Technology Supports for Distributed and Collaborative Learning over the Internet

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With the advent of Internet and World Wide Web (WWW) technologies, distance education (e-learning or Web-based learning) has enabled a new era of education. There are a number of issues that have significant impact on distance education, including those from educational, sociological, and psychological perspectives. Rather than attempting to cover exhaustively all the related perspectives, in this survey article, we focus on the technological issues. A number of technology issues are discussed, including distributed learning, collaborative learning, distributed content management, mobile and situated learning, and multimodal interaction and augmented devices for e-learning. Although we have tried to include the state-of-the-art technologies and systems here, it is anticipated that many new ones will emerge in the near future. As such, we point out several emerging issues and technologies that we believe are promising, for the purpose of highlighting important directions for future research.

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Categories and Subject Descriptors: K.3.1 [**Computers and Education**]: Computer Uses in Education—*Collaborative learning, distance learning*

General Terms: Management, Design, Human Factors, Standardization

Additional Key Words and Phrases: Distance learning technologies, distributed learning, collaborative learning, distributed content management

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ACM Reference Format:
Li, Q., Lau, R. W. H., Shih, T. K., and Li, F. W. B. 2008. Technology supports for distributed and collaborative learning over the Internet. ACM Trans. Intern. Tech. 8, 2, Article 10 (February 2008), 24 pages. DOI = 10.1145/1323651.1323656 http://doi.acm.org/10.1145/1323651.1323656

1. INTRODUCTION

When Thomas Edison invented motion pictures in 1922, he predicted that motion pictures would one day replace textbooks. Nevertheless, textbooks are still considered as the essential material in traditional[1] as well as distance education. During the Second World War, films were used for training. Later, open universities worldwide began to use video tapes and TVs as communication media for learning. During the late 1970s and the early 1980s, computer-based training (CBT) added interactions in automatic training. In the 1990s, multimedia technologies further enhanced training contents. In the mid-1990s, the popularity of the Internet and WWW technologies started a new era of distance learning—distributed learning and collaborative learning.

Distributed learning and collaborative learning apply computer and communication technologies to allow students and instructors to participate in learning activities anytime and anywhere. While distributed learning provides an environment where resources can be shared and dispersed students may participate in learning, collaborative learning puts more emphasis on providing a shared workplace for students to interact and learn through cooperation. Both types of learning technologies offer a complementary platform not only for traditional students to conduct additional learning activities out of the classroom, but also for working adults or other nonregular students to learn according to their own schedules.

Distance learning provides not only convenience to the students in terms of time and space, but also efficiency to the educators—supporting more students, timely updates of contents, and online assessments. However, sociological and educational considerations, such as meeting in person, threats from "the big professor,"[2] the concept of people-centric learning, and effective assessment, are leading us to rethink distance education. The study of "the no significant difference phenomenon" indicates that distance learning can achieve a similar education performance as traditional education. At the time when this paper was being prepared, traditional education was—and continues to be—still the main theme. However, distance learning is considered a strong support to modern education.

This survey article addresses distance learning issues from a technological perspective. We have omitted the sociological perspective, not because it is unimportant but because of the theme of the special issue of this journal where

[1]The term *traditional education* reflects the use of in-class teaching and ordinary assessment methods. These techniques are used in most K-12 schools and universities.
[2]One well-known professor teaches a popular subject, which is delivered to most students, while other professors lose their opportunities to offer the subject.

this article is included. The basic concepts and technology issues covered by this article include the following:

—*Asynchronous and web-based learning*. Contents of distance learning are delivered via learning management systems (LMSs) such as WebCT, Blackboard (go online to `http://www.blackboard.com/`), and Moodle (`http://moodle.org/`). See Sections 2 and 3.

—*Synchronous and real-time distance learning*. Real-time communication facilities, such as chat boards and video conference rooms, are used in synchronized distance learning by the dispersed students and instructors. See Section 2; see also Section 4.3 for integration of real-time communication tools to create a smart classroom.

—*Mobile learning and situated learning*. Mobile devices such as PDAs can be integrated with a LMS to deliver contents and to support real-time communications. See Section 4, where Sections 4.1 and 4.2 discuss architectures and technologies for the development of mobile learning systems and Section 4.3 discusses mobile learning as a convenient tool to create a specific authentic context under a particular cultural environment, which facilitates situated learning.

—*Multimodal interaction and augmented devices for learning*. Advanced human-computer interaction (HCI) technologies can help improve future distance learning; see Section 4.4.2. Augmented paper allows users to read ordinary textbooks with video supplements. Wearable computers can also assist training; see Section 4.4.3.

—*Content management system and repository*. The LMSs deliver contents that are usually associated with systems to manage the contents, that is, content management systems (CMSs). See Section 5.1 for emerging issues and architectures of these systems. These systems typically support a learning object repository (LOR), especially one with contents represented in a distance learning standard (such as SCORM) (go online `http://www.adlnet.gov/scorm/`). CORDRA is one generic definition of such a common LOR (`http://cordra.net/`).

Structurewise, the rest of this article is organized as follows. In Sections 2 to 4, we highlight technology issues. In Section 5, we point out important emerging technologies and possible future research directions. Finally, in Section 6, we briefly conclude the article.

2. DISTRIBUTED LEARNING AND COLLABORATIVE LEARNING

During the last decade, some major commercial e-learning systems, such as WebCT and Blackboard (`http://www.blackboard.com`) have been developed. They offer a certain degree of support for distributed learning or collaborative learning, and are now being widely adopted in schools or commercial organizations. With these systems, instructors can manage their course materials, keep track of students' progress, and communicate with the students. On the other hand, students may access these systems at their preferred schedule through the Internet. These systems provide the students with one-stop access to the course materials of different subjects, while both the students and the course materials may be geographically dispersed. They typically include email and discussion forums to allow both the students and the instructors to interact with each other asynchronously. Blackboard further provides a text-based chatting function as well as a virtual classroom to facilitate synchronous collaborative learning.

Although existing e-learning systems have already provided a substantial amount of support for e-learning activities, there are still a number of design issues that need to be addressed in order to come up with a truly distributed and collaborative environment for e-learning.

In brief, *distributed learning* focuses on integrating people and learning resources that are distributed among different geographical locations. To achieve this goal, some major problems must be addressed. First, learning materials are in practice hard to be integrated as they may be developed by different people or organizations, and are likely stored in different formats. Second, as learning materials are being built up, the system may become very large and need more effort to maintain. Third, with more and more people using the system, hosting issues such as scalability and security control may need to be considered. Fourth, users may be connected to the e-learning system through networks of different connection speeds. When multimodal or multimedia learning materials are being used and their size becomes large, content distribution may become a challenge.

On the other hand, *collaborative learning* emphasizes providing a shared workplace for students to interact and learn through cooperation. Major issues include the kind of workplaces that must be provided and how they can be constructed. In particular, appropriate technologies should be selected to support effective communication among e-learning users and the persistence of their conversations.

Due to the diversity of the problems involved in distributed learning and collaborative learning, a set of solutions is needed to address the problems in a comprehensive way. The solutions are categorized as follows:

—*Current standards*. Standards provide guidance for the development of learning materials. They encourage and facilitate sharing and reuse of learning materials. They also address the problem of lack of openness in existing commercial e-learning systems, in which proprietary databases are commonly used. A popular standard is the Shareable Content Object Reference Model (SCORM; go online `http://www.adlnet.gov/scorm/`), which is a specification for standardizing the reusability and interoperability of learning materials. It was developed by the Advanced Distributed Learning (ADL) initiative. SCORM focuses on several major issues. First, it defines a model for packaging learning content to facilitate content delivery. Second, it defines a standard way for e-learning systems to communicate with each other. Third, it requires the inclusion of metadata to describe the course content, facilitating efficient and effective identification of appropriate course materials. By conforming to the SCORM standard, different systems can find, exchange, and reuse course materials. This is especially important for a large-scale distributed learning environment, consisting of multiple dispersed learning management systems managing various learning resources.

—*System hosting*. As e-learning systems are becoming popular and more people are gaining access to them, there is an increasing demand for a system architecture that would accommodate and manage a large number of users, including access control. Typically, an e-learning system needs to maintain and deliver course materials, track student progress, and support student collaboration. These tasks may involve substantial workloads when the number of users becomes high and multimedia learning materials are to be distributed to the users. One way to address this issue is by adopting distributed system technology [Tanenbaum and Van Steen 2007], which combines a collective set of computers and presents it to the users as a single coherent system. Through this technology, one may assign suitable amounts of computation or data storage resources to manage various tasks of an e-learning system. Such resources can also be dynamically adjusted during run-time to accommodate the change in workload of different tasks.

Another critical issue for hosting e-learning systems is security control. Careful measures should be taken to ensure that only authorized users are able to perform any e-learning activities, including content authoring, content retrieval, and student collaboration, and only those who have these rights may be able to modify or access a particular set of learning materials. An emerging approach to protect e-learning content from unauthorized usage is by digital rights management [Koenen et al. 2004]. General approaches for consideration include simple password-based usage control, digital watermarking, and certification of hardware and/or software. A more detailed guideline for security control in e-learning systems can be found in Weippl [2005].

—*System support for content delivery*. Contents may be requested dynamically through a variety of e-learning activities. Delivery problems typically arise when multimedia data, including sound, video, and graphics, needs to be delivered. This multimedia data is usually large in size and the e-learning users may be connected to the e-learning system through networks of different connection speeds and client machines of different processing performance and local storage space. From the content perspective, to accommodate the diversity of e-learning users, adaptation in content delivery must be taken to provide satisfactory services. This can be done by considering data size, media quality, and relevance as well as network bandwidth in a data optimization process when preparing client-specific e-learning content for delivery. An implementation can be found in Smith et al. [1999]. Another solution to the multimedia content delivery problem of e-learning systems is to employ standards to allow the interoperable adaptive multimedia communication [Timmerer and Hellwagner 2005]. The standards provide a coding format and device independence approach within the context of MPEG-21 to support multimedia streaming by adapting to the client performance and network conditions. From the system perspective, peer-to-peer technologies

[Androutsellis-Theotokis and Spinellis 2004] can also provide a complementary solution by connecting the client machines directly into peers without an explicit central server for coordination. Multimedia data is partitioned into pieces, and each of them may be maintained by a client. A peer-to-peer network can offer a high data transmission rate as well as system scalability and availability by integrating the resources from peer client machines. With this technology, e-learning users may exchange multimedia data directly among themselves with maximum data transmission performance, especially when the number of users is high.

—*Support for asynchronous learning mode*. Asynchronous learning mode [Hiltz and Wellman 1997] provides students with great flexibility as they may choose to learn according to their own schedule. Students may access the e-learning system at any time and initiate and/or retrieve learning communications through the system. In other words, e-learning users, including instructors and students, may not be able to interact at the same time. Their collaboration is mainly conducted through the ongoing conversations stored in the system. Hence, an effective way to extract relevant context from ongoing conversations is essential in helping e-learning users get a clear view of a learning activity.

In general, asynchronous learning is facilitated by emails and discussion forums, which are commonly found in existing e-learning systems, such as WebCT and Blackboard. Blackboard has further added voice-based mails and discussion forums, a more native type of communication, to enhance the asynchronous learning. Such tools typically only organize conversations from learning activities into simple threads or categories. E-learning users can set up collaboration areas and group the conversations based on date/time stamping or discussion topics. However, as the conversation or e-learning materials get larger in volume, it becomes much more difficult for e-learning users to extract relevant context for their collaboration. A possible solution to this is to put annotations to key events or conversations [Plaisant et al. 1999] so that they can be identified easily during collaboration. In addition, Web mining techniques [Kosala and Blockeel 2000] can also be used in information retrieval from a complicated conversation data set. Generally, Web mining can be conducted through tracing the content, the link structure, and the usage of the domain being searched.

—*Support for synchronous learning mode*. Synchronous learning mode [Chen et al. 2004] allows e-learning users to conduct collaborative learning in a shared workplace at the same time. It offers e-learning users interactive communication and instantaneous responses in learning tasks. Students' queries and learning problems can be solved more quickly under this learning mode. The implementation of a synchronous learning mode depends on a suitable choice of communication platforms. For example, electronic whiteboard, instant messaging, video conferencing [Wheeler et al. 1999], and distributed virtual environments (DVEs) [Chim et al. 2003] have been developed for consideration. Instant messaging provides simple text-based chatting facilities, while an electronic whiteboard lets people communicate with freehand writing and drawing. Video conferencing enables people to have face-to-face communication over the network, and is particularly good for supporting verbal, facial, gestural, and other forms of visual communication. DVEs provide an interactive, simulated shared three-dimensional (3D) space for users to conduct e-learning activities. Among these communication platforms, DVEs are the most demanding in terms of data transmission and interactivity requirements. They support learning activities that rely on different simulated cases and interactive responses, such as surgical or aviation training. Unlike video conferencing, there is a lack of standards to govern the data transmission process in DVEs. One problem is how to identify and deliver relevant 3D objects while retaining system interactivity. A possible solution to this problem is to adopt an on-demand distribution approach and a synchronization mechanism [Li et al. 2004]. The on-demand distribution approach allows complicated graphic objects, including geometric models and texture images, to be delivered progressively to the e-learning users. The synchronization mechanism, on the other hand, helps maintain a consistent state of the shared objects among e-learning users.

Finally, as both synchronous and asynchronous learning modes are complementary technologies, instead of applying either of them individually, they should be integrated to maximize the benefits of e-learning applications. Such an approach may offer a way of constructing comprehensive online learning communities, providing a social and collaborative network to e-learning users. Such communities emphasize learning with groups rather than individuals. Users may discuss issues, conduct brainstorming sessions, seek advice, and work together on coursework or projects. The combination of both learning modes can extend the collaboration of e-learning users both online and offline, which is critical to users living in different time zones.

3. DISTRIBUTED CONTENT MANAGEMENT

With advances in Internet technology and especially the World Wide Web more recently, the content that an organization (e.g., a university) relies upon and hopes to integrate into a content management strategy has become much more diverse, including hypertext and multimedia. This represents a shift from the traditional content management systems which focus on conventional types of data like text documents, research papers, monograph books, manuals, etc. The environment in which the content is produced and consumed can be very heterogeneous, or may involve many data formats, processing tools, and operating systems.

3.1 Historical Perspective

Content management systems evolved from both the content publishing and (enterprise) content repository approaches. On the one hand, the content publishing side has over the years learned how to deal effectively with complicated structured information, and with repurposing content for different application needs. Some specific issues addressed by these systems include constructing complex data structures, validating content against schemas, and transforming these data into a variety of output formats for specific modes of distribution including the Web, CDROMs, and mobile devices. Meanwhile, enterprise communications tools such as emails, forms, records, and the like have focused mainly on sharing and replicating data across distributed heterogeneous networks. While structured document systems have mainly dealt with managing the structure of the content, office systems (such as emails) have generally focused on reusing data in heterogeneous environments at the expense of document structure. As these two approaches move closer, they have become less mutually exclusive. In particular, emails have become more structured. University Web sites are populated by all sorts of documentation, which may be stored in a structured database. The frequency of updates, custom formats and content, and changes resulting from increased use and expectations of content on the Web have challenged content management systems (CMSs) to become more flexible and provide more powerful content repositories. In addition, large organizations like educational institutions tend to have people distributed in several, if not many, locations, complicating the control of and access to information. Indeed, the evolution of educational information systems has created a mixed environment of computing platforms, applications, data formats, and standards. These challenges directly affect the value of the information and result in increased costs for the educational institutions to use these systems, which explains why we are seeing interest growing in more integrated data structures and distributed content management systems.

3.1.1 *The First-Generation CMS.* The earliest content management technologies, including emails, databases, and other information management systems, were based on the concept of a centralized collection of applications, and data was usually stored on large mainframes. Known as *Paleolithic content management*, most content in this approach was stored in diverse, noncompatible formats specific to the tools that generated it, even if that diverse content was managed on the same server. In order for one department to share its information with another, it often was easier to print it out and have it rekeyed than to try to interpret disparate character sets and encoding formats and build conversion programs to modify it electronically.

Since data has been the lowest common denominator for many, if not all, applications, the direction taken was to come up with data interchange technology. After character mapping tools became available, structured information tools for data interchange came into existence. First generic coding approaches, for example, GenCode, were developed based on the notion of separation of the information content of documents from their formats, and they served as predecessors to SGML [Goldfarb 1991, 2002]; the latter was then followed by HTML and XML (go online `http://www.w3.org.XML/`). The data interchange approach resulted in the need to create applications that were occasionally somewhat redundant in each of the processing environments. On the other hand, for people developing better ways to manage content (e.g., office documents), connecting machines together was the most frequently pursued strategy. This approach meant that the content had to be much simpler to allow tools to behave

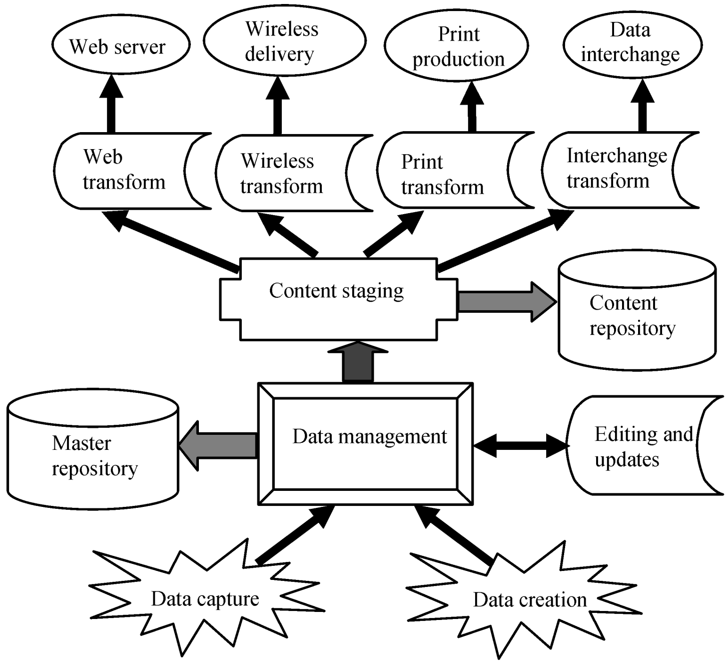

Fig. 1. A monolithic CMS system delivering data in various "consumption" formats.

similarly in diverse environments. The interconnectivity strategy relied on plain text documents or proprietary binary formats and managed information at the document or file level. In the case of office automation, for instance, there was little structure below a document that could easily be managed across different office systems. Only a very few select metadata fields would be passed from one operating system to another, such as file size and date.

3.1.2 *The Second-Generation CMS.* The second-generation CMS is known as *monolithic content management*, and IBM was among the first to begin integrating data storage and data presentation technologies. The idea was to put all types of content into a single homogeneous environment on a central server and grant authorized personnel with controlled access to read or edit it. Tools used to enhance the content and/or organize the output were also made available. These large monolithic systems were rarely integrated with each other. Content was usually stored in deliverable formats, such as books or periodical pages that were difficult to reuse effectively in other formats, such as CDROMs or Web pages.

For certain application systems such as the publishing industry, monolithic approaches to content management are still the dominant architecture today. It is often assumed that all users must maintain live sessions on the system to use it, all data is stored in a central repository, and all users should be limited to an identical set of compatible tools. Ultimately, input tools and processes become a serious bottleneck and a significant delay in collecting the required data. See Figure 1. Emulating the processes and tools designed to manage print-oriented content, Web content management systems (WebCMSs) emerged in the late 1990's as the importance of Web content grew. The WebCMS systems have added many things needed only for Web or other electronic forms (link management, Web page posting and publishing, search indexing, and other capabilities). So, in essence, they have created a new class of monolithic CMS systems. In one enterprise, both WebCMS and traditional CMS systems may therefore coexist, having the same data in them in different native formats, using different editors and tools, with different schedules and even differently trained working staff.

3.1.3 *The Third-Generation (3G) CMS.* With the introduction and proliferation of distributed personal computers, the monolithic approach was greatly challenged (and also complicated) by the distributed and synchronized content management paradigm. In this (known as *3G CMS*) approach, information is no longer stored in a centralized mainframe, but fragmented across a number of personal computers located in different places. Many strategies have evolved to replicate content and keep collections synchronized. Some fundamental issues related to content distribution design include the following:

—*Content partitioning*. Similar to the issue in traditional distributed database design, content distribution can be designed based on *horizontal* and/or *vertical partitioning methods*. For horizontal partitioning, a set of documents can be clustered into a number of fragments (subgroups), each subgroup containing a collection of complete documents that are related to each other according to some sort of metadata (e.g., authors and topics). For vertical partitioning, a document (or a set of PPT files belonging to the same course) is decomposed into fragmented segments based on chapter/section headings, and these segments along with others derived from applying the same partitioning method to other documents are distributed and stored into physically decentralized servers.

—*Content replication and allocation*. No matter whether the fragments are obtained from vertical or horizontal partitioning, they are subject to replication if access to them is expected to be frequent from the distributed sites, so as to improve the content availability and access efficiency. Such (replicated) fragments will be allocated to different sites based on *fragment affinity*, that is, how likely the fragments are to be accessed together, and load balancing.

—*Distributed content retrieval*. Since content in an integrated and distributed CMS has been partitioned and allocated to different sites, retrieval of the content has to be conducted in a distributed manner. Depending on the way the fragments were derived, distributed content retrieval may involve "union" or "merge" of the fragments stored in different sites.

—*Distributed content maintenance*. While the partitioned and replicated fragments offer several advantages, such as improved content availability, reliability, faster retrieval, and fine-grained access control, the gains are not obtained for free. In particular, there are issues and problems to be resolved in terms of maintenance. How to correctly conduct content update and to keep the replicated content fragments consistent in such an integrated and distributed CMS are some of the major issues to be addressed.

It is the advent of the World Wide Web that has changed people's expectations and requirements on how systems should behave. Most databases and file synchronization tools have begun to offer transformation capabilities to feed an HTML version of the data. Gradually, tools and systems such as relational databases have become more structured-document friendly, for example, Oracle 9i. Also, scripting languages like JavaScript and dynamic page content, for example, ASP and JSP, simplify the process of formulating complicated document requests and feeding them to a Web browser session. A request made from a browser session or another thin client is routed to the central server for extraction, and the result is transformed into a consumable format such as HTML and delivered back to the requestor. Many database tools come equipped with powerful filtering and replicating functionality, and where they fall short, scripts or other programs can complement them. Given the widespread familiarity with languages such as Perl [Srinivasan 1997], building the glue between consistently organized data content is feasible, and replication and synchronization of data content into a monolithic system model is a viable approach to exposing that content to the Web or an Intranet.

A newer direction of CMS evolution is toward distributed and integrated content management [Waldt 2004], sometimes referred to as the *3.5G CMS*. To understand what it means to have an integrated and distributed data server or CMS, it is important to know a few concepts from mainstream computer science. The first is the concept of a federated database system [Heimbigner and McLeod 1985]. Federated systems are distributed across a network on more than one system using different databases tools, operating systems, applications, etc.. The next concept is *loose coupling*. It refers to systems that are integrated in such a way that they work well independent of each other and are not dependent on each other to continue working. Systems that are tightly coupled tend to break down more easily when something changes and are usually dependent on specific versions and flavors of applications and operating systems in use. A federated system needs to be loosely coupled to allow data to be accessed and moved between systems in a cost-effective and timely manner [Sheth and Larson 1990].

3.2 Representative Distributed Course CMS

We now examine a number of representative distributed course content management systems that have been developed in recent years, including Moodle, ANGEL Learning Management Suite (LMS), and ATutor.

—*Moodle*. As a free, open-source software package, Moodle (go online to `http://moodle.org/`) is a course management system (CMS) designed using sound pedagogical principles to help educators create effective online learning communities. Moodle runs without modification on various OSs like UNIX, Linux, and Windows that support PHP, including most Web host providers. Data is stored in MySQL or PostgreSQL, but work is currently underway to make full use of database abstraction so that other databases can be used just as easily. (Oracle and Microsoft SQL Server are two specific target DBMSs.)

Moodle has many features expected from an e-learning platform, including forums, content managing (resources), quizzes with different kinds of questions, blogs, wikis, database activities, surveys, chat, glossaries, peer assessment, and multilanguage support. Moodle's interoperability features include the following:

(1) Quizzes and quiz questions, allowing import/export in a number of formats: GIFT (Moodle's own format), IMS QTI, XML, and XHTML.
(2) Resources, using IMS Content Packaging, SCORM, and AICC representation.
(3) Integration with other CMSs such as Postnuke (via third-party extensions).

—*ANGEL Learning Management Suite*. ANGEL Learning, Inc., develops and markets enterprise e-learning software globally. Products include ANGEL Learning Management Suite (LMS) (go online `http://www.angellearning.com/`) and ANGEL ePortfolio. ANGEL may be used to create a virtual learning environment for institutions ranging from elementary schools and districts to higher education and corporate training centers. The company subscribes to a philosophy of openness and community-based product development. ANGEL Learning has demonstrated commitment to interoperability standards such as SCORM.

ANGEL LMS provides enterprise software capabilities for teaching and learning, K-12 through higher education and beyond. The suite includes a Learning Object Repository (LOR) and ANGEL LIVE synchronous tools, open database schema, and other features. ANGEL LMS 7—the latest release—harnesses the Internet to create powerful environments for teaching and learning. It features easy customization and secure, simple integration. As learning management system technology becomes integral across the educational spectrum, ANGEL offers a complete suite of simple, yet powerful online teaching and learning tools, as summarized below:

(1) *Simple usability*. Designed for product usability, ANGEL offers simple navigation in a user-friendly interface.
(2) *Powerful automation*. ANGEL LMS 7 mines and automates the analysis of the extensive data stored in the LMS and presents the data immediately upon login to facilitate assessment and reporting, and increase instructor efficiency.
(3) *Actionable information*. Exclusive ANGEL agent technology makes data actionable. ANGEL agents can easily be set to perform many functions—send emails, schedule meetings, unlock course content—for one or a group of students automatically.
(4) *Personal communication*. Synchronous communications are included in ANGEL 7—virtual office hours, desktop sharing, instant messenger, whiteboard—with personalized teaching and learning. Drag-and-drop

editing and subject-based page design themes make individual and course personalization simple.

—*ATutor*. ATutor (go online to `http://www.atutor.ca/index.php`) is an open-source Web-based learning content management system (LCMS) designed with accessibility and adaptability in mind. Administrators can install or update ATutor in minutes, develop custom templates to give ATutor a new look, and easily extend its functionality with feature modules. Educators can quickly assemble, package, and redistribute Web-based instructional content, easily retrieve and import prepackaged content, and conduct their courses online. Students learn in an adaptive learning environment.

ATutor has also adopted the IMS/SCORM content packaging specifications, allowing content developers to create reusable content that can be swapped between different e-learning systems. Content created in other IMS- or SCORM-conformant systems can be imported into ATutor, and vice versa. ATutor also includes a SCORM 1.2 Runtime Environment for playing and managing SCORM-based sharable content objects (SCOs). The standard features in ATutor are summarized as follows:

(1) *My courses*. Instructors and students can manage the ATutor courses that they teach and/or are enrolled in.
(2) *Adaptive navigation*. Learners can move through ATutor content using global, hierarchical, or sequential navigation tools. Navigation elements can be displayed as text, icons, or both text and icons, or hidden to simplify the environment.
(3) *Work groups*. Learners can collaborate with others on course projects, communicate as a group through the forums, share resources using the file storage function, and work together authoring project documents.
(4) *SCORM run-time environment and SCO manager*. ATutor SCORM run-time environment and SCO package manager are provided to add prepackaged, interactive, and interoperable content to courses.
(5) *Student tool preferences*. Instructors can choose from the available course tools and menu modules, selecting only those used in a particular course. Tools can be located on the course home page, or moved to a separate student tools page.

4. MOBILE LEARNING, SITUATED LEARNING, AND ADVANCED DEVICES

Communication technologies and mobile devices are enabling a so called m-learning (mobile learning) era. Typical mobile devices include PDAs, cell phones, and UMPCs (ultra mobile personal computers). These devices can be integrated with communication modules to enable access to the Internet for real-time audio-visual communication. In addition, with a global positioning system (GPS), mobile devices further facilitate location-aware services, including location-based e-learning.

4.1 Architectures for Mobile Learning

Mobile devices do not work alone in m-learning. Whether a server stores content in a client server or a three-tier architecture, a learning management system

(LMS) and software architecture are generally defined as a middleware between a content server and mobile client devices. However, mobile devices have limitations and drawbacks, which should be considered in practical implementations.

4.1.1 *Middleware for Mobile Learning.* Location flexibility is an advantage of mobile learning. Grohmann et al. [2005] proposed a prototype called *ARIS Mobile*, which is a part of the WINFOLine learning environment implemented across the German education network. AMPLe [Young and Liang 2006] is another similar system supporting mobile learning on PDAs and cell phones. Based on Microsoft .Net framework and Mobile Internet Toolkit, the AMPLe system enables a cross-platform architecture to support mobile devices via Wireless LAN and GPRS. The AMPLe system includes both an instructor module for learning resource and curriculum management as well as assessment, and a learner module for communication, information inquiry, and personal notes. Another middleware proposed in Shih et al. [2004] enables m-learning in a similar manner on PDAs and cell phones. The work was extended to include an augmented paper and a hyper pen device (an OCR-like pen) [Shih et al. 2005] for m-learning. A complete system for m-learning architecture based on SCORM has been presented in Shih et al. [2007]. The project discussed in Shih et al. [2005] was further extended to support m-learning on set-top box for digital TVs. There are also a few other similar systems focused on context-aware m-learning and location-sensitive services [Malek et al. 2006; Jung et al. 2006; Specht et al. 2006]. In general, a middleware for mobile learning needs to have a LMS on the server side to support learning object retrieval on different mobile devices via different communication protocols.

4.1.2 *Performance Considerations on Mobile Devices.* PDAs and cell phones have smaller memory capacity and limited computation power as compared to regular PCs. In the long run, mobile devices will continue to perform inferior to PCs. Hence, adaptive technologies, such as converting media formats, are required to guarantee user satisfaction. Another drawback is the limited bandwidth of wireless communication. Most mobile devices are connected to the Internet using Wireless LAN, with some of the devices using GPRS, 3G, and other technologies. Unless wireless communication bandwidth can catch up with fix-line networks, transcoding techniques are needed to cope with different bandwidths.

The biggest drawbacks for mobile devices, however, are the limitation of battery life and the restriction on I/O devices. If it is not possible to improve the battery life significantly, convenient recharging methods should be implemented. Since mobile devices need to be small, they are limited as to screen size and input mechanism; a higher-resolution screen may not solve the problem due to the resolution of human vision, unless glasses are used. However, glasses-based monitors may not be acceptable to many users. Similarly, small keypads limit input speed. Audio input is possible but it may not work in some environments and it suffers from a relatively higher error rate. Gesture recognition via video cameras is still primitive due to the difficulty in handling lighting variations and diverse image backgrounds. In a nutshell, limitations in I/O devices of mobile devices restrict the usability of m-learning. Another issue not related to performance but affecting the usage of mobile devices is the influence of microwave radiation on humans. Although there is no conclusive medical evidence yet as to its effects, worries about its possible effects have caused at least some concern on the part of users.

4.2 Adaptation of Learning Resources and User Interaction

Since mobile devices suffer from the limitations mentioned above, the development of learning resources and user interfaces for mobile devices should be considered differently than those for ordinary PCs. Currently, adaptation of learning resources on mobile devices can be achieved semiautomatically.

4.2.1 *Guidelines for Developing m-Learning Contents.* In view of the limitations of mobile devices, guidelines can be considered from a few perspectives. A number of important issues discussed in Grasso and Roselli [2005] are summarized below:

—*Target user group*. Grasso and Roselli [2005] suggested developers study all possible user scenarios and experiences before designing the content. Not everyone is suitable for m-learning, since some users may not be familiar or comfortable with using PDAs. After the target user group is selected, the content can then be developed.
—*User interface design*. In addition, interactions should be consistent and simple, for example, by assigning each button to a fixed function consistently. Scrollbars should be avoided.
—*Limited media selection*. If video is used, a suitable resolution and format should be selected. The size and details of a picture or drawing should be readable. Similarly, the amount of words used on a screen or a page should be limited.
—*Performance and hardware*. The resolution of video or image selected should meet the performance of hardware and communication channels. In the extreme case, the sequence of navigation should be considered with the caching strategy of a mobile device, so as to guarantee both performance and QoS.

The above guidelines are considered from the technology perspective. Pedagogical issues should be further investigated to ensure the usability of contents.

4.2.2 *Content Reflow and Media Adaptation.* The guidelines for developing contents may be hard to follow. However, technology can help users adjust the contents. Content reflow is a technique used to resize images and font sizes of a learning object to produce a new layout which is more suitable to a particular screen size and resolution [Shih et al. 2004]. In addition, multimedia resources of different formats and resolutions can be coordinated to fit different computing power and screen sizes. The framework proposed in Gang and

Zongkai [2005] includes two layers—a multimedia layer and a learning object layer, which are integrated to ensure a high adaptation quality of learning resources. Another similar system [Lemlouma and Layaida 2005] proposes an infrastructure to deal with user interactions and a hierarchical image navigation mechanism. Thus contents can be well adapted to a small screen device. The Pocket SCORM project [Shih at al. 2004] also supports content reflow on PDAs and cell phones; the mechanism proposed can be used on UMPCs of different resolutions. TERESA (Transformation Environment for inteRactivE Systems representAtions) [Mori et al. 2004] is a tool that enables one model (i.e., content) to be delivered to different interfaces. TERESA has three levels of abstractions: a task model, an abstract user interface level, and a concrete user interface level. The tool allows users to design presentation tasks which are transformed into an abstract user interface. This interface is then realized in a practical implementation, that is, concrete interface. Demonstration of TERESA shows that the tool is able to generate different interfaces on PC screens, cell phone screens, and voice-based systems. In addition to adaptation on interface designs, video communication technology allows the same video stream to be transmitted once from the server, but received by different clients with different resolutions, that is, spatial frequencies. Thus different devices on the Internet are able to receive videos of different qualities based on the types of device and the capacity of media channels.

4.3 Location-Aware and Situated Learning

Despite of the limitations of mobile devices, m-learning has the main advantage of location flexibility. With an optional global positioning system (GPS), location context can be acquired and predicted [Ashbrook and Starner 2002]. With sensors, user positions can be precisely identified in a museum or gallery [Proctor and Burton 2003] such that location-aware information can be presented.

4.3.1 *Location-Based Services.* Depending on the technology used, the location of a mobile device can be determined either using GPS or sensors. Location-based services include advertisement, location-aware maps, and online timely tours. Usually, GPS is used outdoors in a large geographical area. User behaviors can be acquired and predicated [Ashbrook and Starner 2002] such that social presence awareness [Kekwaletswe and Ngambi 2006] can be utilized in various learning contexts, ranging from classroom, library, to residence. Based on the different communication channels available, short message service via GPRS can be used for frequently asked questions, or instant learning objects can be delivered if WiFi is available [Kekwaletswe and Ngambi 2006]. Sensors and Wifi can be integrated with pocket PC devices [Proctor and Burton 2003], so that location-aware information of, for example, museum artworks can be downloaded instantly to provide audio or visual information. This type of services is different from the ordinary audio-guided messages. Location-aware service allows users to visit at their own pace. In addition, interactive questions and answers can be incorporated on location-aware mobile devices for educational purposes.

4.3.2 *Situated Learning via Mobile Learning.* Situated learning means that learning is applied to a particular context and social situated. Since mobile devices are location-aware, it is convenient to implement situated learning via mobile learning devices. In addition to accessing location-aware information (such as in a museum tour), instructors and students can be at different locations, where a particular scenario is created within a particular social environment. For instance, the students may be asked to talk to a seafood retailer for information about a particular crab. Interactive questions on PDAs can be answered immediately. In addition, a mission can be accomplished by a group of students located at different places in a city. Real-time audiovisual communication and scenario are created under a hyperspace, where real-world social behavior and virtual world mission-based learning are integrated. Moreover, situated learning and instance suggestion enable a so-called cognitive apprenticeship, where instructors work alongside the students. This type of support is a form of scaffolding in which students need not fully understand the problem before they learn. A context-aware middleware has been proposed in Malek et al. [2006], in which contextual elements are acquired via mobile devices by the users. The proposed middleware architecture aims to support tasks such as acquiring, interpreting, modeling, storing, reasoning, updating, and adapting context.

4.3.3 *RFID for e-Learning Management.* An interesting technique which may not be used directly in learning but can assist the management of a distance learning environment is called *radio frequency identification* (RFID). Small RFID tags can be embedded in books, student ID cards, or devices. With an RFID reader, a system can identify who are participating, what types of devices are used, and possibly what activities are involved.

4.4 Multimodal Interactions, Augmented Paper, and Wearable Computers

Human interactions are multimodal by nature. However, a typical user interface is limited to single input (e.g., keyboard) and single output (e.g., screen). Technologies for multimodal interaction were presented in Kernchen et al. [2005] and in Serrano [2006]. Advanced technologies such as augmented paper [Shih et al. 2007] and wearable computers [Thompson et al. 1997] provide another possible future direction of e-learning.

4.4.1 *Multimodal Interaction.* Multimodal interaction is taken as an important research issue in computer-human interaction (CHI). Interactions can be achieved using gesture, speech, pointing devices, and even brain waves. However, advanced interactions usually need sophisticated devices, which are typically not mobile. Thus mechanisms of possible multimodal interactions on fixed and mobile devices [Kernchen et al. 2005] and cellular phones [Serrano et al. 2006] have been proposed. The framework proposed in Kernchen et al. [2005] allows dynamic discovery, binding, and usage of different interface devices (e.g., screen, speaker, camera) while a user is carrying a roaming device, which is equipped with a multimodal user interface. A component-based approach for the development of multimodal interactive systems on mobile phones

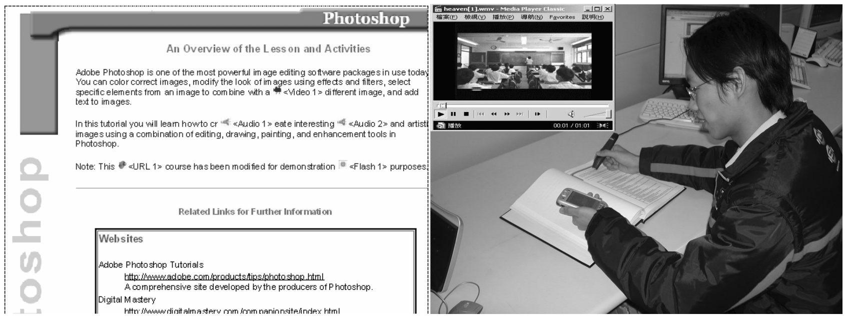

Fig. 2. Augmented Paper and Hyper Pen.

was discussed in Serrano et al. [2006]. Multimodality is implemented via speech recognition, keypad, and dedicated keys. Evaluation of user scenario was also discussed. Smart Classroom [Shi et al. 2002] is a multimodal interactive system, which uses computer vision, voice recognition, and communication technologies for tele-education. The system includes a physical classroom setup and a remote communication system. The classroom contains a touch screen SmartBoard for the main media presentation and an auxiliary screen to display remote students and interactions, which is controlled by the remote communication system via a sophisticated software architecture. In addition to ordinary audiovisual interaction, the Smart Classroom system further enables a pen-based user interface, a laser pointer-based interaction tool, and an automatic speech-recognizable assistant agent.

4.4.2 *Augmented Paper and Advanced Devices for Learning.* Augmented paper enhances ordinary hardcopy papers by adding hyper links to audio, video, and even Web sites. The technology can be used in the development of e-learning systems. The Hard SCORM [Shih et al. 2007] is a project developed at Tamkang University, Taiwan. The project provides a pervasive e-learning system to allow SCORM 2004-compliant course materials to be accessed by PCs, PDAs, cell phones, digital TVs, and augmenter papers. As illustrated in Figure 2, the left diagram shows a learning object produced by the authoring tool of the Hard SCROM project. The right diagram shows a student using a Hyper Pen (an OCR-based pen device to recognize customized tags on paper) to access augmented paper. The hyper links on the paper can trigger a video presentation or a Web site (on the top of the right diagram). Navigation behavior is controlled by hints from audio messages.

In addition to augmented paper, there are other advanced devices useful for e-learning. As shown in Figure 3, the uTable is a new approach for implementing a pen-based interaction table. An off-the-shelf projector with large viewing angle, hiding under the table, provides the rear-projection display content. A specially designed pen with a laser emitter at the nib serves as the interaction tool. A laser beam is emitted when the nib touches the table, and the under-the-table camera identifies the red dot to facilitate the interaction. The prototype of uTable is a box with a 50-in surface. The rim is small enough (less than 8 mm) for a potential implementation of multi-LiTable array.

Fig. 3. uTable (*courtesy of Yuanchun Shi, Tsinghua University, China*).

4.4.3 *Wearable Computers.* A wearable computer system [Thompson et al. 1997] typically contains a small computer, a helmet like device with a see-through display, a microphone, and an earphone. The devices can be used in training and support mobile factory personnel. With wireless communication, a user is able to access local and remote resources while he/she is moving through a facility. It is possible to extend wearable computers in a collaborative environment such that team work in educational training can be realized.

5. FUTURE DIRECTIONS

Based on the previous studies, we enumerate and elaborate below a number of emerging issues on Internet and related technologies for distance education, much of which serves the purpose of highlighting the directions for future research.

—*Ubiquitous learning*. With wireless communication, ubiquitous learning (u-learning) brings the outdoors to the indoors. For instance, situated learning can be realized in a classroom if students can have conversations with different types of people (e.g., fishmen, bartenders, or salesmen) from the street. U-learning also brings the indoors to the outdoors. For instance, students carry PDAs with positioning devices are able to carry out missions assigned by the instructor. The PDAs can be used to access positions of teammates and to retrieve information from a large encyclopedia database. In general, u-learning covers a broader range of issues compared to m-learning. The use of sensors can help identify user locations, user identities, tool locations, tool identities, and, possibly, behavior identities. This provides the context for learning. Both u-learning and m-learning need to have adaptive contents designed for different situations.

—*Web 2.0*. With the emergence of Web 2.0 technologies [O'Reilly 2005], a more active way of e-learning can be supported. Although there is still a lack of consensus on the definition of Web 2.0, it usually refers to technologies for setting up the Web or combining resources as a platform for people to communicate, share, and develop content in an easy, active, and collaborative way. In particular, there are four popular components of Web 2.0, namely, Blog, Wiki, RSS, and AJAX. Blog supports individual users to build a Web site in a minute using some predefined Web components. Such a Web site usually contains entries of information in journal style. Wiki supports collaborative

Web site construction. It offers a simple Web-based editing interface for users to collaboratively edit the content of a Web site. A good feature of this kind of Web site is that they are usually highly interconnected with hyperlinks, which provide references for users to trace out relevant information on a topic. The Really Simple Syndication (RSS), on the other hand, deals with content delivery. It allows users with special browsers to automatically check out the changes of some frequently updated Web sites. In addition, Asynchronous JavaScript and XML (AJAX) [Eichorn 2006] has been made available since 2005 to address the limited interaction facilities and the page reload problem. It provides more interaction control, such as context-sensitive menus and window interface, for users to interact with the application. In addition, besides relaxing the need of preinstallation or maintenance of add-on plugins, AJAX applications also require only a minimal amount of data transmission for application download, as they are driven by light-weight JavaScript and XML codes. Finally, during run-time, AJAX can collect information from Web servers to update only a required part of the application content without reloading the Web pages.

—*Security challenges on the Internet*. Security control in existing e-learning systems is not well addressed. Information provided by Internet-based e-learning systems can be accessed by unauthorized people if appropriate measures are not taken. This information may include confidential data such as personal information or academic results, in addition to the valuable e-learning contents. To address this problem, Secure Socket Layer (SSL) offers a good choice. It provides end-point authentication and communication privacy over the Internet using cryptography. In particular, once a user has logged into an e-learning system, the data protection process would be carried out transparently to the user. Security becomes a tougher challenge in a distributed environment, which is increasingly complicated by the amount and types of nodes on a distributed network. Unifying the various security models used across the distributed system is sometimes called *single sign-on*, which can reduce the complexity for users navigating through and sharing data. In contrast to single sign-on, which is also referred to as *door-to-door* security (i.e., security that is enforced upon entering a system), the Security Assertion Markup Language (SAML) from OASIS allows security information to be captured as an XML instance that may move with the data, which is often referred to as *wall-to-wall* security, or security that works wherever the data is being used.

—*Structuring shared content and repositories*. If learning objects are to be shared among a distributed community such as universities, it is useful to use similar, if not identical, data models and formats to allow the data to move freely between users without a lot of modification. A good example is the DocBook standard from OASIS (`www.oasis-open.org/docbook/`). Expressed in XML, the data is both robust and portable and can move between distributed federated systems more easily than proprietary formats. This eliminates the need to store all data in centralized monolithic systems. However, resolution of naming conflicts and rediscovery of these learning objects in a global repository are challenging issues. The Content Object Repository Discovery and Registration/Resolution Architecture (CORDRA) is "an open, standards-based model for how to design and implement software systems for the purposes of discovery, sharing and reuse of learning content through the establishment of interoperable federations of learning content repositories" (quoted from `http://cordra.net/`). Reusability of learning objects is an interesting research issue.

—*Applying structure while creating content*. Since unstructured data can be difficult to manage and decipher, there is a belief that only rigorous XML structured editors, for example, XMetaL or Epic, should be used to create valuable content. Another approach to structured text editing is to incorporate forms and text entry fields into Web content, so as to collect and verify content across a distributed network. This approach also shifts the functionality to the server software and eliminates the effort to maintain a software client on many distributed client machines. It is very likely that we will continue to see many more tools and approaches for creating structured content that is more easily used within a distributed content management architecture.

—*Distance learning on grid*. Grid computing is considered as a hot research area in recent years. Grid connects computers, storages, sensors, and services via fixed-line or wireless Internet (and other networks). The goals of Grid computing include resource sharing and coordinated problem solving and enabling dynamic virtual organizations/world. The advantages of Grid include data and performance reliability (avoiding single point of failure), performance (avoiding network and computation bottleneck), and resilience (guaranteeing the existence of data and its backup). In line with the emergence of new Grid concepts, distance learning can be considered as one important application of Grid, and as a service to this emerging virtual world.

—*P2P and online learning community*. One of the major problems in the research and development of distance learning systems is how to provide organized effective support for communication, interaction, and collaboration in networked virtual learning environments [Jin 2002]. Mechanisms for collaborative virtual environments-based every-citizen learning communities need to be devised to support peer-to-peer (including human-human) communication, in addition to human-computer communication, where human users and software agents coexist and interact.

In addition to the above issues, a few important issues not discussed in this article are briefly mentioned below. These technologies are promising in enabling the development of more intelligent and/or attractive e-learning systems, though not necessarily over the Internet or any networks.

—*Intelligent tutoring and adaptive testing*. Most existing distance learning systems copied traditional education systems by providing the standard set of course materials to the distance learning students. However, the effect has not been satisfactory due to the diversity in student background, objectives, and time availability. Although there is not yet any widespread practical application of the research results, technologies involving artificial intelligent, educational theory, and statistics are good candidates in implementing automatic systems to guide students through different learning paths within the same learning content. For example, remedial courses and personalized materials can be generated [Leung and Li 2006] for each student if necessary. In addition, adaptive testing materials can be generated depending on learning performance. Typical example technologies that are applicable to generating tutorials or tests include deductive reasoning, neural networks, ontology, student-problem charts, and item response theory.

—*Further development in distance learning standards*. Standardization is important to promoting distance learning. Different distance learning systems and materials need a common vocabulary and representation such that LMSs are interoperable and learning objects can be exchanged. SCORM 2004 was designed for these purposes. In addition, Question & Test Interoperability (Q&TI) was developed by the IMS Global Learning Consortium (`http://www.imsglobal.org/question/index.html`) to describe a data model for the representation of questions, test data, and their corresponding result reports. As a bridge between SCORM and Q&TI, the Common Cartridge interoperability standard (`http://www.imsglobal.org/commoncartridge.html`) was released by IMS in spring 2007. Common Cartridge includes Content Packaging and Metadata from SCORM, Q&TI, and the IMS Tools Interoperability Protocol. In addition, the Learning Design specification (also by IMS) supports the use of a wide range of pedagogies in content development of online learning.

—*Game-based learning*. A good game-based learning (GBL) system creates an internal world under a specific context, with a pedagogical consideration for a particular group of students. GBL systems can encourage students (especially young students) to solve problems together, that is, it promotes problem-based collaborative learning. The development of good strategies to encourage students to participate and to assess students' learning performance is the key issue. GBL examples can be found online at `http://icampus.mit.edu/projects/GamesToTeach.shtml` and `http://www.futurelab.org.uk`.

6. CONCLUSION

With the advent of Internet and WWW technologies, distance learning (e-learning, or Web-based learning) has enabled a new era of education. In this survey article, rather than attempting to cover exhaustively all the related issues and aspects such as educational, sociological, and psychological perspectives, we have focused on the technological aspects supporting e-learning over the Internet. A number of technological issues have been discussed, including distributed learning, collaborative learning, distributed content management, mobile and situated learning, and multimodal interaction and augmented devices for e-learning.

While the technologies and systems that we have surveyed can be considered state-of-the-art, it is anticipated that many new ones will emerge in time as the technologies evolve. In Section 5 we have pointed out some important emerging issues and technologies. While most of these are Internet and Web dependent, there are also some issues/techniques which are orthogonal to the Internet and Web but pertinent to developing more "intelligent" and attractive distance learning systems. In our view, all of these emerging issues/techniques help shed some light on the development of future e-learning technologies and systems, and we are leaving readers to comment and decide which ones are the most important ones.

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Received June 2006; revised February 2007; accepted April 2007