 11—concurrencyScheme vocabulary

Name	Values
concurrencyScheme	concurrent
	roles

Each role shall be described in the ‘roles’ field of the Concurrent access metadata. This is shown in [Table 12](#). Each role has a name (in the ‘role’ field), and the role selection mechanisms that this role has are listed in ‘roleSelectionMechanism’ metadata field. Furthermore, the role can declare which services are accessible if the user is assigned a particular role, in the ‘availableAPIs’ field.