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Chapter LV
Learning Object Model for Online Laboratories

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ABSTRACT

Online learning environments provide the students access to the course content at any time and from anywhere. Most of the existing e-learning systems are designed for content-based subjects that deliver course content such as text, images, video, audio, and simulation to the student through the Internet. In recent years, several online or remote laboratories have been developed to bring the e-learning concept to the lab-based courses. These systems, mainly Web-based, allow students to conduct real laboratory experiment, as opposed to computer simulations, from anywhere and at any time. In this chapter, we introduce a model for providing lab-based lessons as learning objects (LOs). The learning object model has been widely used in content-based e-learning systems. We then propose a learning management system (LMS) framework that helps students to remotely access the lab-based learning objects (LLOs). We will also present some experimental results and implementations.

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INTRODUCTION

The term e-learning refers to a mixture of different preferred learning methods, which delivers to the learner through the use of information technology and is supported with instructional design and engaging content. The trend of using e-learning as an educational platform is increasing in corporations, universities, and industries. The dream of teaching and learning from anywhere, at anytime becomes reality with the construction of the e-learning infrastructure. Great attention has been paid to apply e-learning strategy for the future education. However, seldom research can be found in the literature for the e-learning subjects that involve hardware (i.e., lab-based experiment courses).

LOs are discrete units of learning resources based on agreed e-learning standards. However, there are some difficulties to apply the LO concept to the lab-based course due to the different nature of their content. For the lab-based course, it uses the real hardware that is actually not considered in the existing e-learning standards.

In this chapter, we propose a framework for online laboratories to facilitate the design and deployment of lab-based courses. The framework is an extension of the Sharable Content Object Reference Model (SCORM), which handles and processes the lab apparatus in a standard and uniform e-learning environment. We will introduce a LO model applied to lab-based lessons. The framework is then used as a container to facilitate access to the lab-based LOs.

BACKGROUND

An e-learning system that uses learning object model consists of three components: the LO itself, which is the actual content (text, graphic, animation, etc), meta-tags, which describe the object, and finally a learning content management system (LCMS), which stores, tracks, and delivers content. The metadata is used to describe and index the LOs. This helps learners to seek and retrieve the specific material that they are looking for from a repository.

In this section, we provide some background relevant to understanding of an e-learning system, which is based on the LO model and LCMS. A short review on the related research and key organizations engaged in developing related standards will be presented.

Reusable Learning Objects

The term learning object was first popularized by Wayne Hodgins in 1994 (Polsani, 2003). The main idea is to have learning material broken down into smaller pieces that could be later combined by instructors, learners, and eventually computers.
into larger structures to support learning. The LO is any entity, digital or non-digital, which can be used, re-used, or referenced during technology supported learning (IEEE Learning Technology Standards Committee, 2002). It is commonly viewed as the smallest element of stand-alone information required for an individual to achieve an enabling performance objective or outcome. As these entities can be reused in other subjects, they are often called reusable learning objects. Figure 1 illustrates the concept of reuse of LO in different learning content.

**Learning Content Management System**

An LCMS is “a multi-user environment where learning developers create, store, reuse, manage, personalize, and deliver digital learning content from a central object repository” (Nichani, 2001). LCMSs consist of the two following components:

- **Learning management system (LMS):** LMS manages students and learning events and collates data on learner progress.
- **Content management system (CMS):** CMS simplifies the creation and administration of online content (articles, reports, pictures, etc.) used in the e-learning system.

In a CMS, complete learning courses are assembled from several self-contained chunks called content components. As we defined earlier, these content components, when used in the learning domain, are also so-called LOs.

**Key Organizations**

Many organizations are working to develop e-learning-related standards that ensure interoperability of learning solutions. Some are presented next:

- **Advanced Distributed Learning (ADL, 1997):** ADL, launched by the U.S. Department of Defense and the White House Office of Science and Technology Policy. Their SCORM Model provides one of the best and most recent examples of the application and integration of these learning standards.
- **Aviation Industry Computer Based Training Committee (AICC, 1988):** AICC had published a variety of recommendations, including hardware and software configuration. Their computer-managed instruction (CMI) guidelines had the greatest impact.
- **IMS Global Learning Consortium (IMS, 1997):** IMS aims to develop and promote open specifications for facilitating online distributed learning activities. These specifications describe the key characteristics of courses, lessons, assessments, learners, and groups. IMS is a consortium formed by almost 200 commercial, governmental, and other entities.
- **IEEE Learning Technology Standards Committee (LTSC, 1996):** LTSC is an accredited standards development organization within the IEEE. The LTSC focuses on standards development specifically in the area of e-learning technologies. The most widely acknowledged specification is the learning object metadata (LOM) specification, which defines element groups and elements that describe learning resources.

**Related Research**

Providing laboratory-based experiments as an online service has been growing in popularity in recent years. Several online or remote laboratories have been developed to bring the e-learning concept to the lab-based courses. These systems, mainly Web-based and allow students to conduct real lab experiments, as opposed to computer simulations, from anywhere and at any time.
In this section we will introduce a few of these systems as examples.

Starting in 1992 at Stanford, Hesselink et al. (2003) designed an Internet accessible laboratory named Cyberlab (Senvid, 1999). It provides controlling laboratory equipment and instrumentation on an optical processor over the Internet. Students are given the option of observing the Fourier transform computationally through Cyberlab.

Benetazzo et al. (2000) described the specification and design of a geographically distributed system based on an arbitrary waveform generator, oscilloscope, digital multi-meter, and signal analyzer. In his design, students were only allowed to use the equipments, but tutors, Ph.D. students, and some selected students in advanced measurement courses were allowed to contribute in the creation of the lab components.

González-Castaño et al. (2001) designed an Internet access laboratory using the Java/CORBA paradigm. The system provides remote access to real equipment on SBC68K (a single board computer based on a Motorola MC68000 microprocessor), used in a computer architecture laboratory. It uses CORBA technology to manage real equipment so that anyone could invoke it remotely as another set of CORBA objects.

A low-cost, Internet-based tele-robotic system was applied in remote robotic education (You, Wang, Eagleson, Meng, & Zhang, 2001). It is based on China’s Internet. You et al. have addressed some issues involving Internet time delays when data were transmitted between client and server.

**MAIN FOCUS OF THE CHAPTER**

Currently available, online lab systems are mainly concerned about the setting up of remotely accessible experiment systems for research or stand-alone teaching purposes. However, no universal platform has been developed so far, nor any standard development for designing and deploying lab experiments has been proposed. A notable exception is perhaps Pastor, Sanchez, and Dormido (2003), which proposed an XML-based framework for the development of new paradigms on Internet-based laboratories. Moreover, existing LCMS does not provide a suitable framework to incorporate lab-based courses.

The proposed framework can be considered as a container for the experimental and lab-based LOs. Every LO integrated into the framework can then share the resources provided by the framework.

In this section, we introduce the proposed framework for an online laboratory, which included a lab-based LMS or LLM for short and the LO model for lab-based subjects. We will also present sample experiments we have implemented.

**Learning Management System**

As shown in Figure 2, the framework is an extension to the SCORM (ADL, 2004) specification with proposed additional modules, such as apparatus virtual user interface, apparatus run-time environment, and so forth. These modules mainly deal with functionalities of lab apparatus and e-learning server communication. The SCORM specification published by ADL is a reference model that defines the interrelationship between e-learning system components, data models, and protocols so that LOs can be shared across systems that conform to the SCORM model. It contains a collection of specifications adapted from global specification bodies and consortia to provide a comprehensive suite of e-learning capabilities.

The SCORM deals with the launching, communicating, and tracking of content between the learning resources and the LMS. It provides means by which learning resources can be reused and interoperated across multiple LCMSs. It consists of three components, which are:

- **Learning resources:** Learning resources represent learning content (Web page, JavaScript, XML document, Flash object,
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Figure 2. Proposed e-learning framework for online laboratory

To extend the SCORM to the lab-based courses, we propose to extend the framework with two addition modules called apparatus virtual user interface (App-VUI) and apparatus run-time environment.

App-Virtual User Interface

To carry out an experiment from the Internet, students need to work in an interactive environment. The App-VUI provides multiple students to observe and conduct the online lab experiments. The App-VUI allows the student to issue control commands through the user interface (UI). Meanwhile, the experiment feedbacks, such as the apparatus response and status, are all shown in the App-VUI display area.

App Run-Time Environment

In most cases, for a real lab session, one apparatus can only be used by one user at a time. Multi-user’s operation may confuse or damage the hardware if no prevention is taken. In our design, we consider the following two basic principles:

1. For any online lab session, only one user is permitted to conduct a particular experiment at a time.
2. A user can conduct a particular experiment within a specified time period, that is, timeout mechanism.

Based on these principles, the user has to wait for the apparatus to become available if a student is using the apparatus. For any lab session, there is
one daemon provided by the apparatus run-time to collect the user command and experiment data. A sequence diagram of an online lab session running in the apparatus run-time environment is given in Figure 3.

Before we discuss the details of the apparatus run-time environment, the SCORM’s run-time environment (as shown in Figure 4) will be presented.

As can be seen in Figure 4, in the SCORM run-time, the launch process defines a common way for LMS to start a Web-based LO and defines procedures for the establishment of communication between the launched object and the LMS.
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Figure 4. SCORM conceptual run-time environment

Figure 5. Proposed apparatus run-time environment
The communication mechanism is standardized with a common API using ECMAScript (ECMA, 1961). The API is the communication mechanism for informing the LMS of the conceptual communication state between an LO and an LMS (e.g., initialized, terminated and/or in an error condition) and is used for retrieving and storing data (e.g., score, time limits, etc.) between the LMS and the LO.

Corresponding to SCORM run-time, we have introduced an apparatus run-time environment to solve the communication between LCMS and lab apparatus. The apparatus run-time environment is the key to achieve the e-learning goal in lab-based courses. In general, the app run-time provides the run-time environment to manage a variety of lab apparatus and coordination with the SCORM run-time. Figure 5 depicts the proposed model.

As shown in Figure 5, there are three types of interfaces for the apparatus run-time to communicate with other modules:

- **Message processor**: Message processor is responsible for interacting with the client. Its functions include receiving the control commands and sends feedback of the experiment data and status to the student.

- **Apparatus API**: Apparatus API provides communication channel for app run-time environment and apparatus to exchange data. These APIs provide all the necessary functions for initiating a connection to the actual apparatus and delivering data and commands.

- **SCORM interface**: SCORM interface is used to exchange the information about the student and learning progress with SCORM run-time. The LCMS contains all user information and status data for historical purposes or for other purposes such as reporting, auditing, diagnostic, or statistical.

The SCORM interface is a set of APIs provided by apparatus run-time to allow LLM to communicate with the LCMS in a consistent manner. Figure 6 illustrates the communication relationship between an apparatus run-time and SCORM run-time. As shown in Figure 6, four APIs are currently considered in the proposed system, which are Initialize(), GetValue(), SetValue(), and Commit(). The “Initialize()” API must be called to execute “GetValue()” or “SetValue()” to read or change LCMS’s data. The “Commit()” API is used to enable the “SetValue()” function and terminate the last “Initialize()” call.

To provide the online lab services, the app run-time includes several core modules, such as session management, load balancing, and report generation.

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**Figure 6. SCORM interface**

![SCORM Interface Diagram](image-url)
Session Management

In face-to-face lab sessions, the lab technician is responsible for guiding the student to conduct the experiment and collect the experiment results. In the app run-time environment, the session management is acting the same role. The session management module is responsible for monitoring the lab sessions in order to:

- Terminate the experiment once time-out occurred
- Reset the apparatus for a new user
- Inform the lab manager in case of any hardware failure

Considering the management of a real laboratory, all students who enrolled the course share the lab resources based on a scheduled timetable. The design guarantees that only one user has the chance to access the apparatus at a time.

Load Balancer

In the real world, lab resources, such as lab schedule or opening hours; equipment; and lab assistants are always limited. Hence, some form of load balancing is necessary. The purpose of load balancing is to increase utilization and enhance apparatus availability. In this case, a few lab apparatus, which have the same functions and I/O, need to be developed and made available in the app run-time environment. So, when several requests come to the same experiment, the load-balancing module can perform automatic balancing to redirect the request to point to different apparatus according to a pre-scheduled rule.

Report Generator

Once the student completes the experiment, he/she may need to download the experiment results and control command data for further analysis. In the proposed apparatus run-time environment, there is one report generator module, which performs the data collection during a lab session. All data, such as the experiment feedback, status or user command, will be collected automatically. To enhance the readability, the proposed report generator could process these data according to the different XML schema. So, it could easily generate a personalized report for different user using the same experiment data.

Apparatus API

To allow a user to conduct online lab experiment, there must be a common way to start, stop, and control the apparatus. In the proposed app run-time environment, a set of APIs have been defined to provide a consistent manner to communicate with apparatus. These APIs provide a standard way to initialize a connection, send a command, and receive data from an established socket. So, different LCMSs could provide the same online lab experiment services by invoking the same APIs.

Lab-Based Learning Object Model

The LLO is different from the normal LO in terms of communication. For LO, only one communication link between user and LCMS is considered. For LLO, full-duplex communication between LCMS and lab apparatus must be considered. An LLO consists of both the hardware and the controller software. To allow the user to access and control the hardware, a communication mechanism must be provided for data exchange between the LLM and the controller software. An LLO model is presented in Figure 7.

In the proposed infrastructure, an LLO refers to real hardware with a controller (i.e., electrical board, medical equipment, and optical device) that can be connected to the network via TCP/IP protocol. The TCP connection is used for the important data (i.e., user command and experiment status), whereas, the user datagram protocol (UDP) con-
Connection is introduced for streaming data (i.e., experiment video). The controller can be any form of embedded or PC-based devices with a communication module that enables the connection to the network. For the software part, it executes the local control of the hardware and collects the experiment’s data. As a whole unit, the controller must have the physical interface such as DA/AD converter and data acquisition card to link with the actual equipment. Besides the controller and the lab apparatus, an XML-based apparatus markup language (AML) description file is used to describe the apparatus as shown in Figure 7.

The controller is developed in a modular manner. A modularized controller is shown in Figure 8. Modularizing is the designing of software applications before coding. Modular design makes the control program more readable and maintainable. Every module shown in Figure 8 is one function, which performs a specific task.
The communication between LLO and LCMS, generally, could be treated as computer to instrument communication. Instrument communication refers to the mechanism for machine-to-machine’s data and information exchange. Basically, the instrument sends or receives information to/from another end of equipment, machine, or computer. Information from the instrument may inform the other end about its processing status, performance, and errors. If the interface is implemented using a defined standard, then machine could use the same interface to “talk” with others as human beings, say a same language, so, they could understand each other. Sometimes the communication interfaces are used not only to monitor a machine, but also to control it. This includes downloading settings; configuring various software controls; and starting and stopping the machine processing.

**Apparatus Markup Language**

In short, AML is a specification for using XML to aid in the exchange of data and commands with apparatus. The AML is used to describe the control UI, commands, and data that can be transferred. A tool reads the AML, then automatically creates an appropriate UI for issuing commands, and finally sends the commands in response to user input. When responses come back, the same tool can use the AML specification to interpret the incoming data and automatically present it with an appropriate UI.

Pastor et al. (2003) presented an XML-based framework, Remote Laboratory Extended (RELATED), for the development of Web-based laboratories. The idea is to define an abstract entity called RLAB system by an XML DTD so that lab experiments can be described by RLAB. Then, the RLAB schema is published on the server for general use.

A group at NASA’s Goddard Space Flight Center is using a dialect of XML called the instrument markup language (IML) (NASA, 1999), which is used to describe graphical user interfaces (GUIs) to control and monitor the instrument; command sets and command formats; data streams; communication mechanisms; visualizations; and more. The astronomical instrument markup language (AIML) is a domain-specific implementation of

<table>
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<th>Table 1. Definition of an indicator meter</th>
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<td>type=&quot;indicator&quot; /&gt;</td>
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the more generalized IML. Both AIML and IML vocabularies are based on XML, which is an instrument description that encompasses instrument characteristics, control commands, data stream descriptions (including image and housekeeping data), message formats, communication mechanisms, and pipeline algorithm descriptions.

A similar project, virtual instruments markup language (VIML) (Nacimiento Software Corporation, 2000) has been submitted to XML.ORG (XML, 2006) (an industry Web portal formed and introduced in June 1999 by OASIS) and is under development. The VIML can be used to describe location, protocol, and device information for a network of virtual instrumentation devices and/or systems. The main objective is to publish control panel of virtual instrumentation to Web.

We have proposed a much simpler AML to describe and present a lab-based LO. We have defined two categories of component for the LLO: control variable and indicator variable. The former refers to those control components whose value could be changed. The indicator variable is used to show the status of the LLO, and the user is not allowed to control it (or the value of the indicator cannot be changed by user). The followings are four examples to define an indicator meter (see Table 1), control meter, control knob, and indicator graph using AML. The first and fourth are components to show the changes or status of the LLO. The second and third are control components to allow the user to change the value (the value could be sent to the apparatus via the established connection). The AML file can be written according to the definitions format provided using any common text editor.

Once the AML has been created, it can be imported to the LCMS server. An XML parser provided by the LLM could interpret the AML and automatically generate the UI. The UI packages the command, which will be send to the lab apparatus and also display the feedback.

When a user starts a lab session, the client computer downloads and installs the XML parser only once. Every time the UI is displayed, only the AML file is downloaded. Thus, especially in slow connections using the parser would consume much less resources than making a UI directly using Java.

Figure 9. Coupled tank

![Coupled tank](image-url)
Implemented Learning Objects

In this section, two lab apparatus, which have been developed based on the proposed LLO concept, are presented to illustrate the implementation of e-learning framework for lab-based courses.

Coupled Tank

The coupled tank apparatus, as shown in Figure 9, consists of two small Perspex tower-type tanks mounted above a reservoir, which functions as storage for the water. Two independent pumps pump water into the top of each tank. The level of water in each tank is monitored by a capacitive-type probe that outputs a signal proportional to the water level. A microcontroller device is also attached to the coupled tank apparatus. The objective of this experiment is to maintain the water levels in the tanks at the specified heights. The apparatus is designed for teaching elementary feedback control principles.

A Web-based UI is created to allow students to interact with the coupled tank via the Internet (see Figure 10). For the coupled tank, the display area is created to plot the pump voltages and water level in real-time manner. This VUI allows the student to conduct an experiment with a different controller, such as manual, ON/OFF, proportion-integral-derivative (PID) control, and to study the effect of adjusting the various parameters settings available in the controller. The student can also download all data collected by the LLM for further analysis when the experiment has been completed.

Ohm’s Law Board

The objective of this experiment is to teach the student the basic principles of Ohm’s Law. During this lab session, students are allowed to interact with a circuit board to conduct various experiments (see Figure 11). The student could change the power supply, turn the on or off the switch, and measure the voltage and current so that he/
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Figure 11. Ohm’s Law circuit board

Figure 12. Apparatus VUI for Ohm’s Law (client interface)
she could find the relationship of resistance (R), current (I), and voltage (V).

The board is connected to a computer through a data acquire card (DAQ). It could be controlled locally or remotely (with additional communication module). The designed VUI of Ohm’s Law circuit is shown in Figure 12. The VUI allows user to change the Power supply through a knob. Once the knob has been changed, the user could press the “Measure” button to read the current and voltage shown on the meters. In addition, the different connection can be achieved through turning, on or off, the different switches.

**FUTURE TRENDS**

The e-learning framework for lab-based courses could lead to applications not limited to education, as it offers the opportunity for efficient collaboration in research and development. Technologies developed for education could be transferred to industry for a wide array of applications, including remote control of appliances, instruments, dangerous processes, and smart structures.

In addition, it is recommended that further research might cover how to improve the performance of the system in terms of Internet time delays, apparatus usage efficiency, and framework scalability. Of course, one important direction is to standardize the LLM and LLO to facilitate the developing and deploying of lab-based courses. It may take years to become true. In this case, more elaborate research work has to be done.

**CONCLUSION**

In this chapter, we have proposed an e-learning framework for online laboratories for future education. It can potentially be made available to a broad spectrum of students of an e-learning system. It provides students opportunities for developing intuition and understanding theoretical knowledge far beyond the horizon of students today. We have also introduced a simple AML to define and identify lab-based courses. The concept of a LO is extended to include lab-based components. As we have followed the current standards for the content-based e-learning systems, the proposed lab-based LOs could easily be integrated into the existing systems, which follow these standards.

Based on the proposed e-learning framework, we have developed a sample online laboratory, namely OnlineLab, in School of Electrical & Electronic Engineering, Nanyang Technological University (NTU) of Singapore (NTU, 2004). The OnlineLab has an apparatus management system so that we could import new apparatus into the system and remove the old one.

**REFERENCES**


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**KEY TERMS**

**Apparatus Markup Language (AML):** AML is a specification for using XML to aid in the exchange of data and commands with an apparatus.

**Application Programming Interface (API):** API is a set of data structures, routines, and any other programming elements that allow developers to use some part of the system software.

**Content Management System (CMS):** CMS is a system for storing, tracking, and delivering the content.

**Learning Content Management System (LCMS):** LCMS is “a multi-user environment where learning developers create, store, reuse, manage, personalize, and deliver digital learning content from a central object repository.”
Learning Management System (LMS): LMS manages students and learning events and collates data on learner progress.

Learning Object: A learning object is any entity, digital or non-digital, which can be used, re-used, or referenced during technology supported learning.

Learning Object Metadata: Learning object metadata are the attributes required to describe a learning object.

Sharable Content Object Reference Model (SCORM): SCORM is a collection of specifications that enable interoperability, accessibility, and reusability of learning content.

Extensible Markup Language (XML): XML is a standard for creating markup languages that describe the structure of data.