

eLearning for Engineering

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Abstract – Current content-based eLearning solutions do not meet the requirements of engineering education in that they lack the necessary fundamentals of engineering pedagogy, namely iterative experimentation and contextual collaborative learning. An eLearning solution for engineering must bridge the gap between the physical and virtual worlds with a comprehensive framework based on modular components that provide students with remote access to resources, and establishes a virtual collaborative community. This eLearning framework must be generically reusable, and must be able to provide users with a seamless user interface. This paper discusses the architecture of the engineering eLearning portal that integrates traditional courseware with the virtual classroom, the virtual laboratory, and eCollaboration tools. The specific implementation of this architecture for Aerospace Undergraduate Studies at the University of Toronto, namely the AeroLab Portal, is also discussed, including details of the specific software, hardware and technologies used.

Index Terms – Collaborative learning, Distance education, eLearning, Engineering portal, Remote laboratory

INTRODUCTION

The notion of eLearning as an evolution of Computer-Based Training (CBT) was initially promoted by the corporate world [1]. The academia, however, quickly recognized the potential of eLearning as a complementary means of content delivery and hence began to integrate it into the traditional curricula, heuristically [2] and systematically [3], whereas corporations have diverged from the original notion into eCollaboration as a tool for improving employee productivity. Despite the growing popularity of web-based content delivery in academic programs, the relevance of eLearning to engineering education is constantly challenged, due to the two key features of engineering pedagogy [4]:

- 1) engineering education heavily relies on experimentation; students develop engineering intuition by continuously iterating between mental concepts and real hardware, and
- 2) a vast portion of engineering knowledge is contextual and can only be learned through the senses and social interactions.

Therefore, the current academic usage of eLearning, based on a unicast topology through which students learn individually from static content, does not adequately meet the requirements of engineering education. For engineering

education, an eLearning solution must not only provide access to content repositories but also act as a virtual extension of the classroom and laboratory environments, in terms of physical resources and collaborative community. Consequently, a suitable framework for engineering eLearning must include the convergence of corporate eCollaboration and academic web-based content delivery, plus the means of accessing physical and conceptual resources in the context of classrooms and laboratories. This framework can be realized through the concept of a corporate intranet portal. In general, a portal is a web system that provides an intuitive and personalized gateway to resources on a network [5]. In the past, portals were synonymous with search engines that provided links to websites on the internet. More recently, however, portals have expanded to include both the aggregation of resources and the platform for building a collaborative user environment. This new hybrid notion of a portal is therefore capable of hosting the virtual extension of physical resources as well as the foundations of a virtual collaborative community, making it a proper solution for engineering eLearning.

Web-based education using synchronous and asynchronous learning network environments has been addressed in the literature extensively [e.x., 6]. While the main focus remains on the effective content delivery and administration, few works have emphasized the need for the collaborative aspect of web-based learning [e.x., 7]. Also, very few papers have discussed the specific requirements for engineering distance education [8-12]. Most notably, in [8, 9] web-based learning has been extended to web-based experimentation as a key feature in the deployment of eLearning solutions for the engineering curriculum. This work has been further extended in [10] to include collaborative aspects of engineering education. Yet, a comprehensive and generic framework for engineering eLearning has remained to be developed.

This paper presents an architecture, based on the hybrid notion of a portal, as a platform for creating a collaborative and experiential learning environment, suitable for engineering education. The proposed architecture for the engineering eLearning portal extends the traditional provisions of courseware technology to a virtual classroom, laboratory, and collaborative community. The specific implementation of this architecture for Aerospace Undergraduate Studies at the University of Toronto, namely the AeroLab Portal, is also discussed, including details of the specific software, hardware and technologies used. Finally, further developments of the eLearning Portal and its application to eEngineering are discussed.

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ENGINEERING eLEARNING FRAMEWORK

The features of the engineering eLearning framework have already been established by the requirements of engineering education [10]. However, for the framework to be generic, and thus applicable to a multitude of academic programs, additional requisites are imposed. The key requisites to ensure a generic framework are reusable components that can function independently, and yet be highly integrated in terms of both functionality and the overall user experience. In addition, the components should be platform independent (in terms of hardware) and individually upgradeable, without affecting the continuity of the system. To meet these requirements an eLearning portal must have, in addition to a modular architecture and topology, a means of integrating diverse content into a seamless user interface.

eLEARNING PORTAL ARCHITECTURE

The engineering eLearning portal must have a modular architecture to ensure generic reusability of the engineering eLearning framework that it is realized from. The portal is therefore functionalized by the four key social interactions experienced in the classroom and laboratory environments; namely student-content, student-instructor, student-resource, and student-student interactions. Each of these interactions corresponds to one of the four modular components in the architecture, i.e., traditional courseware, the virtual classroom, the virtual laboratory, and eCollaboration, respectively. In addition to the four key components, the portal also contains an integrated Learning Management System (LMS). A schematic of the entire engineering eLearning portal is presented in Figure 1.

1. Traditional Courseware

Traditional courseware is used to provide students with access to content. Several courseware packages have been developed in both academia and the corporate sector to meet the requirements of content delivery. The modular architecture of the portal allows the traditional courseware component to be implemented using any available courseware technology. Third-party courseware is seamlessly integrated into the portal environment by content integration. This content integration mechanism also allows for a dynamic range of content that can be delivered through the courseware component.

Internal Content

List and document content can be stored within the portal in a content database. A list is a set of data columns that are linked to a menu-driven user interface. Document content is stored in a library, which is a list of documents with associated columns of metadata. Columns in both lists and document libraries can be populated with static data, dynamically-calculated data, or metadata. Metadata contains information about a specific list entry or document, such as the last time it was edited or the user that created it. Lists can also be linked to each other so that the entries in one list can be used to populate columns in another, such as a list of tasks being used to populate a calendar.

San Juan, PR

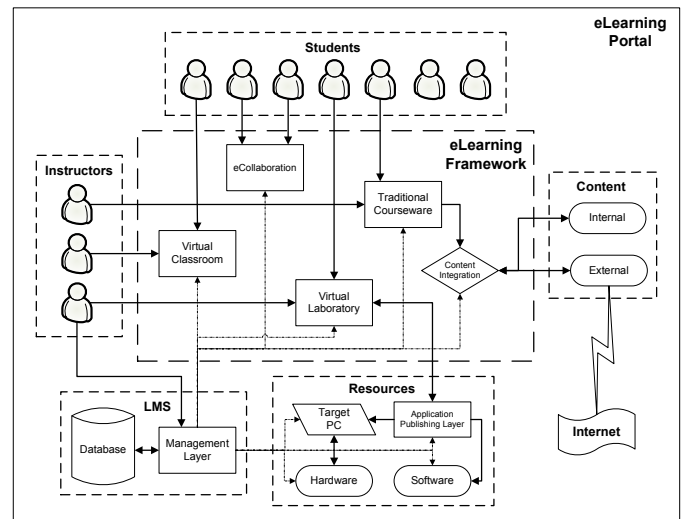


FIGURE 1

SCHEMATIC REPRESENTATION OF THE eLEARNING PORTAL ARCHITECTURE.

External Content

Content outside of the portal, such as file shares, external databases, websites and internet content, can also be integrated into the portal. Each piece of external content is displayed using content integration to ensure a seamless interface with internal content. In the case of external websites the content can be indexed to a present link depth, and then results will be included in the portal search engine.

Search Tools

Content within the portal is stored within a central content database, and is aggregated using a database level content index. Although external content is not stored in the central database, it is still included in the content index. Each piece of content is treated as an object with an associated set of searchable metadata. Integrated filters allow full text search of documents and files. Each piece of the portal system, such as sites, pages, lists, document libraries, and users are also treated as objects. This allows the search engine to crawl every object within the portal. Search results therefore include not only content objects, but lists, repositories, and users. In addition, a topic assistant can be trained to suggest useful topics based on a user's search.

2. Virtual Classroom

The virtual classroom is used to provide students with access to instructors, and is the primary means of contextual education. To replicate the classroom environment in a digital medium the instructor must, in addition to broadcasting mixed media presentations, simultaneously interact collectively with students. To do so, a variety of synchronous communication modes are required to connect students to instructors in virtual lectures, tutorials, and assignment workflows. Hence, the primary components of the virtual classroom are the lecture broadcast, tutorial meeting, and assignment workflow.

Lecture Broadcasting

The virtual classroom uses a combination of broadcast

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publishing and collective communication tools to implement the core lecture component. Broadcast publishing is used to stream audio/video and textual content to remote students, in an interleaved format that facilitates the integration of live video and textual eDocuments, such as lecture slides, into a single content stream. For specialized demonstrations an instructor can utilize some of the eCollaboration sub-components to share applications and even the entire desktop session with students, for demonstrating an experiment from the virtual lab, or explaining a particular feature of a website.

A combination of group chat rooms and instant messaging is used as a collective communication medium during the lecture. It allows students to communicate with each other, or with the instructor, without having to interrupt the lecture broadcast. In the case of student-instructor communication, this is ideally suited as means for students to pose questions. The instructor can either answer the question on the shared chat room, or address the issue in the live broadcast.

Lecture broadcasting uses a broadcast publishing point, usually restricted to students in a particular, to publish content for the virtual classroom. However, publishing points can be made public or even posted on the internet, allowing special events and presentations to be broadcast to students at other institutions. In addition, students can be given broadcasting access to publish their own content to a wider audience.

Tutorials

Tutorials are important supplements to any lecture series. The virtual classroom allows students to remotely interact with teaching assistants (TAs) through a variety of communication means. For an informative tutorial, the TA can use the lecture broadcast component to give a tutorial session. For discussion-based tutorials, a group instant messaging chat room with shared whiteboard allows for collective and collaborative learning. The tutorial sessions can also be run using a variety of peer-to-peer communication tools for direct communication between a TA and student. Instructors can also use these same tools to communicate directly with students. The virtual tutorial builds on the fundamentals of the virtual classroom with more personalized and direct communication modes.

Assignments

Assignments for the virtual classroom are handed out, submitted and marked all in the context of the portal. An instructor can either post an assignment to a shared lecture chat room, or to the traditional courseware component. Students can then complete the assignments using the software resources available through the virtual laboratory, including simulation, design, and office suite applications. Students can store their incomplete assignments in the portal content database while they work on them, ensuring that their work is accessible from any location. Completed assignments are submitted electronically, and then marked online by the instructor or TA, and returned as digitally commented documents. Hence, the entire assignment workflow is maintained within the context of the portal, and can be completed in an entire web-based format.

3. Virtual Laboratory

The virtual laboratory is used to provide students with access to software and hardware resources, and is the primary means of delivery experiential education. Experimentation is a fundamental component of engineering education. The laboratory is the primary facility through which experimentation is taught using a variety of hardware setups. The lab provides a means to contextualize and reinforce concepts taught in the classroom. However, a physical laboratory is limited in the access to software and hardware resources that it can provide. Remotely-accessible hardware setups, and published software applications, remove the physical constraints limiting access to lab resources, allowing resources to be accessed at anytime from anywhere.

The experimental process is iterative in that data is collected, analyzed and then new data collected based on the results of the analysis. In a teaching laboratory, this often requires a student to perform an experiment multiple times. Students should perform the initial experiment using the physical hardware to gain experience working with physical components. Experimenting with actual hardware also allows students to gain insight into the limitations of the equipment. Subsequent experiments can then be performed remotely using the virtual laboratory. Using remote access experiments ensures that students gain the necessary experience with the physical hardware, while also removing the physical access limitations.

Application Publishing

Access to software resources on a remote server is provided through an Application Publishing Layer (APL) that, in addition to hosting the full Graphical User Interface (GUI) of any application, also provides virtual channels that allow the remote application to print or save directly to the local computer. The application publishing layer utilizes a web-based terminal server client to channel a desktop session from the remote server to the local computer.

Experiments

Access to physical hardware resources is provided through a published application GUI, running on a target PC that communicates with the physical hardware components using data acquisition boards. Streaming video allows the student to observe the progress of the experiment directly. Numerical results are displayed through the GUI on a variety of graphs and numerical displays. In addition, the virtual lab replicates the interactions with a laboratory instructor. Presence information for lab instructors is available from the experiment interface, allowing students to easily contact lab staff. An instructor can also remotely interact with a user's experiment session to help answer questions or demonstrate a particular technique.

Simulations

The virtual laboratory includes simulated experiments based on industry standard engineering simulation and virtualization software, published through the APL. This provides users with access to both software and hardware (computing) resources.

Since multiple simulations can be run in parallel, access to each virtual experiment is not limited to a single student. In addition to full simulations, the virtual laboratory is capable of performing Hardware-in-the-Loop (HIL) simulations that run physical hardware as part of a simulated system, with a student's local computer acting as the target PC interface.

Lab Reports

The complete lab report workflow occurs within the context of the portal, from initial data collection to final submission and marking. Data collected during the course of an experiment is automatically saved to a student's personal document library (see eCollaboration), along with a report template that automatically imports and plots the data using a standard form. With engineering simulation and analysis software available through the virtual laboratory, students analyze their results and populate the report template. Completed reports are submitted electronically to a TA or instructor who then marks and returns the report as a commented document. Since documents can be edited from within the portal the entire lab report workflow is completely self contained, automated, and paperless.

4. eCollaboration

eCollaboration is used to provide students with access to each other, and is fundamental to contextual-based engineering education. A combination of communication and resource sharing tools are used to allow students to interact on a collective and collaborative basis. However, eCollaboration must not only provide a basis for collaborative learning, but must also provide a collective community that facilitates the self organization of students into teams, and provides students with the means to publish their own content.

Asynchronous Communication

Email is the most ubiquitous asynchronous form of web-based communication. Software generated emails, called alerts, are used to track content changes on a specific site. When the site content is updated, an alert can be sent out to students to inform them that new material has been made available. Discussion boards are used in the portal for collective communication, usually in the form of a question and answer board. However, discussion boards are limited in their usefulness since they are usually tied to a specific page on a site. Web discussions, which are free-floating discussion boards, can be moved between pages and attached to any content objects, such as a link or image, allowing discussion threads to move with students as they make their way through the portal.

Synchronous Communication

Instant Messaging (IM) is the most ubiquitous synchronous form of web-based communication. The multiplex capability of IM provides an advantage over other real-time communication tools since a single student can simultaneously communicate with several other users. Other synchronous communication tools utilized for eCollaboration include group chat rooms, shared white boards, and audio/video chatting,

each of which builds on the foundations of IM with increased levels of interaction.

Presence

Presence represents the current state of a student, and includes the username, contact information, availability and a list of supported communication modes. Within the portal a student's presence is generated by each communication tool and is broadcast through any instance of their username. Students can therefore tell if another user is available by simply looking at their username. In addition, a student's presence can be linked to an external calendar to automatically change with their schedule.

Application Sharing

Application sharing allows a group of students to collaborate using the same software application. Sharing can be limited to a single application or can include a student's entire desktop environment. Control of the application can either be maintained by the student hosting the application, or can be simultaneously delegated to any number of other students. The second mode is generally used by a team of students collaborating on a document, such as a report or experiment write-up.

User Directory

The portal contains a directory of all registered students, instructors, and teaching assistants (TAs) that is searchable based on user profile entries. The ability to search by more than just username ensures that students can easily find each other, even if they aren't sure who exactly they are looking for. A group of students can use the directory to find each other and self-organize into a team for completing a specific assignment or project.

Team Sites

Groups of students working on a common task or project can self organize into a team. These groups can then create team sites in the portal on a self-serve basis using dynamic templates and wizards. Each member of a team has their own personal view of the site, allowing them to customize the user interface and displayed content. Team sites are intended for group collaboration, and therefore contain a rich set of collaboration and project management tools. The main feature is a shared document library that allows students to collaborate and share documents. Team document libraries are optimized for collaboration with a rich set of document management tools, such as version tracking and document. A single student can also check out a document from the library to prevent other students from making changes to it. Simplified versions of team sites, called workspaces, can also be created by a group of students for performing a specific task such as conducting a meeting or collaborating on a specific document. Presence is highly integrated into team sites, helping to facilitate communication between students by allowing students to access all of the communication tools without having to open a separate browser or application.

Personal Sites

Personal sites are customizable websites that provide students with a private area for storing personal documents, and a place to publish their own content. Students can select portions of their personal site to publish to the portal, or post on the internet. Child sites can be created under each personal site, allowing students to create dedicated shared workspaces with peers.

Personal document libraries act as student-based content repositories that can be accessed from a variety of mediums. When a student logs on to a local workstation in the classroom or laboratory, their personal document library is automatically mapped as a network drive. In addition, when a student accesses the virtual laboratory or published software applications, their personal document library is also connected to the session.

5. Learning Management System

The LMS layer of the portal architecture includes all of the features found in a traditional LMS, with specialized tools for monitoring software and hardware. The LMS layer monitors each software module in portal, as well as the physical laboratory hardware and server resources. The interface for the LMS centralizes the management of the entire engineering eLearning portal to a web-based control set that allows an administrator to control the system at multiple levels, from individual hardware component interactions to global configuration settings. The LMS layer also manages the registration and authentication of users against a central database that centralizes a user's profile. Each component of the portal authenticates users through the LMS layer, which provides token-based credentials for Single Sign-On (SSO) throughout the portal.

AEROLAB PORTAL IMPLEMENTATION

The AeroLab Portal at the University of Toronto is an implementation of the engineering eLearning portal for Aerospace Undergraduate Studies. The network topology of the AeroLab Portal is modular in terms of software applications and server hardware to ensure generic reusability of the engineering eLearning portal it is realized from. Each component of the portal architecture is implemented using enterprise level sever applications, each run on a dedicated server. The five core servers that make up the AeroLab Portal are the domain controller (DC), portal server, real time communications (RTC) server, application server and video server. An addition server is also dedicated to each experiment in the virtual laboratory, called the Remote Access Aerospace Lab (RAAL).

To ensure complete platform independence of the implementation, all server applications are run on virtual machines hosted on the physical server hardware. Virtual machines use a combination of hardware pass-through and virtualization technologies to run a guest operating system on top of the host server. Applications on virtual machines can therefore be migrated between servers with little effort.

TABLE 1

AEROLAB PORTAL SERVER HARDWARE SPECIFICATIONS

Server	CPU	RAM	HDD	NIC
RAAL	Intel PIII 600MHz	256 MB	10 GB	100 M-bit
Application	Dual Intel Xeon (x64) 2.8 GHz	2 GB	100 GB	Dual 1 G-bit
RTC	Dual Intel Xeon (x64) 2.8 GHz	2 GB	100 GB	Dual 1 G-bit
Portal	Dual Intel Xeon (x64) 3.0 GHz	4 GB	1 TB	Dual 1 G-bit
DC	Dual Intel PIII 1.1 GHz	1 GB	50 GB	Dual 100 M-bit
Video	Intel Pentium D 3.2 GHz	1 GB	250 GB	1 G-bit

TABLE 2

AEROLAB PORTAL SERVER SOFTWARE SPECIFICATIONS

Server	Software	Function
RAAL	MS Terminal Services Experiment GUI	-remote desktop access -interface to experiment hardware
Application	MS Terminal Services Engineering Software	-remote desktop access -software resources
RTC	MS LCS 2005 MS Office CWA	-all RTC tools -web-based IM client
Portal	MS SPS 2003 SQL Server 2005 x64	-user interface/collaborative sites -backend database for portal
DC	MS Active Directory ISA Server 2004	-domain and user database -firewall and VPN connection
Video	MS WMS 9 Series GeoVision Web Server	-video and textual broadcasting -live video from analog cameras

The AeroLab Portal runs under a Microsoft Active Directory™ domain with each server (including virtual machines) running Microsoft Windows Server 2003™ R2. Portal features are based on modular component of the Windows Server System and include Live Communications Server™ (LCS) 2005, Office Communicator Web Access™ (CWA), SharePoint Portal Server™ (SPS) 2003, SQL™ Server 2005, Internet Security & Acceleration (ISA) Server 2004 and Windows Media Services™ (WMS) 9 Series. The video server encodes analog video from cameras in the physical Laboratory using a GV-1240 DVR capture card, which is then streamed to the virtual laboratory using GeoVision Webcam Server.

Each physical server hosts one or more virtual machines using Microsoft Virtual Server™ 2005 R2. The network is hosted on a 1 G-bit switch linked directly to the University of Toronto network backbone via high bandwidth fiber optics. Inter-server communications is isolated on a dedicated VLAN segment of the switch. Hardware and software specifications for each server are summarized in Table 1 and Table 2, respectively.

CONCLUSION

Current courseware technology does not meet the essential requirements for engineering education; it lacks effective means for interactive and collaborative learning, and it does not allow learners to experiment with the physical

hardware as they need to do in the real world. In response, a comprehensive and generic architecture was proposed in this paper for engineering eLearning with the emphasis on experiential and collaborative learning. This architecture is, in essence, a rapprochement between the academic and corporation eLearning. It implements the portal technology to establish a seamless integration of content-delivery and collaboration tools, plus providing direct access to hardware resources, i.e., experiment setups, as well as software applications. Modularity of the architecture constituents enables one to readily implement various courseware and eCollaboration technologies and also to easily apply the architecture for various engineering courses. Of particular interest is the application of the proposed eLearning framework for the hands-on, project-based engineering design courses. The AeroLab Portal developed based on the proposed architecture was used for such a design course in the current year at the University of Toronto, and an analysis of the results will be reported in the future works. Using AeroLab Portal, it is also planned to develop inter-university engineering courses and examine the pedagogical implications of portal-based engineering education.

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