Developing an integrated Web engine for online Internetworking education: a case study

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Keywords

Learning methods, Computer based learning, Students, Remote consoles

Abstract

An integrated Web engine (IWE) has been developed by the Internetworking program at Dalhousie University, Halifax, Canada to deliver remote learning experience to geographically remote Master's students. The University intends to increase its student base through online education, retaining the same quality of interactions as the onsite program. To this end, the IWE accommodates three technology-enabled learning environments that correlate with the three pedagogical approaches and types of onsite interaction. Discusses the e-learning metrics, pedagogical and technical considerations that influence the design and implementation of the IWE environment. The IWE uses *de facto* networking standards, commercial and broadband Internet connectivity to ensure real-time secure interaction with equipment and deliver lectures respectively. A four-tier role architecture, consisting of faculty, local, remote facilitators, and students, has been determined to be appropriate and adapted to maintain academic integrity and offer the same quality of interaction as the onsite program.

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Introduction

The modern university needs to extend lifelong learning opportunities to its students any time, any place and at any pace to be successful in the global educational marketplace (CMEC&IC, 2001; Schocken, 2001). Online student learning is made possible by advancements in network infrastructure and development of voice/multimedia protocols for seamless transport of information. However, the developer of an e-learning system faces several challenges in designing frameworks for an online learning environment that ensures strong effective, secure student interaction that best replaces the face-to-face interaction taking place in onsite classrooms and laboratories. This is exacerbated in courses involving high technical content, specifically in a laboratory environment like those employed in Internetworking (INWK) and information systems (IS) courses which extensively use networking hardware and computer/simulation software tools. In addition to a clear understanding of the knowledge domain requirements, the challenge lies in supporting good pedagogy and learning practices given technical constraints with regard to bandwidth, quality of service, real time interactions, multiple users and security.

Remote labs have been successfully used in electrical engineering education to interact with spectroscopy, measurements and control systems laboratories (Arpaia *et al.*, 2000; Ferrero *et al.*, 2003; Casini *et al.*, 2003). However, none addresses the pedagogical, facilitation, and security issues within a technical framework, other than mapping the instructional content to appropriate technology. Examples of such mapping are remote instrumentation (Arpaia *et al.*, 2000), Java servlet technology (Ferrero *et al.*, 2003), user-friendly interface design (Casini *et al.*, 2003), and use of broadband communication (Dorneich, 2002). The developer of an e-education system faces several critical challenges in designing an effective, accessible, responsive, secure and multi-user online environment. The e-learning design framework must employ interactive hands-on laboratories, secure real-time student interaction and incorporate effective online learning strategies including appropriate pedagogy, facilitation and skill building techniques to impart knowledge and meet instructional outcomes. In this paper, we build-on, and significantly contribute to existing e-education frameworks research (Dorneich, 2002; Safoutin *et al.*, 2000; Fels, 2000; Shang *et al.*, 2001) in several ways:

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- demonstrate the feasibility of designing e-education systems for strong remote student interaction with faculty in onsite lectures;
- add pedagogical and instruction level knowledge conducive to active, collaborative remote online laboratory instruction;
- incorporate effective remote site facilitation to mimic the face-to-face interaction taking place in onsite laboratories; and
- show how to integrate authentication and access control into standard e-education architectures, thus providing a secure delivery mechanism that is reusable across geographically distributed educational applications.

Our work supports the special requirements for, and is designed in the framework of online synchronous lab based Internetworking e-education.

The Masters in Engineering in Internetworking (Dalhousie University, 2003) offered by the Faculty of Engineering at Dalhousie University in Halifax, Canada is an interdisciplinary program and one of the first of its kind in the world, offered since September 1997. To meet the diverse background of the students and to meet the graduate study requirements, the program consists of ten courses, each offered in a compressed two-week format, and is scheduled over a ten-month period, followed by a project. The students of the program mainly consist of professionals already in the Internetworking field or related industries wishing to upgrade their skills. The onsite program employs three types of interaction to ensure effective learning:

(1) Lectures by expert instructors.
(2) Hands-on laboratories.
(3) Group interaction with peers through case studies, projects and group work that correlate with the three well known pedagogical approaches viz., objectivist, constructivist and group interaction respectively (Leidner and Jarvenpaa, 1995; Jonassen *et al.*, 1999; Hiltz *et al.*, 2000).

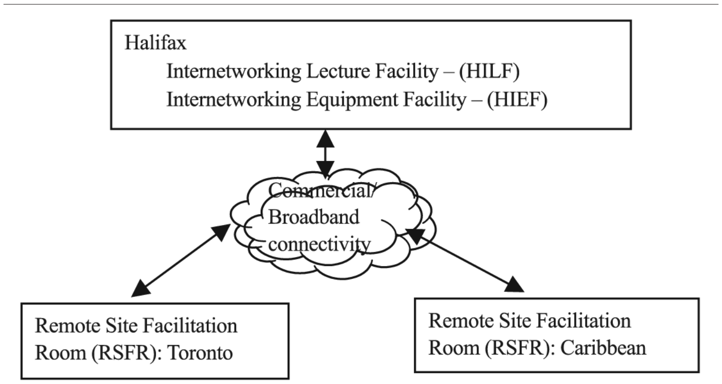
In its quest for a viable online Internetworking program, the program must not lose sight of the fact that it should continue to offer the same quality of interaction with the faculty, the laboratory equipment and with peers that it now offers its onsite students (Janicki and Liegle, 2001; Picciano, 2002; CMEC&IC, 2001; Shang *et al.*, 2001; Sivakumar, 2003; Sivakumar and Robertson, 2004). A good strategy is necessary to enable online students to participate in onsite lectures, access the Internetworking equipment from remote geographical locations and work in virtual teams. Thus, an integrated design approach that promotes student interaction with good infrastructure management can be used to ensure effective learning to meet the pedagogical goals of the program. Such an approach has the added advantages of better student performance and enhanced educational product design. For this, the online program uses an integrated Web engine (IWE) that accommodates three different modes of technology-enabled learning that correlate with the three well known pedagogical approaches and types of onsite interaction. They are:

(1) Remote lecture room (RLR).
(2) Remote interactive laboratories (RIL).
(3) Interactive home learning (IHL).

The RLR emulates a classroom environment and corresponds to the objectivist approach. The RIL is aimed at delivering remote laboratory experience moderated by laboratory facilitators and corresponds to the constructivist pedagogical approach that uses collaborative methods to achieve learning outcomes. The IHL facilitates inter-student communication to encourage peer interaction and uses group processes in learning. In this framework, the word "online" is used to indicate a number of remote sites with several students at each remote site as shown in Figure 1. The word "onsite" indicates the Halifax site which is where the onsite classrooms and the Internetworking equipment facility are located. As shown in Figure 1, the Halifax Internetworking lecture facility (HILF) together with the remote site facilitation room (RSFR) constitutes the RLR. The Halifax Internetworking equipment facility (HIEF) together with the remote site facilitation room constitutes the remote interactive laboratory (RIL).

The paper is organized as follows: first, we describe the features of the onsite Internetworking program and the potential online implementation issues faced. A discussion of the research framework and how e-learning metrics, technical

Figure 1 Integrated Web engine framework for the Internetworking program



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constraints and pedagogy all influence the design and implementation of the IWE is provided. We discuss the factors that affect design and implementation of the RLR and its interaction scenario. We also discuss the design factors, facilitation issues, work scenario and authentication issues in the remote interactive laboratory. We show how the people involved in the program are part of a four-tier role architecture that was devised to maintain academic integrity and quality of interaction. We conclude with a discussion on issues that affect online internetworking education, system limitations and provide directions for future research in this challenging area.

Features of the onsite Internetworking program

A brief description of the salient pedagogical features of the onsite program is provided in Table I as this highlights the requirements and implementation issues faced by the online program. The course outline, laboratory equipment used and the learning approach employed is summarized in Table I. The course outline reflects the emphasis placed on building a strong knowledge base of mathematics, real-time operating systems and platforms necessary for solving Internetworking problems in an analytical fashion before simulating, modeling and implementing solutions. The courses on network architectures, wide area networks and network security describes the properties and performance characteristics of wired and wireless media in order that students appreciate the reason for the design of Internetworking standards and protocols as they are today. The course on emerging technologies discusses recent innovations in the wireless Internet and optical networking. A perusal of Table I indicates the emphasis placed by the program on the laboratory portion that accounts for approximately 40 per cent of program content. Lectures account for 50 per cent of course content. Purely collaborative activities such as case studies and course projects account for the remaining 10 per cent of course content.

The onsite lectures emphasize the underlying fundamental principles of study and the theoretical foundation of Internetworking in a chiefly objectivist knowledge-centric environment (Leidner and Jarvenpaa, 1995). This approach, which is the most extensively used method in higher education, uses a passive method to deliver expert educational content from the instructor to the student, and therefore, is appropriate for imparting factual and procedural Internetworking knowledge (Leidner and Jarvenpaa, 1995). In addition to the study of communication network architectures, their interconnection, and routing technologies, the program provides comprehensive "hands-on" laboratory experience. Most Internetwork engineering activities in a modern enterprise is conducted in a collaborative setting with a good deal of interaction between team members. This makes it imperative that the program model and implementation of a collaborative learning environment onsite is critical to acquiring problem solving, reasoning and management skills required of potential employees in the workforce (Denning, 1992). This requirement is met by suitably designing laboratory activities such that they are carried out by students in groups of three or four. The Internetworking laboratory involves the use of hardware such as routers and switches obtained from Internetworking vendors including Cisco Systems (Cisco, 2003) and Nortel Networks (2003), network analyzers, network simulation software OPNET (2003), personal computers and servers. Students learn to apply theoretical Internetworking knowledge to practical networking issues, hands-on configuration of equipment, strategies and techniques for troubleshooting and maintaining networks in a state of the art laboratory environment. Thus, the laboratories build practical Internetworking abilities and skills and correspond to a constructive, collaborative, situated, learner-centric environment (Jonassen *et al.*, 1999; Hiltz *et al.*, 2000; Wenger, 1998). Situated learning has been used in technology-based courses to present academic knowledge in a practical context to teach students problem solving skills (Wenger, 1998) and is employed in the Internetworking laboratory to transform the novice students into experts in the context of the Internetworking community in which they will ultimately work. That is, the students will have gained a broad range of hands-on experience and a large repertoire of Internetworking knowledge to understand the practical conditions under which to apply specific Internetworking principles, theories and techniques. The case studies, projects and presentations capitalize on specific interests of the student in a group-oriented setting.

The onsite program located at Dalhousie University, Halifax owns all of the equipment used for delivering hands-on experience and comprehensive exposure to networking equipment. Some of the challenges faced by the program include equipping the

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Table I Brief course description, equipment requirement and learning activity type for the INWK-M.Eng Program

Course title	Course description	Equipment/software	Activity type (%)
Introduction to computer communications	Fundamental concepts associated with computer networks used in communications with in a network and between networks	Routers, switches, packet analyzer	Le-50 Lab-40 CP-10
Mathematics for Internetworking	Probability, statistics, data collection, distribution fitting, Markov chains, reliability, stochastic processes, queuing systems, sampling probability distributions, Monte Carlo simulation techniques for Internet modeling, analysis	Software: Minitab	Le-80 Lab-10 CP-10
Physical and data link layer standards and protocols	Physical layer issues of data communications networks including modulation-demodulation techniques in wired, wireless and optical systems. Performance in noise and bandwidth constraints. Data link layer issues: media access, framing, error control procedures, and standards	Network simulation software: OPNET	Le-50 Lab-40 CP-10
Internet communication protocols	Transmission control protocol/Internet protocol (TCP/IP), protocols for address resolution, Internet control, routing, broadcasting, end-to-end communication, network management, domain name systems and popular applications	Routers, PCs with free BSD software	Le-40 Lab-50 CP-10
Network architecture	Internetworking, bridging and routing algorithms, and encapsulation	Routers, switches, LAN analyzer	Le-40 Lab-45 CP-15
Telecommunication and WANs	Cellular, wireless systems and wide area networks. Telecommunication transport and signaling standards	Routers, switches, phones, WAN analyzer	Le-50 Lab-50
Real time operating systems and platform architecture	Real time OS configurations; Internetworking platform architecture issues including caching, hardware and software performance	Software: Borland C++	Le-45 Lab-45 CP-10
Emerging Internetworking technologies	Emerging technologies, design alternatives; underlying theory and practice required for a reliable multi-service Internet environment	Routers, switches, ATM switch	Le-60 Lab-30 CP-10
Network security and management	Security threats; attacks and breaches; security goals, mechanisms and technologies; security protocols; and issues for network design. Network management protocols, network planning and design; troubleshooting; monitoring and network performance management	Routers, switches, LAN/WAN analyzer	Le-50 Lab-40 CP-10
Simulation, modeling and analysis	Discrete event simulation, modeling complex systems, comparing system configurations, variance reduction techniques, experiment design and optimization, simulation of Inter-intranets	Network simulation software: OPNET	Le-35 Lab-45 CP-20

Notes: Le = Lectures; Lab = Internetworking laboratory work; CP = Case study/project work

Internetworking laboratory with state of the art equipment. Specifically, a pressing challenge is to maintain devices that are not obsolete in order to provide an up to date "community of practice" to the students. In the Internetworking community devices typically are replaced every three to four years. This necessitates that the Internetworking program follow the same time-scale for refurbishing its laboratory facilities with modern equipment, in order to maintain its reputation for cutting-edge education. However, such upgrading of equipment is expensive. Also, the Internetworking laboratory is not used 24 hours of the day. In fact, the onsite students use the laboratory equipment for six hours per day over the two-week period when the course is offered. If the program is to increase its revenue base, then it must do so by using the equipment more efficiently. One approach for the program to increase its student base is through online education aimed at fulfilling the needs of geographically remote students. This should help with the expenses involved with refurbishing equipment and staying current.

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Research framework

E-learning encourages the student to spend time electronically to bring about learning. The research framework proposed by Alavi and Leidner (2001) urges study within the context of instructional strategies and learning processes. At the intersection of these strategies and processes are methods of instructional delivery and theories of learning. E-learning entails the following issues:

- student interaction;
- pedagogy employed in instructional design;
- infrastructure management for delivering learning material; and
- tracking student performance for grading purposes.

Online learning design objectives include tailoring course content and technological capabilities to address how students engage in learning, fostering effective learning strategies, providing a rich repertoire of resources and aids, and articulating an instructional design that incorporates the latest techniques in pedagogical research in order to support learning at a pace that is comfortable to the student (CMEC&IC, 2001; Schocken, 2001). Thus, it is important to address how e-learning metrics, technological considerations and pedagogical issues affect the design and implementation of the IWE.

e-Learning metrics that influence IWE design

A critical analysis of the metrics that can be used for evaluating student interaction with an electronic learning system from student, university/instructor/facilitator and technology viewpoints is provided in previous works (CMEC&IC, 2001; Sivakumar, 2003). Good e-learning requires effective, real-time, reliable and secure student interaction. Other steps in the e-learning process rely on this crucial student interaction phase. The most important measure that a student will use for repeat interaction with an e-learning system of a university is the ease in using the system. Student interaction is deemed successful if it is two-way, integrated, recorded and managed. Interaction management involves customization and personalization of the interaction, learning process and the communication channel. Tailoring the response to the requirement of the educational goals of a program customizes education. The interaction is personalized by tailoring system response to user preferences thereby allocating network resources to ensure real time delivery (receipt) of information to (from) the student. An important measure for sustained student interaction with the e-learning system includes ease of use and addressing privacy issues. Students must be well informed and assured of security measures such as, authentication, encryption, and access control mechanisms in place to ensure privacy. The communication channel characteristics, protocols and technology must be designed for real time applications. At any time, if the student cannot obtain a satisfactory response from the e-learning system, it must be possible to locate a facilitator in a reasonable period of time (CMEC&IC, 2001). To summarize, critical student-centric design metrics encompass ease of use, learning at any time, and at any place; system availability and ease in locating a facilitator (CMEC&IC, 2001); quality of inter-student interaction and multi-media exchanges (CMEC&IC, 2001,); privacy and secure communication (Sivakumar, 2003); and real-time perception (IMS Global Learning Consortium, 2003).

From the university's viewpoint, critical e-learning system design factors include accessibility, reliability of system, help available, responsiveness of the system and appropriateness of system response to student input and support for multiple simultaneous student interactions (Sivakumar, 2003). The system design must support an effective testing strategy based on skills, knowledge and learning outcomes. Interactive hands-on laboratories that foster skill building and problem-solving techniques on an individual or group basis must be part of the e-learning system especially in technology intensive courses. The system design must also include provision for a reliable authentication and access control mechanism to secure e-learning resources from unauthorized users. Encryption of communication helps protect the privacy of students. Instructional design must be tailored to take care of student difficulty in understanding and using information imparted in lectures and laboratories. The overall cost of the e-learning system must be minimized with the use of available off the shelf software, equipment, components and protocols. The e-learning environment must foster group discussion and encourage inter-student interaction. The university-centric metrics by which an e-learning resource may be evaluated can be drawn from:

- curriculum quality;
- ease of use;

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- continuous student assessment methodology;
- real-time feedback to track student performance;
- multimedia simulations, laboratories and user interaction; and
- enhanced problem-solving techniques on an individual or group basis (Dorneich, 2002; Sivakumar, 2003).

E-learning system designers and universities use these metrics to design, develop/adopt and implement technology including learn-ware, protocol or infrastructure in the system and measure the effectiveness of the e-learning system in encouraging student interaction.

Technology considerations that influence IWE design

Ease in using an e-learning system is a function of system design and is determined by factors including accessibility, usability, system reliability, available online help, possible multiple simultaneous interactions, system responsiveness and appropriateness to student input (CMEC&IC, 2001), and flexibility in content presentation (IMS Global Learning Consortium, 2003). E-learning architecture sub-systems include learn-ware, protocol, communication channel, infrastructure and their interactions (Sivakumar, 2003). The system architecture must be modular and the infrastructure must support real-time and multi-user use (Hampel and Slawik, 2001). System integration must address interoperability of sub-systems and support for standards. Learn-ware consists of multi-media enabled learning tools, computer simulation software, and interactive laboratory hardware that promote online instruction ("The e-learning," 2001). The protocols deal with the rules for implementing orderly multi-media communication within the e-learning environment. The infrastructure or technology deals with the hardware/firmware components with which the e-learning system is designed, including protocol stacks, implementation languages, operation systems and physical equipment. It is critical that learn-ware products be developed using pedagogical approaches to create a dynamic, engaging environment that promotes a student's online learning and participation (Janicki and Liegle, 2001, IMS Global Learning Consortium, 2003). Protocol metrics encompass interoperability, latency, security features and quality of service (QoS) provisioning. The latency associated with a protocol is implementation dependent and is an important design metric as various implementations by different vendors of the same protocol may have varying latency associated with them. Multi-media protocols employed must be interoperable and with low latency (Harasim, 1999). Security issues are critical to the success of the e-learning and include issues such as whether authentication and non-repudiation is required, when to use authorization, and what encryption standard is used. Secure communication addresses student security and privacy concerns. Authentication verifies student identity and may be employed to limit student access to instructional material and online laboratories and thereby provides mechanisms to protect learning material from unauthorized dissemination and must be integrated into the operation model of online learning course providers. Communication may be encrypted to secure online student interaction with the system and ensure privacy. The e-learning infrastructure deals with the functionality of the various components of the e-learning system. The infrastructure must address the critical issue of whether different components can be added in a modular fashion to achieve new functionality and is typically implemented as a set of logical modules or entities, with a specific functionality associated with each module (IEEE P1484.1/D9, 2001). This approach has advantages in that additional functionality can be added by incorporating new logical entities. Critical features such as security and QoS provisioning can now be addressed in a modular framework with an entity assigned the task of ensuring access control and provisioning QoS before communication is established (Li, 2000). QoS provisioning is important as the QoS parameters of the communication channel including bandwidth, system latency, delays related with Internet traffic, packetization, and access (Kostas *et al.*, 1998) impact real-time perception of interaction with the e-learning system. The choice of core network technology impacts bandwidth utilization, and hence, the latency and delay experienced by the student and is an important design constraint. Important service metrics from the university's viewpoint include extensibility of the e-learning service model to provide custom (tailored) services to the student community and help support an e-learning system.

Pedagogical factors that influence IWE design

Pedagogical metrics include fostering effective e-learning strategies, a curriculum that uses a

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rich repertoire of learning resources and aids, instructional design incorporating pedagogical techniques and creating a dynamic e-learning environment, continuous student assessment and real-time feedback. Learn-ware employing multimedia enabled learning tools such as simulators and interactive hands-on laboratories help create a dynamic, engaging learning environment (CMEC&IC, 2001, IMS Global Learning Consortium, 2003). Such an environment fosters skill building and enhances problem-solving skills on an individual or group basis. Pedagogical techniques that must be part of instructional design in such an environment include the objectivist, constructivist and group interaction approaches. The objectivist approach emphasizes that students learn by explicitly being informed or taught by subject experts. The constructivist approach is based on performing authentic activities and constructing knowledge in authentic learning environments such as labs (Hiltz *et al.*, 2000). The group interaction approach is based on groups of learners engaging in collaborative problem solving that increases student engagement with the subject matter resulting in better learning (Hiltz *et al.*, 2000). Also, learning objectives can be met within either a self-paced environment, in which the learning occurs at a rate comfortable to the individual, or within a directed environment in which the learner has to follow a particular sequence of instructions at a pace that is directed for them. The learning environment may also be classified as either synchronous, requiring the simultaneous participation of students in the class, or as asynchronous in which a student may participate at a time convenient to them (Cornell, 1997). Also, online interactions can be classified into:

- one-to-many interaction using two-way video conferencing;
- one-to-one interaction with equipment/hardware/software and e-learning learn-ware;
- many-to-many interaction between peers; and
- one-to-many interaction between a facilitator and students.

In general one-to-many interactions easily lend themselves to synchronous modes, while one-to-one interaction with software/hardware/courseware is more conducive to asynchronous modes. The e-learning system design should aim at maximizing the e-learning metrics requirements from both the student and university viewpoints with available technologies and within cost objectives to meet the pedagogical goals of the program.

The IWE for Internetworking education

The IWE framework for the online Internetworking program is shown in Figure 1. The IWE's course content, instructional design, role architecture and delivery mechanism must be tailored to:

- provide an objectivist pedagogical approach for the delivery of remote lectures;
- provide a constructivist approach in a collaborative learning environment for remote laboratory interaction;
- match the characteristics of the delivery media to the specific learning outcomes and processes including the provision of unambiguous feedback and guidance;
- define appropriate instructional roles for remote environment; and
- determine desirable student competency outcomes.

Currently, the RLR is designed to be delivered using standard Internet protocol (IP) platform over a broadband connection and is designed to encourage strong interaction between the instructor and the remote student. We consider, first, the technology features of the RLR framework (media and instructor-centric) to achieve the primary technical design criteria:

- use of *de facto* networking protocols;
- timely and secure delivery of lectures presentations over a broadband network;
- support for strong interaction between the instructor and the remote student; and
- effective delivery of lecture notes and other material.

The remote interactive laboratory is aimed at delivering remote laboratory experience, and moderated by laboratory facilitators. The technical design of the RIL reflects the progress made by the program in reworking the Internetworking laboratory to enable students to interact online with the devices in the Halifax equipment room. Specifically, we consider the student-centric features that must be part of the RIL technology framework to accomplish and achieve the following:

- use of *de facto* networking standards, free software for connecting to the Internetworking laboratory at Halifax;
- secure interaction and information transfer between the remote site and equipment facility at Halifax;
- delivery of laboratory notes and other relevant material such as wiring information and diagrams to students at remote locations independent of the technology available to the student (with some minimum

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technology expectation level at the destination);
- delivery over current and emerging high speed networks that are expected, over time, to become predominant throughout the world; and
- non-intrusive identification of the student at the time of initial access to laboratory resources.

For each component of the IWE, we next consider the pedagogical and instructional goals that influence facilitation and role design in the IWE. In a remote lecture delivery scenario, the delivery mechanism and instructional design are tailored to:
- model an objectivist remote learning environment in which the instructor engages the learner to deliver vast amounts of factual and procedural information;
- design multi-media content that provides unambiguous technical information; and
- match the characteristics of the media (delivery medium) to support the remote student's interaction process with the instructor (media synchronicity theory).

In the remote laboratory delivery scenario, the delivery mechanism, laboratory course content and instructional design are tailored to:
- model an active remote learning environment in which the learner is engaged in achieving learning outcomes;
- model a collaborative learning environment for group interaction at a remote site;
- match the characteristics of the media (delivery medium) to the specific learning outcomes and processes (media synchronicity theory) including the provision of unambiguous feedback, and guidance;
- design appropriate roles in the RIL environment; and
- determine desirable learning outcomes.

The IHL facilitates inter-student communication to encourage peer interaction and uses group processes in learning.

RLR technology

One of the challenges facing the program is how best to mimic the onsite face-to-face interaction between students and faculty, which is critical to learning technology-intensive courses. Two types of course support systems for delivering lectures to a remote location were considered. The course support systems may be classified as synchronous or asynchronous depending on the type of learning environment that they support. The synchronous system requiring the simultaneous participation of students with faculty in the class i.e. a "virtual classroom" and the asynchronous system allows students to participate at a time convenient to them (Cornell, 1997). The asynchronous transmission mode is closer to the digital library model with real-time playback capabilities and would require instructors to submit the teaching material using database engines that students can access at a time convenient to them (Cornell, 1997). The main features of synchronous systems include the use of video, audio, whiteboard, application sharing and chat (Bagi and Crooks, 2001). Studies have shown that delivering lectures to a remote audience using interactive video (involving two-way audio and video conferencing) resulted in no appreciable change in the learning outcomes when compared with traditional on-site face-to-face instruction. Russell (1999) reviewed 335 works in the period 1928-1998 that compared face-to-face onsite instruction with remote instruction using two-way video conferencing, and lectures delivered by video-tape, satellite or television. These studies highlight that the pedagogy embedded in the medium of instruction is more important to achieving learning than the instruction medium. Hence, for this pilot project, the program has decided to adopt the synchronous learning environment approach requiring instructors to deliver lectures to students using two-way video conferencing that transmit information voice and video streams in real time. Here, instruction is achieved in a one-to-many, instructor-centric framework that mimics the face-to-face interaction of a traditional classroom. Many factors contribute to the quality and quantity of information conveyed using multi-media, e.g. audio can supplement the information provided by text or video-graphics (Schar and Krueger, 2000). It was found that the intonation in an instructor's voice guides student attention to Internetworking concepts and results in better understanding and comprehension, e.g. querying students on their understanding of networking principles. Additional textual and pictorial information is displayed on the whiteboard, and gains the trust of the student with the inherent power of the printed word, e.g. the several steps employed by various routing algorithms. Video is employed in instruction, as an instructor's movement attracts student attention and is employed to illustrate complex dynamic relationships, e.g. implementation of routing/switching algorithms on different network topologies.

E-learning metrics that influence RLR technology choice include effective real-time,

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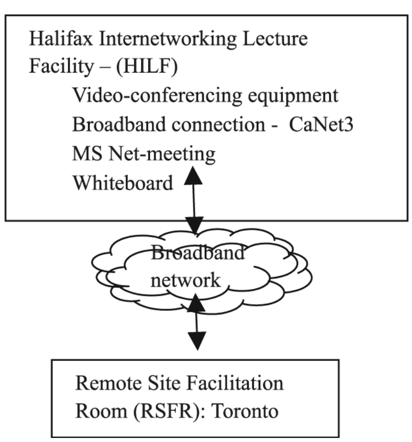
reliable and secure remote student interaction with the instructor (CMEC&IC, 2001, Sivakumar, 2003). In the synchronous RLR environment, real-time perception on the part of the student is chiefly related to Internet delay and to a lesser extent on system latency, packetization, and access delays. Internet delay is a function of the bandwidth of the communication channel and the Internetwork infrastructure used in communicating with the student (Kostas *et al.*, 1998). System latency is associated with the various technologies employed such as codecs, echo canceller, transforming voice/video at both remote and university ends. Packetization delays are related to transmission, buffering, and modem processing. Access delay is encountered at various servers, gateways and access points at the university and the remote site (Kostas *et al.*, 1998). While system latency, packetization or access delays can be minimized by proper system design, Internet delay is directly related to the bandwidth of the communication channel and is critical to the real-time transmission of multi-media information including video. To improve the perception of real-time communication and increase student satisfaction, the program has decided to employ broadband infrastructure in the RLR for lecture delivery to the remote student.

RLR interaction

The logical architecture for delivering lectures to remote sites is shown in Figure 2. As shown in this figure, the use of video conferencing requires the use of a broadband connection from the Halifax lecture facility to the RLR at the remote site. A pilot study to deliver the program to Toronto,

Figure 2 Remote lecture room – synchronous delivery framework



Canada used the high-speed Ca*Net3 (Ca*Net4, 2003) network. The Ca*Net3 is a project funded in part by the Federal Government of Canada that interconnects universities in various provinces in Canada using dense wave division multiplexing technology offering optical wavelength capacities up to 10Gbps. It encourages new methods of learning and research among universities and colleges, via virtual classrooms or laboratories with students and facilities in geographically remote locations. The CA*net 3"s data transmission speeds can support real-time and high bandwidth applications including videoconferencing. In addition to broadband access, the remote site should have an overhead projector screen on which to project the online video content of the lectures, an audio speaker to broadcast the instructor's voice and a microphone/Web-camera to capture the audio/video interaction of the students for transmission to the Halifax facility. The onsite location requires a white-board, instructor-workstation, a TV monitor on which to display the virtual classroom to the instructor, a Web-camera that captures the contents of the white-board or the instructor, a microphone, and a audio speaker to broadcast the students' voices.

In RLR scenario, the instructor sends a copy of the MS PowerPoint presentation, notes and other material being used in the lecture for distribution to the student prior to the commencement of the lecture. At Halifax, the MS PowerPoint slides are projected onto a whiteboard during lectures and the instructor who has control of the whiteboard can then draw, cut and paste text on to the whiteboard to emphasize points during instruction. The students can see the contents of the whiteboard at the remote facility. A two-way video conferencing facility is used so that the instructor may observe the remote classroom on a TV monitor. In this system, the instructor is also provided with a workstation which is used to share applications with the students. A student wishing to gain the attention of the instructor may do so by raising her or his hand, just as in a traditional classroom. The instructor can then request the student to voice their questions/concerns. The lectures can also be delivered using the commercial ISP network with a smaller bandwidth. However, in this scenario, a minimum bandwidth of typically 162kbps each way is required to maintain acceptable interaction quality. Although the voice transmission is very clear, the video is typically jittery in restricted bandwidth transmission when compared with the CaNet3 broadband network. This is attributable to the effect of processing delays including video compression employed in video transmission. The clarity of the contents of

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the whiteboard employed in the PowerPoint presentation could be improved by employing a bigger, bolder font when using the restricted bandwidth environment provided by commercial ISPs.

This pilot project in remote Internetworking lectures will help us identify techniques that:

- enhance the synchronous online lecture experience for both students and faculty;
- minimize failure of online lecture based learning;
- use the right mix of multi-media to teach conceptual and procedural Internetworking course content; and
- build strong interaction between the instructor and the student.

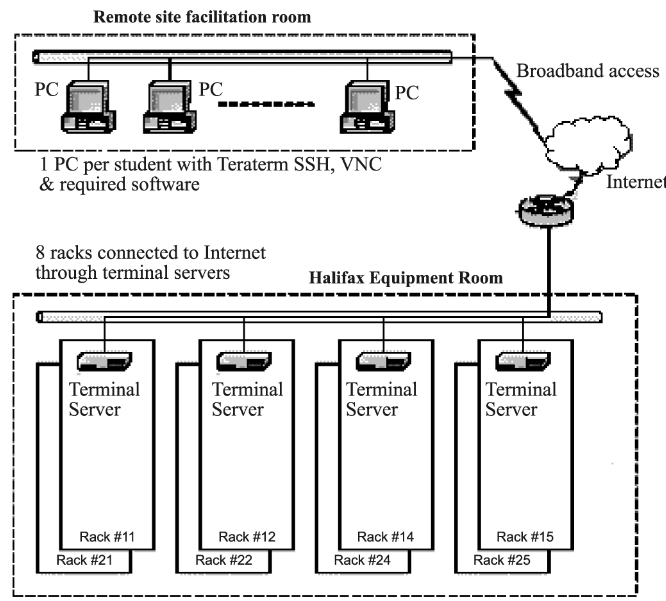
Remote interactive laboratory

Good laboratory based e-learning must begin with real-time, reliable and secure student interaction with the e-laboratory system. The most important measure that a student will use for repeat interaction with a remote-laboratory system of a university is the ease in using the system. From the universities viewpoint, the ease in using a remote-laboratory system is a function of system design and is determined by several factors such as its accessibility, usability, reliability of system, help available, responsiveness of the system and appropriateness of system response to student input and support for many simultaneous users (CMEC&IC, 2001). The communication channel characteristics, protocols and technology must be designed for real time applications. A key issue with the remote delivery of the Internetworking laboratory content is to convert the onsite student interaction with the devices in the laboratory into online real-time interaction with the devices. As noted earlier, the Internetworking laboratory involves the use of hardware such as routers and switches from vendors including Cisco Systems (Cisco, 2003) and Nortel Networks (2003), network analyzers, network simulation software OPNET (2003), personal computers and servers.

Remote interactive laboratory technology

The logical architecture for delivering labs to remote sites is shown in Figure 3. As seen from this figure, the equipment is placed on eight racks in the laboratory. Each rack consists of several Cisco 36xx routers, Cisco 3512 switch,

Figure 3 Logical architecture for delivering Internetworking labs to remote sites



Nortel Passport 100 router/switch and several Ethernet and Token Ring hubs. The RIL is designed to support multiple simultaneous interactions with the equipment at Halifax equipment facility. This is achieved by equipping each rack in the Halifax equipment facility with a terminal server. The terminal server connects a device's port to the Internet and thereby supports multiple simultaneous student interactions with the equipment. Webpages are used to logon and remotely access laboratory hardware. The Internetworking laboratories have been redesigned and the equipment rewired in a manner that allows both online and onsite students to construct different networks topologies without much change in the physical wiring/cabling. The wiring diagrams for lab equipment is also available from the program Web site at http://inwk01.inwk.dal.ca/

The course description listed in Table I shows that most courses require the students to interact with the devices in the laboratory. This enables the student to learn fundamental theoretical concepts in lectures while implementing and understanding these concepts in the laboratory portion of the course. The hands-on component of the various courses requires that students learn how to configure serial, synchronous and asynchronous connections between routers; implement Ethernet or token ring networks; build, implement and configure frame-relay, asynchronous transfer mode and integrated service digital networks; configure routing protocols in routers and Layer 3 switches; configure the spanning tree protocol in Layer 2 switches; configure transparent and source

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route bridging; configure virtual local area networks, virtual private networks; perform routing; setup voice/video over IP networks etc. For this purpose, onsite students access and configure the devices in the laboratory using a command line interface (CLI) or a graphical user interface (GUI). A key issue with the remote delivery of the Internetworking laboratory content is to convert the onsite student interaction with the devices in the laboratory into online real-time interaction with the devices. The remote site facilitation room was suitably designed to enable students at the remote sites to access the CLI of most networking devices using the Internet. The CLI was chosen over a GUI, as students need feedback from the equipment at Halifax in near real-time and transmitting information using a GUI is relatively slower than CLI. Also, the CLI is a reliable, direct, simple method of executing network operating system commands on networking equipment. The CLI allows greater flexibility and control as all options and operations are invoked in a consistent manner and is therefore, easier to learn and use. In addition, CLI can be easily used to write scripts to automate repeated configuration procedures. Furthermore, the use of CLI for remote access requires a communication channel with moderate bandwidth requirement which allows the access of CLI to be achieved through the Internet using a commercial ISP.

Some labs in the program require the use of LAN/WAN analyzers and cannot be accessed using the CLI. The LAN/WAN analyzers are located at the Halifax site and are used to analyze the LAN/WAN traffic. Similarly, simulation tools such as OPNET use a GUI. A key issue in the use of LAN/WAN analyzers and simulation software is to find a suitable method for remote site students to access these analyzers/simulators in the Halifax equipment facility. This problem is overcome by enabling remote students to access these analyzers/simulators using virtual network client (VNC) software on the remote site computers. The VNC software enables the remote student(s) to access and view the output of the network analyzer(s)/simulators on their remote site PCs. However, the use of the VNC at the remote site requires that the remote sites must have a minimum broadband access capability of at least 56kbps per PC.

The university has also addressed the need for a reliable authentication mechanism to verify the identity of genuine students and limit access to instructional material and online laboratories to genuine. This is achieved by restricting access only to authenticated remote students using an access control server at Halifax. Authenticated remote students can now access the devices in the laboratory using software such as Teraterm (1999) to connect to the terminal servers at the Halifax site. Teraterm, is a free Windows-based terminal emulator and telnet client software, was chosen as the university needs to balance the conflicting metric of finding a cost effective e-learning solution with student satisfaction. The availability of free off-the-shelf software is a prerequisite to lowering the cost of the e-learning system. Also, secure communication and preventing security threats is essential to addressing the security and privacy concerns of students. In addition, the communication itself must be encrypted to ensure secrecy. Teraterm has been extended with a secure shell extension to Teraterm Secure Shell (TTSSH) for PCs using the Windows OS. TTSSH is used to provide secure access to the Internetworking laboratory to the students at the remote site. In addition, student's privacy issues are addressed by reassuring them about the nature of the information collected, why it is being collected and how it is used. Also, the program assures the student regarding the security measures such authentication, encryption, and authorization that are in place to ensure their privacy.

Remote interactive laboratory interaction moderated by facilitators

Learning environments can also be classified as synchronous or asynchronous (Cornell, 1997). Also, the characteristics of a media used in communication can be assessed using media synchronicity theory (MST) and include characteristics such as a medium's capacity to provide feedback, symbol variety, instruction of multiple students, tuning message content, extent to which message can be reprocessed and unambiguousness (Dennis and Valacich, 1999, 2000). MST, when applied to the problem of remote learning, helps online education designers to match the characteristics of media to learning outcomes or processes to encourage remote students to work on a specific laboratory oriented activity. MST suggests face-to-face communication supports low one-to-one interactions but facilitates feedback and is useful in arriving at a group consensus (Dennis *et al.*, 1998; Dennis and Valacich, 1999, 2000; Schar and Krueger, 2000).

Most on-site students benefit from face-to-face interaction with instructors in a laboratory environment provided the faculty to student ratio is at reasonable levels. Online programs in professional development graduate level courses to teams of teachers have used facilitation

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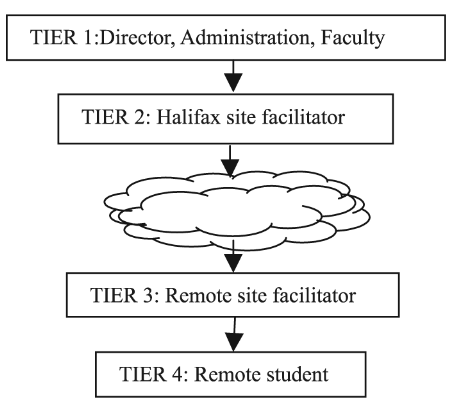
successfully to mimic this face-to-face interaction in an online scenario (Collison *et al.*, 2000). In the Internetworking program, facilitation is used in a remote learning scenario, to maintain the quality of the educational experience while not sacrificing educational standards (CMEC&IC, 2001). This is addressed, by appropriately modifying the three-tier role hierarchy of the traditional onsite university consisting of faculty, teaching/laboratory assistants, and students. This is done in the Internetworking program by replacing the Tier 2 teaching/lab assistants with local site facilitators (LSF) at Halifax and remote site facilitators (RSF) at the remote site and results in a four-tier architecture that better accommodates the objectives of remote laboratory-based learning. The Internetworking program intends to use these facilitators to foster strong student interaction and to maintain the academic integrity of the program by a strong demarcation of roles at the Halifax site and at the remote site and is shown in Figure 4. In this architecture, at the university end, Tier 1 consists of the director, administration and the faculty. Tier 2 consists of LSF. At the remote site, Tier 3 consists of RSFs. Tier 4 consists of the students. In the RIL, face-to-face communication moderated by the RSF is used to speed up the understanding of new information and arriving at a consensus. RSF is a term for such diverse roles including remote site administration and remote site laboratory assistants. The Tier 1 administration handles enrolment, registration and other functions associated with disseminating program information. The Faculty, are the sole course content providers in charge of designing an expert Internetworking curriculum. They administer tests, examine and assess students, provide feedback on student competencies,

Figure 4 Four-tier role architecture for delivering Internetworking labs to remote sites



thus meeting the e-learning resources metrics of expert curriculum that provides continuous assessment and real-time feedback to track student performance as outlined in the previous paragraph. It is also the responsibility of Tier 1 personnel to maintain the integrity of the educational process. The local site facilitators maintain and update lab notes for each course. In addition they test and configure the devices in the Internetworking laboratory for proper use, and create and maintain user account information based on information from the administration. In general, the LSF guided by the faculty maintain a dynamic, engaging electronic-laboratory environment that is easy to use and meet e-learning metrics (2) and (5). The LSF also provide the student with additional reference material (in addition to standard content) during the performance of the lab. At the remote site, the RSF support, maintain, and upgrade network services on servers and workstations at the remote site including maintenance of student drive quotas, backups, and verify that the laboratory at Halifax is remotely accessible from the computers at the remote site. They maintain the operating system, configure the student LAN at the remote site; install, update and maintain the licensed software such as TeratermSSH, VNC and any software that might be required in some courses.

Remote interactive laboratory work scenario

Students typically work in groups of two or three per group in the introductory and intermediate labs. In the advanced labs, e.g. BGP or OSPF in network architecture, they still have to configure the networking equipment by group and then have to interact across groups. It is essential that the remote site laboratory design make use of active learning strategies in a collaborative environment to ensure quality (Hiltz *et al.*, 2000, Meyer, 2002). Also, the activities in the remote Internetworking laboratory are modeled to implement the nine instructional objectives as outlined by Gagne (1987) and Gagne *et al.* (1992). These instructional objectives are:

(1) Gain learner attention.
(2) Inform learners of the objective.
(3) Recall prior learning.
(4) Present stimulus.
(5) Provide learning guidance.
(6) Elicit performance.
(7) Provide feedback.
(8) Assess performance.

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(9) Enhance retention and transfer (Gagne, 1987; Gagne *et al.*, 1992).

A typical scenario for remote laboratory work includes the following.

Activities that capture the learner's attention, inform learner of laboratory objectives and recall prior learning

The remote students are given the lab handout a week ahead of actual performance of the labs. In the first stage of learning, the components of the lab are modeled assuming a single user interacting with content and being tested. Here, each student works in isolation, does not interact with other students and can be modeled by the objectivist approach to learning (Leidner and Jarvenpaa, 1995). The RSF coordinates with the LSF to define and inform the learner of the objectives, learning outcomes and the results to be submitted by the student and corresponds with steps (1) and (2) of the Gagne methodology. The RSF keeps track of individual results. This stage of lab learning is used to recall prior learning and corresponds with Gagne's step (3) and addresses the preparation or background study to be accomplished before actual interaction with networking equipment. The RSF will then set up a question/answer session that requires students to answer questions regarding the lab and corresponds with Gagne's step (6). When teamwork is involved, the RSF assigns the work to be performed by each member of a team. Face-to-face communication between remote students with the RSF is used for achieving learning process convergence (Collison *et al.*, 2000) and helps students identify:

- skill building activities for each lab;
- objective of the lab;
- the commands used in configuring equipment appropriately;
- the physical fixed wiring of the lab;
- actual steps in achieving a lab outcome and how to measure/ record output or simulation results; and
- the correct/expected output and is in accordance with Gagne (1987).

Active remote interaction with laboratory equipment – present stimulus, provide guidance and elicit performance

The RSF coordinates with the LSF to ensure that the remote students can interact in real-time with the equipment in the Internetworking lab at Halifax. At this level, the student has already acquired some knowledge (e.g. has configured a particular interface correctly and is now ready to proceed to the next stage of the lab). The student must submit results to the RSF after the completion of each sequence in the lab. The RSF keeps track of the knowledge acquired, its measurement and conveys this to the learner, e.g. "Please proceed to Step 4 of the lab", and corresponds to Gagne's (1987) steps (5) to (7). Students practice under the guidance of the LSF. This "guided" practice allows the LSF to provide corrective feedback. According to Gagne (1987) corrective feedback is one of the most effective teaching strategies that enhance learning and long-term retention. At this stage, the labs can be thought of as being "directed" with distinctly defined sequence of branches (IMS Global Learning Consortium, 2003) and may involve collaborative learning strategies (Hiltz *et al.*, 2000). Specifically, the collaborative approach will be advantageous especially when more advanced peer students explain difficult theoretical concepts or demonstrate advanced equipment configuration troubleshooting techniques to less knowledgeable students and exploits the prevalence and power of learning by observation (Bandura, 1986). Thus, more advanced peers can instruct less knowledgeable peers to help reinforce important concepts resulting in better retention.

Handling wiring changes

The RSF may also make requests to the LSF regarding changes to the physical fixed cabling on the equipment in the Halifax laboratory. Wiring or cabling information at the Halifax site is communicated to the remote student using streaming video. The requirement for streaming video in the remote site may be minimal as the remote student requires cabling information on equipment only at the beginning of the lab and thereafter whenever a topology change is made. The decision to use streaming video stems from its media synchronicity characteristics such as conveying wiring information in an unambiguous fashion to multiple students at the remote site. In addition, the video clip can be reprocessed i.e. can be reused to verify/confirm cabling configurations at any stage in the laboratory. It is possible to use the video effectively as different groups of students require cabling information pertaining to specific racks of equipment with which they will interact.

Troubleshooting – provide guidance and feedback

Lab objectives are clearly defined in that they evaluate the student on demonstrating particular skills or knowledge of techniques (Mager, 1988). The RSF identifies the stages of the lab that are likely to be most problematic to the students from an analysis of the evaluation criteria not met by most students. To remedy the situation, the RSF

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also provides remedial material after consultation with the LSF if the student has difficulty in meeting particular lab objectives. Such guidance may include scheduling demonstrations of proper configuration/simulation techniques using video conferencing from the Halifax site. The LSF or Faculty at Halifax demonstrates troubleshooting techniques. In addition, video conferencing easily allows the remote student to interrupt and seek clarification from the LSF or Faculty at Halifax. This medium has high concurrency, moderate feedback and is suitable for conveying information unambiguously.

Verifying learning outcomes – assess performance

The RSF also helps to verify that the student has accomplished the lab outcome and corresponds with Gagne's (1987) step (8). In addition the RSF helps co-ordinate intra-group discussion on the results (Hiltz *et al.*, 2000).

Tracking student progress – enhance retention and transfer

The RSF collects student outcome measures and forwards these to the LSF for evaluation purposes. Actual student evaluation is carried out by Faculty or by the LSF under guidance of the Faculty. Appropriate evidence of student competency in the lab include:

- answers to questions;
- appropriate response from configured equipment;
- plots and printout of graphical output from simulators;
- the maximum time in which the lab objective is accomplished;
- and the context in which steps a-d are accomplished (IMS Global Learning Consortium, 2003); and
- analysis and discussion of results.

Teaching and assessment methods that enhance knowledge retention and transfer in students are outlined in (Mayer, 2002). Accordingly, Faculty at the Halifax site, assess student for competency based on their:

- understanding component skills;
- aggregation of component skills into comprehensive skills;
- applying comprehensive skills to solve problems; and
- analysis and critique of the proposed solution.

On obtaining student assessment from the Faculty/LSF, the RSF may generate a skill map (graphical), which outlines the competency acquired by the student and may help motivate the student to focus their learning to acquire the desired competency level.

This pilot project in remote Internetworking laboratory education will help us identify techniques that:

- enhance online interaction;
- minimize failure in online laboratory based learning;
- relate the laboratory material to theoretical course content in the online lecture session;
- build strong capabilities in troubleshooting networking equipment; and
- build proper data collection and result analysis techniques.

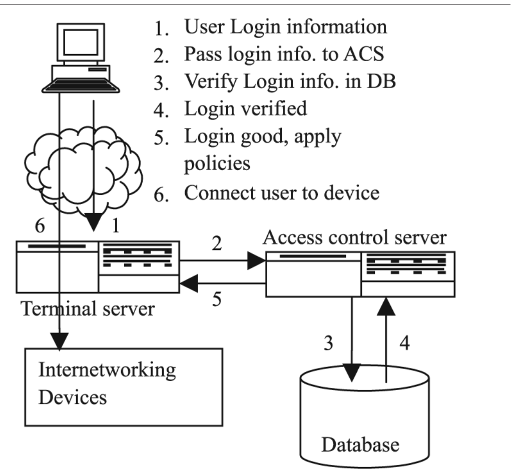
Integrated Web engine student authentication system

Secure communication and preventing security threats is essential to addressing security and privacy concerns. In addition, the communication itself may be encrypted to ensure secrecy. Two key issues to ensure secure interaction with the e-education system are:

(1) Verifying the identity of genuine users (IMS Global Learning Consortium, 2003).
(2) Restricting access to educational resources.

Specifically, we have integrated the features of authentication and access control into one security sub-system that is well suited to securing a large number of lab objects (equipment) accessed through the Internet by a large number of students. The program has addressed the issue of a reliable authentication mechanism to verify the identity of genuine students. The program securely authenticates remote students using (userID, password) before allowing remote access to the terminal servers at Halifax. This involves the use of an access control server (e.g. Cisco's access control server (ACS)) and the user authentication architecture is shown in Figure 5. In addition,

Figure 5 Remote student authentication architecture



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students are assured regarding the security measures such as, authentication, encryption, authorization and other measures that are in place to ensure their privacy.

Interactive home learning (IHL)

The Internetworking program uses several case studies to teach students problem analysis and project management skills. The case studies require student groups to analyze the problem and arrive at several alternate solutions based on real-life constraints including financial, technical and managerial considerations. From a pedagogical point of view, in case studies, the process of arriving at the solution is deemed to be as important as the final solution. Students perform a requirements analysis, study the topology of the existing network, the problems associated with this topology (e.g. congestion or quality of service issues), suggest a technology design, and refine the proposed design to take into account additional constraints such as keeping costs low or other managerial requirements. The students then present their solution to their peers for comments and suggestions on how the design could be improved. In the online environment, collaborative activities such as project work and case studies require synchronous interaction between various group members (Palloff and Pratt, 2003).

The online program uses synchronous online chat in chat rooms to facilitate interaction between students within small groups of four or five. The RSF check on the participation of various members in the group and may also kick-off the process by the judicious use of creative, thought-provoking questions. The RSF does not provide solutions; her/his role is to ensure active participation of all group members in the discussion. The students in the program come from diverse cultural, ethnic and national backgrounds (Sivakumar and Robertson, 2001). It has been observed that if students are allowed to form their own groups, they do so along cultural, racial or linguistic lines. However, like Canada many countries are multi-cultural and the modern work place demands that people from all backgrounds collaborate well with each other. Therefore, the LSF draws up groups for each collaborative component in a course at random. This process is repeated for each course and gives students ample opportunity to work with nearly everyone else in the virtual classroom at some time or the other and helps develop a community of learners. Anecdotal evidence suggests that students who have been through this process continue to stay in touch in the workforce long after their successful completion of the Master's program. The case studies and project work are submitted to the faculty who then evaluate it.

Challenges in remote Internetworking education

The Internetworking program needs to evaluate pedagogical issues that affect interaction in the RLR including whether students prefer a more visual (video) to a verbal (audio) style of delivering lectures, the combination of text, audio and video for optimal procedural content delivery, identify fundamental learning activities achieved in the synchronous RLR environment that are amenable for delivery in an asynchronous delivery environment, skill sets to be cultivated by faculty and the design factors that increase student satisfaction with online lecture delivery.

When the program expands to more remote sites, issues that the program still has to address in the RIL environment include facilitator training. Currently, the remote and local site facilitators are former onsite students of the program. In addition, the RSF are trained on techniques that emphasize how to facilitate well at the remote site for a two-week period for every course they facilitate. In addition, facilitators and faculty are educated on the various components of the e-learning system, their capabilities and deficiencies for a better appreciation of their role in e-learning and helps achieve better employee acceptance of the new technology. The program will further evaluate the remote student's online interaction with the laboratory equipment before its full-scale adoption in order to ensure that it meets the unique requirements of the program. We are confident that this pilot project will help improve the quality of the online laboratory learning by answering questions including:

- How do the learning activities and the quality of interaction of the onsite environment compare with the online environment for successful laboratory based learning?
- Does the online laboratory environment require the same amount of interaction as the onsite laboratory?
- What is the right amount of time required to complete online interaction with equipment ?
- How should the program handle questions regarding problems understanding the lab handout?
- How often must video conferencing be scheduled to demonstrate troubleshooting techniques and provide corrective feedback?

- How do we train competent RSF?
- What is a good ratio of student to RSF?
- Will the remote student's ability to make indirect cabling changes (if required) hamper their understanding of the laboratory? And if so, to what extent, if any?

Lessons learned, system limitations and directions for future research

In the early stages, much of the development of the IWE's RLR and remote interactive laboratory, has focused on understanding the system requirements and developing a viable test-bed to deliver the lectures and labs online by connecting students at remote sites to Internetworking lecture room and equipment facility at Halifax. Future research will focus on analyzing user activity, and evaluate the system with respect to usability of the system and student satisfaction with using the system. Work also needs to be done in evaluating how the facilitation process together with system use result in achieving the pedagogical goals of each course. System limitations include the fact that the current INWK laboratory can accommodate only 30 students maximum in a given time slot. Also, the program employs one remote site facilitator for each remote site. Some issues to be explored with respect to facilitation include tailoring the role of the facilitator to take into account the cultural differences between the students, the facilitators and the university. The online program also needs to model the knowledge domain into levels of expertise from novice, beginner to expert and identify the key problem solving strategies that must be imparted by the RSF and the LSF in order to ensure student transition from novice to experts in the duration of the course. The long-term goal of the program is to study the feasibility of laboratory access from the student's home and study how the remote site facilitation process will have to be modified to accommodate a purely online facilitation scenario.

Conclusion

This paper described the pilot online IWE environment used to deliver remote Internetworking education to students at geographically remote sites. The logical architecture of the IWE is motivated by the requirement to meet e-learning metrics within technology constraints to achieve the pedagogical goals of the Internetworking program. While, pedagogical considerations and learning outcomes motivate the RLR's multi-media delivery mechanism and instructional design, technical constraints (the unique hardware, software and interfaces used) motivate the choice of the remote interactive lab's delivery mechanism and technology design framework. The RLR's technology design provides for a real-time, reliable, remote lecture environment that is designed using *de facto* networking protocols and broadband Internet connectivity. These are tailored to model a remote synchronous, instructor-directed, objectivist learning environment that fosters strong interaction between remote students and the faculty at Halifax. The remote interactive laboratory's (RIL) technical design delivers remote Internetworking laboratory experience by allowing students to access and utilize equipment located at Halifax. The RIL's technical design is implemented using *de facto* networking standards, free software and commercial Internet browser to supports multiple simultaneous real-time interactions and secure information transfer between the remote site and the equipment at the Halifax. The remote laboratory experience is enhanced by employing streaming video/audio that provides unambiguous equipment cabling and wiring information. Remedial laboratory instruction that teach troubleshooting and practical problem-solving skills is provided using video-conferencing. The unique pedagogical and laboratory based instruction requirements of the Internetworking program motivate the role design used in the RIL. The RIL's four-tier role architecture consisting of faculty and local site facilitators at Halifax; remote site facilitators and remote students have well-defined duties and help maintain the academic integrity. The RIL's technical design and role architecture are tailored to model a synchronous, constructivist, collaborative, and directed learning environment that is accessible, reliable, easy-to-use and responsive. The RIL ensures the same quality of interaction with the laboratory as the onsite program, and provides for continuous assessment and real-time feedback to track student performance. Security considerations motivate the access control system design employed that limit access to educational and laboratory resources to authenticated students. The IHL facilitates synchronous online interaction between students in a group working on collaborative projects.

The novelty of our approach lies in designing and implementing a pilot remote synchronous online e-learning system that was tailored to the special pedagogical requirements of the Internetworking program, maintains academic integrity and continues to offer the same quality of interaction as the onsite program using existing technologies to meet instructional goals.

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