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Abstract

This paper discusses the relevance of distance learning to the engineering design education. Some key characteristics of design pedagogy seem to fall beyond the scope of current content-based eLearning solutions, including contextual social and collaborative interaction and iterative experimentation. Consequently, an effective eLearning solution for design pedagogy must bridge the gap between the physical and virtual worlds by establishing a virtual collaborative community and providing students with remote access to software and hardware resources. The paper outlines a comprehensive architecture of the eDesign portal that integrates the traditional courseware technology with remotely-accessible hardware-in-the-loop simulation, eCollaboration, and virtual classroom and learning community. The required hardware and software for implementing the eDesign architecture are detailed, and a preliminary assessment of using the eDesign portal for a second-year design course is discussed.

1. Introduction

The industry has shown clear interest in harmonizing technological expertise amongst various societies, which further facilitates outsourcing resources. In the current engineering world, design of complex systems involves multiple disciplines and hence a diverse assembly of engineers and facilities that are not necessarily placed at the same geographical location. Consequently, the notion of global virtual design teams[1], as a distributed collection of people and resources, integrated across geographical, cultural and functional borders, is becoming increasingly appealing. In response, the newly-revised engineering curricula have begun to recognize the need for the diversity of scope, expertise, and even resources in the engineering education. A multifaceted curriculum aims at training engineers who can work at multinational corporations in teams composed of a wide range of expertise and technical and cultural background. Therefore, the formation of inter-discipline, inter-university engineering programs has changed course from wishful thinking to serious planning, thanks to the rapid advancement of web-based education, usually labeled as eLearning.

The notion of eLearning as an evolution of Computer-Based Training (CBT) was initially promoted by the corporate world[2]. 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[3] and systematically[4]. Whereas corporations have diverged from the original notion into eCollaboration as a tool for increasing project efficiency and improving employee productivity, universities continued focusing on the content-delivery and administration aspects of eLearning.

Despite the growing popularity of web-based content delivery in academic programs, the relevance of eLearning to the revised engineering curriculum, incorporating hands-on design activities as essential components[5], is constantly challenged, due to the two key features of engineering design pedagogy[6,7]:

a. a vast portion of design knowledge is contextual and can only be learned through the senses and social interactions, and

b. design education heavily relies on simulation and experimentation; students develop engineering intuition by continuously iterating between mental concepts and real and/or simulated systems.

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 design education. An eLearning solution for design pedagogy 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 learning community. Hence, a suitable framework for design eLearning, or eDesign, 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.

Web-based education using synchronous and asynchronous learning network environments has been addressed in the literature extensively[8-10]. 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[11,12]. Also, very few papers have discussed the specific requirements for engineering distance education[13-17]. Most notably, in [13, 14] web-based learning has been extended to web-based experimentation as a key feature in the deployment of eLearning solutions for the engineering curriculum. These works have been further extended in [15] to include collaborative aspects of engineering education. Yet, a comprehensive and generic framework for eDesign 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 eDesign. The proposed architecture for eDesign extends the traditional provisions of web-based internet communications to a virtual design environment and collaborative learning community. A framework for the eDesign portal is introduced in Section 2. Section 3 discusses the portal architecture in detail. The specific implementation of this architecture, including details of the applied software, hardware, and technologies, for a second-year design course at the University of Toronto is described in Section 4. A preliminary assessment is discussed in Section 5, and some concluding remarks are made in Section 6.

2. A Framework for eDesign

The features of the eDesign framework are established from the extension of the traditional design process to a virtual community of distributed remote engineers. Although the framework must be highly integrated to facilitate collaboration, it should also be modular, to ensure generic reusability, and dynamic in terms of granular customization. Each design project is unique in terms of its goals and tasks, and as such the framework must be able to meet the requirements of many different projects.

A suitable option for the eDesign 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[18]. 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 learning community, making it a proper solution for eDesign. The backbone of the eDesign portal is a rich collection of synchronous and asynchronous communication tools that connect remote users to the virtual community. To complement communication, collaborative tools link users on a contextual-based interactive level. Although communication and collaboration are paramount in any design project, the resources utilized to conceptualize and test a design solution are of equal importance. Such resources include, in addition to traditional textual content and reference materials, software applications and simulations, hardware test platforms, and human resources. Thus, the eDesign framework provides distributed engineers with a communication-rich environment that, in addition to creating a collaborative community, also links engineers to physical resources and content repositories. The next section describes the architecture of an academic eDesign portal used for teaching engineering design to distributed groups of students.

3. eDesign Portal Architecture

The eDesign portal is functionalized by three key components that make up most engineering design courses; namely team collaboration, software simulation and hardware experimentation, and learning repositories and reference materials; plus the element of social learning interaction as a basic constituent of all engineering courses. Each of these components corresponds to one of the four modules in the architecture, i.e., eCollaboration, Integrated Simulation and Experimentation, Content Repository, and Virtual Learning Community, respectively. Further, the portal also contains an integrated management layer that monitors and controls the functions in each module. A schematic of the entire eDesign portal is presented in Figure 1.

3.1 eCollaboration

eCollaboration is used to provide students with access to each other, and is essential to the eDesign process. A combination of communication and resource sharing tools are used to allow students to interact on a collective and collaborative basis, which aims to replicate the experience of working together in person. Although the primary collaborative tool is application and document sharing, integrated project management tools are equally important.

Application Sharing: Application sharing allows a group of distributed students to collaborate in real time using a common software application. Only a single copy of the host software application is required, allowing students to not only collaborate on document workflows, but also share software resources. In addition, application sharing is compatible with any software application on the host machine, and can also share the entire desktop environment. Control over each shared application is assigned on a granular basis allowing the student hosting the application to delegate control to other peers.

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 a personal view of the site, allowing the student to customize the user interface and displayed content. Team sites are intended for group

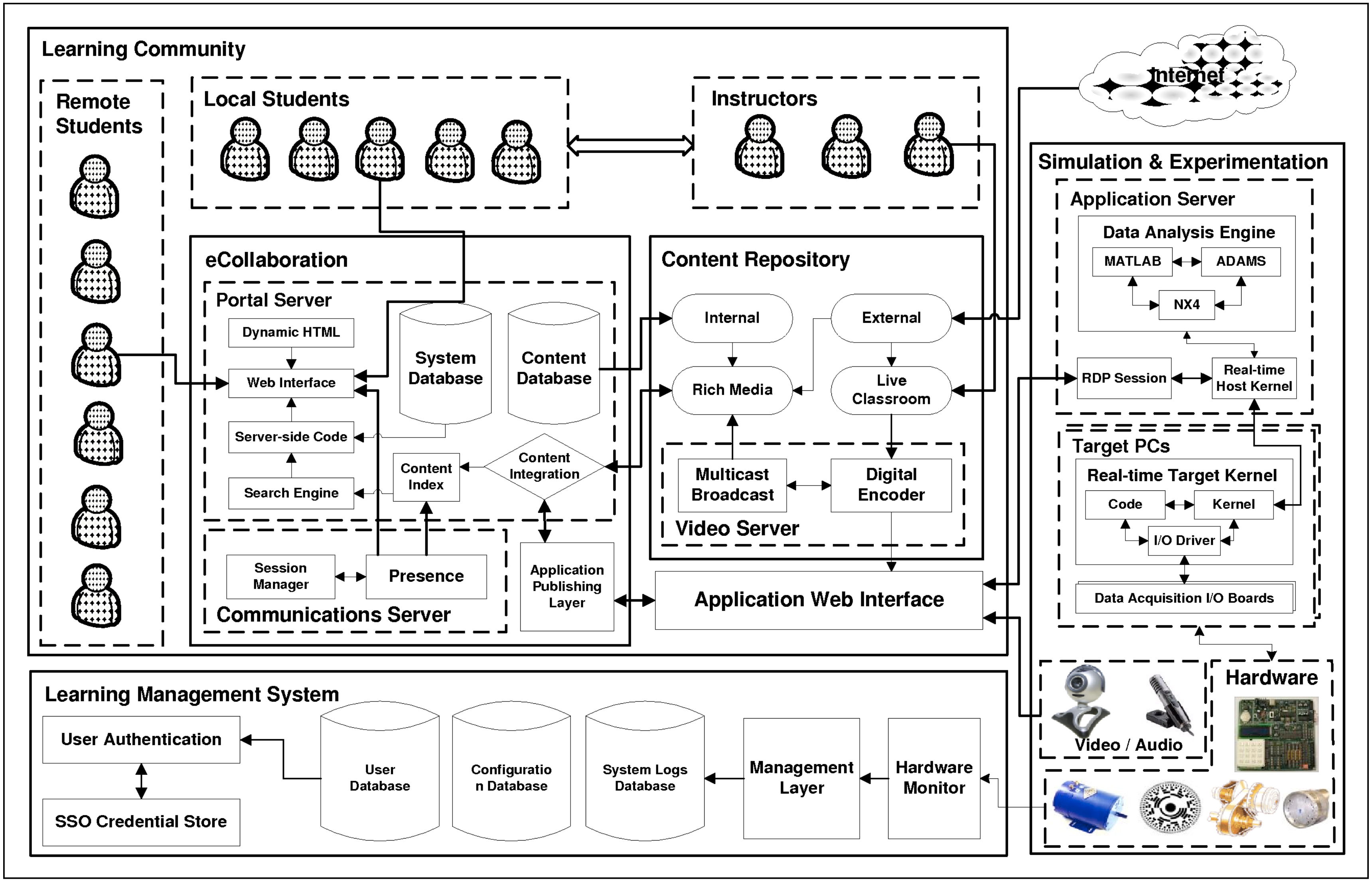

Figure 1. eDesign architecture

collaboration, and therefore contain a collection of collaboration and project management tools. The main element is a shared document library that allows students to collaborate and share documents. Team document libraries are optimized for collaboration with a set of document management tools, such as version tracking and document integration. Each student can also check out a document from the library to prevent other students from making changes while viewing 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.

Each site also contains a set of list templates and customizations for project management. Standard schedule tracking mechanisms, such as Gantt charts, can be used by the entire team to track project progress. Presence (see Virtual Learning Community) is highly integrated into team sites, helping to facilitate communication among students by allowing them to access all of the communication tools without having to open a separate browser or application.

3.2 Integrated Simulation and Experimentation

Software resources play an important role in the design, analysis, simulation and testing of engineering systems. Access to such resources is usually limited to a classroom or laboratory environment, and therefore hinders their usefulness as design tools for eDesign. Deploying simulation components across the internet allows distributed users to access powerful software applications collectively, and extends the capabilities of a traditional computer laboratory to a completely virtual deployment. Furthermore, given the many uncertain factors in the physical systems, such as sensor noise, actuator imperfectness, structural flexibility and damping, etc., a more realistic knowledge of the system being designed is obtained if the simulation incorporates direct links to the hardware components, forming a hardware-in-the-loop simulation (HILS) platform[19,20]. Therefore, an effective eDesign architecture should not only provide distributed students with software simulations but also enable them to experiment with a HILS platform remotely.

Application Publishing: Access to design-oriented software resources on a remote server is provided through an application publishing layer that, in addition to hosting the full graphical user interface of any application, also provides virtual channels that allow the remote application to interact with the local computer's ports for printing or saving data directly to the local hard drive. The application publishing layer utilizes a web-based terminal server client to channel a desktop session from the remote server to the local computer. In this manner, professional level engineering design and simulation applications are made available to remote users.

Hardware-in-the-Loop Simulation: While software simulations rely on a purely abstract model of a system represented by mathematical formulations, advanced simulation techniques use a combination of simulated components and physical hardware to achieve an integrated rapid-prototyping model. To make a HILS platform remotely accessible, the processing unit is divided into two modules. The first module, namely host kernel, interacts with the remote users, runs the software portions of the simulation, and also controls the real-time execution and collects the data. The second module, namely target kernel, boots the real-time application and interacts with the hardware components, such as actuators and sensors. Communication between the host and target kernels is established through the fast Ethernet. Remote users can log onto the server running the host kernel, and take control over the target kernel to execute the real-time simulation and observe and collect the data. Microphone and cameras installed around the platform will provide audio-visual data to the remote students.

3.3. Content Repository

Content is equally important throughout the design process as a reference and concept generation tool. Although there are already numerous content repositories and online libraries available to students, ease of use is an important consideration. To that end, the portal utilizes a content integration layer that brings together diverse types of internal and external content, and displays it through a consistent user interface.

Lecture Broadcast: The virtual classroom uses a combination of broadcast 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 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.

Internal Content: Lists of data and document content are stored within the portal environment in a content database. A list is a set of data columns in a database that are linked to a menu-driven user interface, such as a list of events displayed in a calendar format. Documents are stored in libraries, which are lists of documents with associated columns of metadata, such as the last user to edit a document. Columns in both lists and document libraries can be populated with static data, dynamic calculated data, or metadata. Metadata contains information about a specific list entry or document, such as the last time it was edited, and allows students to filter content based on various search scopes. 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. List templates are available for specialized content, such as a project budget or tracking bugs in a design. Custom list can also be created that allow any type of data to be entered and displayed in a custom data view.

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 and returned along with other portal search results. Libraries and content repositories can also be linked to the portal and displayed using content integration.

Search Tools: Content within the portal is stored in 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 also lists, repositories, and users. In addition, a topic assistant can be trained to suggest useful topics based on a user's search.

3.4 Virtual Learning Community

In a physical classroom or laboratory, the students, instructors, TAs and other support staff make up a community that interacts on numerous social levels within the context of any particular course or project. To extend the design process to a distributed group of users via eDesign, it is therefore required that these social interactions be promoted across the portal. As such a virtual learning community is required that brings together all of the communication and collaboration tools into a collective aggregate that interacts on a level beyond the context of a purely academic endeavor.

Asynchronous Communication: Email is the most ubiquitous asynchronous form of web-based communication. Student's can set automatic alerts to email themselves when another user in their team uploads a document or changes some content. Discussion boards are used for collective communication, and are most useful when a record of a dialog is required. 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 common synchronous form of web-based communication. The multiplex capability of IM provides an advantage over other real-time communication tools, since it allows a single student to simultaneously communicate with several other users. Other synchronous communication tools utilized for eDesign 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 indicates the current state of a student, and includes the username, contact information, availability, and a list of supported communication modes. Within the portal students' presence is generated by their online activity, and is broadcast through any instance of their username. Students can therefore determine if other users are available by simply looking for their name, such as in a list of team members or in a list of assigned tasks. In addition, presence can be linked to an external calendar to automatically change with their schedule. Presence links together the communication layer of the portal with the interface level to create an interactive community environment that is accessible from any page or site.

User Directory: The portal community is listed in a central directory that contains entries for each user, including contact information and public information from user profiles. With multiple metadata entries associated with each user in the directory it is very easy for students to find each other, even if they don't know 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 design task. The directory also allows students to quickly and easily locate human resources, such as instructors or teaching assistants. The user directory acts as a central "phonebook" for the portal community, bringing users together.

Personal Sites: Personal sites are template-driven websites that allow students to publish their own content and store personal documents in a document library. Students can select portions of their personal site to publish to the portal, or post on the internet providing a large audience for their work. Child sites can be created under each personal site, with dedicated workspaces for specific tasks or projects, which can then be shared with other users.
Personal document libraries act as student-based content repositories that can be accessed from a variety of mediums. When students log onto a local workstation in the classroom or laboratory, their personal document library is automatically mapped as a network drive. In addition, when students access a published software application their personal document library is also connected to the session.

4. Implementation

The proposed eDesign architecture is developed for a second-year design course at the University of Toronto. This course is the corner stone of design component for the Engineering Science program. The first two years of the program provide a rigorous background in engineering fundamentals, with students specializing into a particular option in the third and fourth years. Hence, all students had an identical background in terms of their undergraduate engineering education. The average class size for the course is 180 students, divided across three laboratory sessions. Within each laboratory session students are grouped into teams of three. Students were given a workshop at the beginning of the course as an introduction to the eDesign portal.

The network topology of the eDesign portal is modular in terms of software applications and server machines to ensure generic reusability and ease of migration. Each component of the portal architecture is implemented using enterprise level server applications, each running on a dedicated high-end server machine. The four core servers that make up the eDesign portal are Domain Controller (DC), Portal Server, Real-Time Communications (RTC) Server, and Application Server. An additional server is also dedicated to running the host kernel for each remote hardware-in-the-loop simulation platform.

Table 1. eDesign Portal Hardware Specifications

Server	CPU	RAM	HDD	NIC
HILS	Intel P4 2.0MHz	1 GB	40 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/Audio	Intel Pentium D 3.2 GHz	1 GB	250 GB	1 G-bit

To ensure complete platform independence of the implementation, all server applications are run on virtual machines hosted on the physical 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.

The eDesign Portal runs under a Microsoft Active Directory™ domain with each server running Windows Server 2008™ R2. Portal features are based on modular components of the Windows Server System and include Live Communications Server™ (LCS), Office Communicator Web Access™ (CWA), SharePoint Portal Server™ (SPS), and SQL™ Server.

Each physical server hosts one or more virtual machines using Microsoft Virtual Server™ 2005 R2. The network is hosted on a 1000Base-T 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 ensuring high availability. Hardware and software specifications for each server are summarized in Table 1 and Table 2, respectively.

Table 2. eDesign Portal Software Specifications

Server	Software	Function
HILS	MS Terminal Services Dymola MATLAB/Simulink	- remote desktop access - interface to experiment hardware via Target PCs
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/ Audio	MS WMS 9 Series GeoVision Web Server	- video and textual broadcasting - live video from analog cameras

The host kernel of each hardware-in-the-loop simulation platform consists of Dymola™ for object-oriented system modeling and MATLAB/Simulink® with the Real-Time Workshop® and xPC Target® toolboxes for generating the real-time code of the system model and downloading it on the target kernel processors, and also for interactively controlling the real-time execution, tracing the signals, and fine-tuning the system parameters. Remote users can access the host kernel through Microsoft Terminal Services™, and can also observe the experiment through the webcams and microphone. The target kernel consists of several low-end Pentium processors that are synchronized using broadcast memory technology (SBS Technologies, Inc.), which allows data to be simultaneously shared with several processors through a TCP/IP hub with very low read and write latencies. Each target node is equipped with a PCIM-DAS1602/16 data acquisition board (Measurement Computing, Inc.) for interfacing with the hardware components.

5. Assessment

To have a preliminary assessment of the effectiveness of the eDesign paradigm for undergraduate design education, a variety of usage statistics and student feedback was collected throughout the course. Based on the portal usage statistics, it was found that the most heavily used feature of the eDesign architecture was the Team Sites feature of the portal. Given the team-based nature of the course it is not surprising that students made the most extensive usage of the Team Sites, which provide direct intra-team collaboration tools. Greater than 90% of the students in the course made use of the Team Sites, despite the fact that using Team Sites in the course was optional. The most popular feature of the Team Sites by far was the shared document library. On average each team uploaded 100 MB of files to their shared document library. Based on student feedback, they found this feature most useful when collaborating on written documents, such as the final design report. Only 40% of the teams made use of the additional collaboration tools in the Team Sites (e.g., shared calendar). Many of the students indicated that they did not make use of these additional Collaboration tools since they provide redundant function to other collaboration tools outside of the eDesign architecture that were already in use. Interestingly, we did observe a correlation between Team Site usage and the performance of individual teams throughout the course. Students that extensively used the Team Sites, particularly the Collaboration tools in addition to the shared document libraries, tended to have a better performance in the course, reflected in both their assessment and physical prototype. However, it is unclear if the Team Sites contributed to the success of the teams, or rather that successful teams were more willing to make use of the Team Site features.

The second most commonly used feature of the eDesign Portal was the Application Publishing module. In particular, students reported that remote access to engineering design and simulation applications was very convenient when off campus (e.g., from a home computer). Although the remote applications were only used by a small subset of the class (typically less than 20%), students that did make use of the feature did so on a regular basis.

Many of the other features of the eDesign Portal (e.g., IM communication tools) were only used by a niche handful of students. In general we found that students were enthusiastic about new tools that provided functionalities that were otherwise unavailable through a consumer product (e.g., the Team Sites). On the other hand, students were reluctant to make use of tools that provided redundant functionality to consumer products that they were already using (e.g., IM client). This finding suggests the need for a better integration between existing consumer level communication and collaboration tools and the eDesign architecture in future iterations.

6. Conclusion

Current courseware technologies do not meet the essential requirements for engineering design education; they lack effective means for interactive and collaborative learning, and they do 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 design 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., hardware-in-the-loop simulation platforms, as well as software applications. Modularity of the architecture constituents enables one to readily implement various courseware and eCollaboration technologies. The proposed eDesign architecture is being developed for a second-year design course at the University of Toronto, a list of software and hardware used for this development was given in the paper, and a preliminary study of student usage was reported. More studies are needed and planned in the upcoming years to assess the effectiveness of eDesign Portal, particularly with respect to inter-university courses and remote access to hardware-in-the-loop simulation platforms.

The eDesign portal can readily be extended to other engineering courses that involve laboratories and large groups of remote students, as discussed by the authors in another paper[21]. Pedagogical implications of eEngineering, and eDesign in particular, are yet to be examined thoroughly. Some crucial issues must be addressed as to whether and how human mind can transform from the traditional approaches of knowledge acquisition and construction to new paradigms where physical presence becomes less relevant to the learning process in order to gain a wider scope of the learning subject.

7. References

1. M. Huysman, C. Steinfield, C.Y. Jang, K. David, M.H. Veld, J. Poot, and I. Mulder, “Virtual Teams and the Appropriation of Communication Technology: Exploring the Concept of Media Stickiness,”. Computer Supported Cooperative Work, Vol. 12, No. 4, 2003, pp. 411-436.

2. J. Cross, “An informal History of eLearning,” On the Horizon, Vol. 12, No. 3, 2004, pp. 103-110.

3. J. Puustjarvi, “Integrating E-Learning Systems,” Proc. IASTED International Conference on Web-based Education, Innsbruck, Austria, Feb. 2004, pp. 417-421.

4. M. Nichols, “A Theory for eLearning,” Educational Technology and Society, Vol. 6, No. 2, 2003, pp. 1-10.

5. M.S. Leonard, E.W. Nault, and J.S. Tulenko, “ABET Outcomes-Based Assessment: Providing Opportunities to Cooperate and Collaborate Across the University Campus and Among Universities,” Proc. ABET Annual Meeting, Pittsburgh, PA, Oct. 2002.

6. M. Brereton, “The Role of Hardware in Learning Engineering Fundamentals: An Empirical Study of Engineering Design and Product Analysis Activity,” Ph.D. Dissertation, Stanford University, Stanford, 1999.

7. M.R. Emami, “Application of Learning Models to the Engineering Design Pedagogy,” *2009 ASEE Annual Conference and Exhibition*, Austin, U.S.A., June 14-17, 2009.

8. H.A. Latchman, C. Salzmann, S. Thottapilly, and H. Bouzekri, “Hybrid Asynchronous and Synchronous Learning Networks in Distance Education,” Proc. International Conference on Engineering Education, Rio de Janeiro, Brazil, 1998.

9. C. Qu, and W. Nejdl, “Constructing A Web-based Asynchronous and Synchronous Collaboration Environment Using WebDAV and Lotus SameTime,” Proc. The 29th Annual ACM SIGUCCS Conference on User Services, User Services Conference, Vol. 29, Portland, U.S.A.2001, pp. 142-149.

10. C. Snow, “Network EducationWare: An Open-Source Web-Based System for Synchronous Distance Education,” IEEE Transactions on Education, Vol. 48, No. 4, Nov. 2005, pp. 705-712.

11. H. Lu, “Open Multi-Agent Systems for Collaborative Web-Based Learning,” International Journal of Distance Education Technologies, Vol. 2, No. 2, Apr-Jun 2004, pp. 36-45.

12. P.L. Isenhour, M.B. Rosson, and J.M. Carroll, “Supporting Interactive Collaboration on the web with CORK,” Interacting with Computers, Vol. 13, 2001, pp. 655-676.

13. D. Gillet, “eMersion: A New Paradigm for Web-Based Training in Engineering Education,” Proc. International Conference on Engineering Education, Oslo, Norway, August 2001, pp. 8B4, 10-12.

14. D. Gillet, F. Geoffroy, K. Zeramdini, A.V. Nguyen, Y. Rekik, and Y. Piguet, “The Cockpit: An Effective Metaphor for Web-Based Experimentation in Engineering Education,” International Journal of Engineering Education, Vol. 19, No. 3, 2003, pp. 389-397.

15. G.J. Fakas, A.V. Nguyen, and D. Gillet, “The Electronic Laboratory Journal: A Collaborative and Cooperative Learning Environment for Web-Based Experimentation,” Computer Supported Cooperative Work, Vol. 14, 2005, pp. 189-216.

16. Gustavsson, T. Olsson, H. Akesson, J. Zackrisson, and L. Hakansson, “A Remote Electronics Laboratory for Physical Experiments using Virtual Breadboards,” Proc. 2005 American Society for Engineering Education Annual Conference and Exposition, Portland, USA, 2005.

17. M. Auer, and D. Ursutiu, “Distributed Virtual and Remote Labs in Engineering,” Proc. International Conference on Industrial Technology, Maribor, Slovenia, 2003, pp. 1208-1213.

18. Collaboration Research and Education Network (CREN), 2006 http://www.cren.net/know/techtalk/events/portals.html#questions

19. P. T. Faithfull, R. J. Ball, and R. P. Jones, “An Investigation into the Use of Hardware-in-the-loop Simulation with a Scaled Physical Prototype as An Aid to Design,” Journal of Engineering Design, Vol. 12, No. 3, 2001, pp. 231-243.

20. A. Martin, M.R. Emami, “Analysis of Robotic Hardware-in-the-loop simulation architecture,” *IEEE/RSJ 2007 International Conference on Intelligent Robots and Systems*, San Diego, USA, October 29 – November 2, 2007.

21. M. Helander, M.R. Emami, “eLearning for Engineering,” *The 9th International Conference on Engineering Education*, Session M5H: Technology for Teaching, Puerto Rico, U.S.A., July 23-28, 2006.