Chapter I

A Survey of Distance Education Challenges and Technologies

Timothy K. Shih[1], Tamkang University, Taiwan

Jason C. Hung,
Northern Taiwan Institute of Science and Technology, Taiwan

Jianhua Ma, Hosei University, Japan

Qun Jin, University of Aizu, Japan

Abstract

Distance education, e-learning, and virtual university are similar terms for a trend of modern education. It is an integration of information technologies, computer hardware systems, and communication tools to support educational professionals in remote teaching. This chapter presents an overview of distance education from the perspective of policy, people, and technology. A number of questions frequently asked in distance learning panel discussions are presented, with the suggested answers from the authors. The survey presented in this chapter includes communication, intelligent, and educational technologies of distance education. Readers of this

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

chapter are academic researchers and engineers who are interested in new research issues of distance education, as well as educators and general participants who are seeking for new solutions.

History, Trend, and Elements of Distance Education

With the growing popularity of multimedia and Internet technologies, distance education programs have become popular and thus, importance of the related technologies are realized by educational professionals and information technology researchers. However, distance education is not totally new. The use of computer and information technologies in education has a long history. Ever since Thomas Edison predicted that motion pictures would replace textbooks for learning in 1922, the use of video was popular in training. Especially, in the World War II, the U.S. Army used video tapes to train employees. Shortly after WWII, video technology and television were used for training and demonstration. In this period, instruction was broadcasted in a single direction. There is no **interaction** between audiences and the instructor. However, the advantage is, the number of participants to the program can be larger than the traditional classroom education, especially when satellite communication was integrated with video broadcasting. **Efficiency** of video training was the first reason for education to use modern technology. The use of computers follows video technology as the second phase of modern education. Computer-based training (CBT) and computer-assisted instruction (CAI) use information technologies and educational theory to develop interactive software. The solution allows students to interact with their instructor (i.e., a computer) in a limited way. Mostly, CBT was limited to drill and practice. However, CBT and CAI were the first attempt to use computers for teaching, which enrich a new instruction delivery style — the **automation**. In spite of this advantage, CBT and CAI software had a problem in the ’70s and the ’80s — lack of **stability**. In that stage, computer hardware, operating systems, and system programs evolved dramatically and quickly. A CBT program is hardly used for several years due to the change of its supporting environments. Stability was a main consideration for computer-based modern education. Since the early ’90s, the third period of modern education was stimulated by the invention of multimedia and Internet technologies. Multimedia presentations as CD ROM titles for education, Web-based distance-learning programs, and even online video conferencing based on ISDN, ADSL, and broadband communication channels became popular. With the new millennium and beyond, computer and communication technologies will be integrated with

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Contents (i.e., the integration of 3Cs). Distance education is certainly one of the potential activities rely on this integration. However, new technologies can be further investigated. For instance, real-time protocols, broadband and wireless communication technologies, multimedia streaming algorithms, intelligent tutoring, behavior analysis of students, copyright protection and authentication mechanisms, visual computing, and new learning models, as well as other issues of distance education still need researchers, engineers, and participants to work together, to make the third revolution stage of modern education successful. The *International Journal of Distance Education Technologies* (JDET) is a primary forum for disseminating practical solutions to the automation of open and distance learning. We hope the journal will look at some of these problems from the technology perspective, and contribute solutions to the third stage of modern education.

We begin with the presentation on categories of distance learning, which include distance learning programs in conventional universities and virtual universities, as well as e-learning portals. Elements of distance learning including policy, people, and technology needs toward the success of distance education are also presented, followed by some highlights of challenge issues. In Section II, we collect 18 questions which were frequently asked in several panel discussions in distance education related international conferences, with some suggested answers from the authors or panelists. Then, we present a survey of distance education technologies, which are divided into three categories according to the theme of JDET.

Categories of Distance-Learning Programs

Distance learning is widely available in **conventional universities**, as regular and continuous education programs. Types of courses offered include general education, management and business administration, engineering, language education, and others. Most courses taught in classroom are possible for distance learning, except a few cases which require lab experiments (e.g., chemistry). Degrees or certificates offered including bachelor, master, and even doctorate levels. Supporting systems or tools used in this type of distance-learning programs can be divided into two types:

- **Traditional tools:** Videotape (S-VHS), cable/public television, satellite video conferencing, tele-conferencing, textbook

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

- **Computer-assisted and network tools:** CD-ROM titles, Web browser, Whiteboard, Chat room, Real player, Quicktime, Windows Media Player, broadband video conferencing, WebCT, LearningSpace, Blackboard

Note that, textbooks are still widely used, even it is possible to publish their electronic versions on the Internet. Proprietary communication tools are developed to support online discussion, either in a limited bandwidth environment (e.g., chat room) or in a broadband communication facility (e.g., video conferencing). A few integrated systems such as WebCT are commercially available. These systems provide functions ranging from administration, courseware creation and management, communication, assessment, and some even provide course contents. It is interesting to see how a traditional university evaluates performance of distance-learning students. Some rely on fax, e-mail, or even surface mail to collect reports and homework. In some cases, secure online quizzes and chat room participations are counted as evaluation criteria. However, personally-proctored examinations are commonly found in this type of distance education (i.e., distance-learning programs in conventional universities).

With a similar functionality but different audience target, **virtual universities** are also widely available for continuous education programs. University of Phoenix and Athabasca University are one of the largest virtual universities in U.S. and Canada, respectively. Virtual universities allow students to take the flexibility of time and location. Students who have their industrial career will be able to complete their higher level education without sacrificing their business. In some cases, a distance-learning course in virtual university can be completed in five to six weeks. And, it is possible to shorten the number of years to gain a diploma (as compared to four years of study for an undergraduate degree). Software systems and student evaluation strategies in virtual universities are similar to traditional universities. Even some virtual universities aim to provide a 100% remote learning based on Internet, to get a degree, some residential requirements are necessary, especially for a higher level degree.

E-learning portal is another style of distance learning. It is similar to virtual university, but with a different emphasis on the kind of audiences and courses. E-learning portals aim to provide a solution to small or middle size companies, which like to have their employee training or customer service on the Internet. Practical courses instead of theory studies are welcome in e-learning portals. In some cases, customized course contents can be built to satisfy the needs of individual companies. Usually, e-commerce facility is incorporated with an e-learning portal to provide additional services (e.g., book selling).

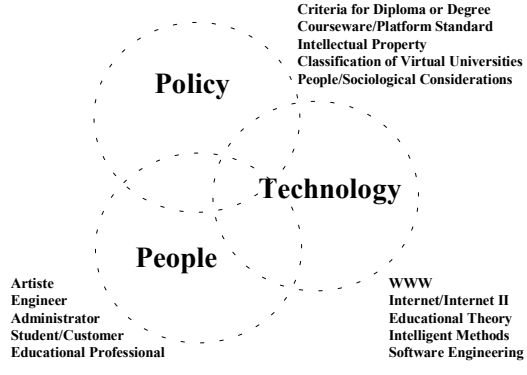
Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Elements of Distance Learning

In spite of the slight difference among the three categories of distance-learning programs, the fundamental elements of distance education are similar. These elements (shown in Figure 1) are the essential components which affect the development of distance-learning programs.

From the policy perspective, the evaluation criteria of distance-learning programs affect the instructional quality and performance of students, which has an influence to how the industry trusts distance education. On the other hand, the approval of diploma is an important factor of attraction to students who wish to join a virtual university. If the government or a university establishes a high requirement, less number of students will enroll. Thus, standard evaluation criteria should be established. The overall evaluation may include teaching evaluation to instructors and the review of course contents, as well as the performance evaluation of students. The standardization of courseware format and platform (e.g., SCORM) (Dodds, 2002) will ease the exchange of course materials. It is time consuming to create high quality distance-learning courseware. Courseware exchange has become one of the possible solutions to reduce the load of a courseware designer. But, each courseware has a copyright. Who should own the intellectual property (IP) is an issue of policy. In some cases, the IP belongs to the virtual university. But, this is definitely different from the IP of a textbook. The IP issue is different depending on different institutes and countries. Moreover, different traditional universities have different focuses and strengths. The focuses of virtual universities are different as well. Other policy issues are related to sociological behavior of students, such as how an individual trusts a friend in the virtual world. We will discuss some of these issues in Section II.

Figure 1. Elements of distance education



Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

From the perspective of who should work for a distance-learning program, there are several types of experts. To create a high quality distance-learning courseware, educational professionals, engineers, and art designers should work together. Distance-learning platforms should be maintained by an engineer or an instructor. The administrator should review and manage distance-learning courses as well as the curriculum schedule. Sometimes, it is hard to divide the boundary. An instructor can maintain the distance-learning platform by himself or herself, as well as handling the schedule. The organization of human resource in a distance-learning program also affects the success of the program.

This journal focuses on the technology perspective of distance education. We will discuss some technical challenges of distance education in the next section. We should point out that, technology should be used by people. That is, an investigation of automatic mechanism to build a better distance-learning system must consider the need of an end user. But, the development of a good software system also affects the decision of a policy, which affects the end user again. Therefore, policy, technology, and people are strongly related in the life-cycle of distance education.

Challenges and Issues of Distance-Learning Technologies

Several advantages make distance learning become popular and important. Convenience and flexibility are some of the main reasons. With the growing number of Internet users, Web-based distance-learning programs enable lifelong education anytime at any location. Scalability of participants is another advantage. With a proper support of network infrastructures and computer systems, a large number of students can join distance-learning programs together. Moreover, timely update of course contents and online discussion give students the benefit of acquiring firsthand information, which is precisely presented by using computer software. All of these advantages accelerate the development of distance education.

However, challenges and issues must be investigated from different perspectives, including sociological, policy, and technical issues. Even sociological and policy issues are less related to technology, in the next section, we present some questions and answers. From the technique perspective, we highlight some research issues as the following:

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

- **Course and user management:** An administration system should provide efficient management tools for administrators, instructors, and students. If online course materials are provided on the Web, a friendly interface and supporting tools are required. For instance, an online student service center helps students to find references, suitable courses, and answers to general questions.
- **Efficient courseware development tools:** It is time consuming for a course designer to develop high quality courseware. A friendly courseware tool helps instructors to design or customizes course materials from reusable course components. In addition, a question database and exam composition tool may help an instructor to design an examination easily.
- **Instance hints and intelligent tutoring:** While a student is navigating an online course, an intelligent agent is able to analyze his or her behavior, and provides real-time and useful suggestions. In some cases, an agent program will guide the student through different learning topology depending on the behavior of the student.
- **FAQ summarization and automatic reply:** It is also time consuming for an instructor to answer questions from students' e-mails. An auto-reply system should be able to use information retrieval techniques to summarize frequently asked questions, and reply to new questions with proper answers.
- **Unbiased examination and student assessment:** It is difficult to ensure the behavior of students while an online examination is under processing but without a human monitor. A surveillance tool can randomly take a snapshot of on-the-spot screen while the examination proceeds. Also, in some distance-learning programs, chat room participation will be counted as an evaluation criterion. An intelligent tool should be able to check if a student has devoted himself or herself in a discussion.
- **Individualized quizzes:** Some distance-learning systems are able to generate different test questions for each individual student on the basis of a similar difficulty level. This type of system will ensure an unbiased examination as well.
- **Privacy of student:** Personal information of a student should be hid from another student, the administrator, and even the instructors. Unless it is necessary to assess student performance from his or her personal data (such as answers to an assignment or exam), privacy should be enforced.
- **Broadband and real-time communication:** For online discussion using video conferencing, quality-of-services should be guaranteed with the support of broadband and real-time communication facilities.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

- **Universal and mobile accessibility:** Students and instructors should be able to access the distance-learning Web site from any location with different devices, such as PDAs or cellular phones. Wireless communication techniques may be incorporated in a distance-learning system.
- **Scalability:** As the number of students enrolled becomes larger, distributed Web services should be able to re-direct requests of students to different Web servers to share bandwidth and hardware load.
- **Remote lab and simulation:** Domain specific remote labs connected to Internet need to be developed to support online experiments. If remote labs are not available, online simulation tools (i.e., virtual lab) should be provided.
- **Multilingual support:** Since distance education can be accessed from anywhere in the world, distance education platform and systems should consider multilingual support for the international society.
- **Evaluation standard of distance education:** Standard criteria and questionnaires should be setup to allow teaching evaluation, evaluation of courseware, student performance evaluation, and the evaluation of a distance-learning program.

Some of the previous issues had been solved, as we will discuss in Section III. Before the survey of these solutions, we present some questions and answers frequently occurred in distance-learning related panel discussions.

Problems and Discussions

According to software engineering principles, verification and validation are two key methods to ensure the quality of a software system. Verification means to check whether a software system meet the requirement of a specification. Most importantly, validation checks whether a software system meets the needs of users. A software system not used by any user will lose its value. Thus, it is important to know "what the users need" before any distance-learning system is developed. In addition, methodological and sociological issues of distance education may influence what the users need. It is important to realize these fundamental issues, before we consider any software specification of a distance-learning system.

We collect questions frequently asked in panel discussions of international conferences related to multimedia computing, distributed systems, communica-

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

tion, and database systems. These panel discussions focus on distance learning or virtual society. Some of the panelists are authors of this chapter. We also circulate these questionnaires among experts, either as system developers, or as end users of distance-learning systems. We summarize suggestions and answers[2] from the international society, which is presented next.

1. Who is interested in distance-learning courses? What motivates the students to take distance-learning courses?
   - Adult working students are interested (Shih, Dow, Chee, Jin, Asirvatham, Leong, Arndt)
   - Intercampus courses for university students or geographically isolated students (Dow, Li, Arndt)
   - Professional training for career (Li, Asirvatham, Leong)
   - To get the first degree (Chee)
   - Flexibility in time and location (Shih, Dow, Li, Jin, Leong, Arndt)
   - Can save money (Arndt)
2. What is the role of student service center (i.e., TAs, Curriculum Advisors, and Administrators)? Is the center a success reason to attract students?
   - Education is a service (i.e., the center is a requirement) (Shih, Jin, Asirvatham)
   - Student Service Center is a successful reason (Shih)
   - TA's in Student Service Center help students (Li, Lin, Leong, Arndt)
   - Provide vital human element in learning is necessary (Chee)
   - Korea adult students seem to be independent. Seventy percents of students choose DL program without the help from a tutor (Jung, quoted by Shih)
3. What is the minimal requirement for admission? Will GRE, GMAT, and TOEFL be taken into the considerations?
   - TOEFL Should be considered for courses in English for international students (Shih, Li, Lin, Leong)
   - Basic language and literacy skills is necessary (Chee, Arndt)
   - Working experiences should be considered (Asirvatham)
   - May not be necessary (wide-entrance and narrow-exit, allowing better financial support to the organization) (Jin, Asirvatham, Leong, Arndt)

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

4. What types of courses are suitable for distance learning?
   - Lab facility is a consideration (Shih, Lin, Jin, Chee, Asirvatham, Arndt)
   - Courses with less update of contents (e.g., English grammar, math, etc.) (Shih)
   - Popular courses (for efficiency) (Dow)
   - Courses which can benefit from hypermedia and multimedia technologies (Li)
   - Knowledge-oriented courses (i.e., literature, language) (Chee, Leong)
   - Courses of high degree interaction may be restricted due to facility (Leong)
5. What types of instructors are suitable for distance learning?
   - Instructors who like to have online interactions and to try distance learning tools (Li, Chee, Jin, Leong, Asirvatham)
   - Instructors who wants to reuse course materials (Li, Asirvatham)
   - Instructors who appreciate the flexibility of distance learning (Arndt)
6. What levels of distance programs are realistic (e.g., colleague education vs. elementary education)?
   - College level is suitable (Shih, Li, Lin, Chee, Jin, Asirvatham, Leong, Arndt)
   - K-12 (Shih, Jin, Arndt)
   - Adults and job training (Jin)
7. Is the classification of virtual universities necessary (i.e., university ranking for different purposes)?
   - Virtual universities may have different missions and focuses (Shih, Li, Chee, Jin, Asirvatham, Leong, Arndt)
8. Can students learn from each other? Is group discussion less efficient in distance education?
   - Student can learn from each other if a better communication facility is provided (Shih, Chee, Jin, Asirvatham, Leong)
   - Discussion using chat room tools will be efficient as well. And, discussion should be a requirement (Dow, Li, Asirvatham, Leong, Arndt)
   - Communication techniques should be considered (i.e., human to human and human to computer interactions) (Jin)
   - Conflicts with different view points in an off-line discussion may be higher than those proceeded online or face-to-face (Leong)

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

9. Does student need grade in a virtual university? Does virtual university need to operate the same as a traditional university (i.e., quiz and exam)?
    - Need grade to gain a trust from the society (Shih, Lin, Chee, Asirvatham, Leong)
    - Need grade to enforce and encourage students (Dow, Li, Asirvatham)
    - Grade can be used as a feedback from students (Dow)
    - May not need grade (let the society to make the justification) (Shih, Chee, Jin, Leong)
    - Virtual university should support both graded and non-graded (i.e., audit) options (Arndt)
10. Do traditional and virtual university students behave differently in different Culture? For instance, oriental students are shy to ask questions in class. But, they will ask questions using e-mail.
    - Sending e-mail for question is common everywhere (Shih, Jin, Arndt)
    - Distance education may benefit oriental students in off-line discussions (Li, Dow, Asirvatham, Leong)
11. Will the sociological behavior of students be different in virtual university? For instance, will a colleague student have a difficulty to find girl (or boy) friend in a virtual university?
    - Students can still make some virtual friends (Shih, Dow, Li, Lin, Jin)
    - Sociological behavior could be different (Chee, Asirvatham)
    - Easy to find a friend, but hard to gain trust (Jin, Leong)
    - Face-to-face interaction in the beginning will facilitate further discussion (Arndt)
12. Does the industrial society trust the quality of distance education?
    - The reputation of a virtual university may depend on its founding university (a conventional university) (Shih, Jin, Asirvatham, Leong)
    - Good quality of service and contents will gain trust (Dow, Li, Lin, Jin)
13. Who should design the course material (i.e., the instructor vs. the book author)?
    - A generic course content can be designed by the book author, while allowing each instructor to edit the content as needed (Shih, Dow, Jin, Leong)
    - The instructor should design the content. Copyright of the textbook should be considered (Li, Lin, Chee, Asirvatham, Arndt)

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

14. What about the intellectual property and legal issues of the course material? Should the course material belong to the instructor, or to the university (and for how long)?
    - Belong to the instructor, but commercial profit should be shared with the university (Dow, Asirvatham)
    - Belong to the university (Li, Lin)
    - To be decided by different government and situation (Chee, Jin, Arndt)
15. Will there be a threat from "the big professor" and "the super university"?
    - Yes (Shih, Dow, Li, Chee, Jin, Asirvatham, Leong)
    - Yes, but still need a large number of instructors for online tutoring to fit individual needs (Leong, Arndt)
16. How does distance learning impact high-level education in the near future?
    - Distance learning will affect high-level education, for instance, in continued education and profession education (Dow, Li, Lin, Jin, Asirvatham)
    - Combining traditional lecture and distance learning (Asirvatham, Leong)
    - Will bring a higher degree of competition among universities (Arndt)
17. How does distance learning impact the industry?
    - Distance learning can be used in training and customer service (Dow, Li, Chee, Jin, Asirvatham, Leong, Arndt)
    - The industry can provide feedback to university (Li)
18. Yet another "dotcom" issue (i.e., not so optimistic)?
    - No (Shih, Dow, Li, Lin, Jin, Asirvatham, Leong, Arndt)
    - Distance learning will be used as a supplement to traditional university. Thus, it will last. (Shih, Jin)

The previous questions and answers indicate some problems, mostly related to sociological and policy issues. However, from the perspective of technology, there are a few issues which can result in better situations if automatic mechanisms are developed. It is the hope that, educational professionals, researchers, software developers, and even students can work together to seek out new and useful automatic tools, to make distance education easier and successful. For instance, the role of student service centers is considered important in most answers. But, teaching assistants should be incorporated. A good tool will help TAs to locate questions and answers, which can be annotated to satisfy a particular situation while help is requested. If the list of questions and answers can be properly stored in a database, with advanced information

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

retrieval technology, the system can possibly reply to frequently asked questions automatically. In addition, if a remote lab is hard to build, a virtual lab (i.e., simulation) should be developed ss that chemistry and other experiments can be implemented. Also, advanced communication tools will certainly help group discussion. Regarding the development of courseware, a word processor for typesetting textbooks should be integrated with an authoring tool, such that Web-based courseware can be automatically or semi-automatically created. Image and video watermark techniques will help copyright protection of online courseware. And, secure payment mechanisms developed for E-commerce can be used in distance education. These examples encourage us to develop good distance-learning systems, which should fit the need of instructors, administrators, as well as students.

But, how should a virtual university operate? According to a traditional university, instruction delivery is the most important activity. In order to realize the main activity smoothly, administration is required. A traditional university usually has some student activities and organizations, which need to be properly supported by the university's infrastructure. These are some of the important operation factors of a traditional university. A virtual university also focuses on instruction delivery. But, due to the geographical difference, communication tools should be efficient enough to realize instruction. Communication efficiency points out an important factor: the awareness impact. Awareness indicates how strong an individual feels the existence of another person in the communication. For instance, when two persons have an eye contact, the awareness is high. When people are located in different cities and are talking on the phone, the awareness is lower. Sending postal mail has the lowest awareness among these three communication channels. Since a virtual university is distributed geographically, how to use computer networks to guarantee a reasonable awareness is one of the considerations. Awareness certainly affects instruction quality. On the other hand, a virtual university needs administration, which includes activities such as registration, course selection, accounting, and so on. Furthermore, a university needs to ensure that students are learning in order to meet some evaluation standard. This step is to guarantee the quality of education. A virtual university is different to a traditional university in that assessment is difficult. Conclusively, we believe that, a well-considered virtual university supporting system needs to meet the following three criteria:

- **The administration criterion:** A virtual university environment needs to have administration facilities to keep admission records, transcripts, accounting records, and so on. These administration tools should be available to administrators, instructors, and students (e.g., checking transcript information).

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

- **The awareness criterion:** Distance learning is different from traditional education. Since instructors and students are separated spatially, they are sometimes hard to "feel" the existence of each other. A virtual university supporting environment needs to provide reasonable communication tools such that awareness is satisfied.
- **The assessment criterion:** Assessment is the most important and difficult part of distance education. Tools to support the evaluation of student learning should be sophisticated enough to avoid unbiased assessment.

In the next section, we summarize automatic mechanisms which can be applied in the development of distance education systems. We divide the mechanisms according to the themes of this journal, which are communication, intelligent, and educational technologies for distance education.

Distance Education Technologies

As we have mentioned before, the purpose of JDET is to publish research contributions for the development of automatic tools to be used in distance learning. In the past few decades, computer technologies such as deductive reasoning, neural networks, and statistical analysis mechanisms can be used to develop intelligent tutoring or individualized learning tools. Information retrieval techniques can help the implementation of a precise search engine for seeking after class references. Network technologies ensure real-time interaction in a synchronized distance-learning session, and improve the quality of presentation services. Mobile and wireless communication systems allow distance learning on PDAs and even on cellular phones. On the other hand, educational technologies had been used in different levels of schools to improve the efficiency of instruction delivery and student assessment. Learning models need to be incorporated with new authoring tools to improve the quality of instructions. We present a few success examples in this section, according to communication, intelligent, and educational technologies.

Communication Technologies

Communication and network technologies can be divided into several levels. According to the ISO standard, network architectures can be divided into seven layers. However, other new technologies, such as ATM, use a different

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

architecture. From the perspective of communication tools that are used in distance education, we focus on the network application level, which includes integrated systems rely on other lower level technology, such as those for real-time media streaming. In addition, the communication technologies we discuss here are not from the perspective of human interaction, either are they related to human-computer interactions.

Related to broadband communication technologies, there are a few articles. In Fernandez et al. (2001), distance-learning applications were tested over an IPv6/ATM-based broadband facility. The conclusion states that, users must understand the consequences of QoS differentiation, and the cost they paid. Another ATM-based conference system (Bai, He, Liao, & Lin, 2000) supports multicasting and point-to-point communication. The chapter also discusses an application for distance learning based on this technology. On the other hand, an agent-based architecture (i.e., mStar) to support the development of real-time communication is discussed (Parnes, Synnes, & Schefstrom, 2000). In the article, a bandwidth manager agent determines how bandwidth should be utilized. The strategy adapted considers the number of users, as well as the number of media used. In Maly et al. (1997), an interactive learning system supports two-way video, on-the-fly interaction, and application sharing is implemented on a high speed network. A prototype configuration, based on ATM network, for courses on-demand was developed at Stanford University (Harris & DiPaolo, 1996). Experiences including system integration, educational effectiveness, and economics are also discussed. Wang and Su (2000) also proposed a real-time communication tool to teach speaking skills. A real-time interactive Web-based teaching system for engineering students was developed in Hong Kong (Chu, 1999). Another real-time interactive virtual classroom tool is presented in Deshpande and Jenq-Neng (2001). New coding algorithm is used to enhance the quality of handwritten text video. A set of tools were also developed to record live classroom sessions. The use of operational user profile and the control of end-user QoS are suggested in Vouk, Bitzer, and Klevans (1999). The conclusion suggests a range of user-level delays, which is acceptable by most users. The chapter also recommends a number of facilities for the developers of distance education systems, to make the systems effective. A low-bandwidth streaming technology focuses on the application layer QoS is discussed in Fong and Hui (2001). A hybrid architecture using an exchange server is able to avoid the conflicting requirements, and to allow efficient point-to-point transfer. From the above discussions, we realize that real-time media streaming technology, with the control of quality of services, will be important for interactions in distance learning.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

In addition to network-based tools, middleware systems to support distance education, or to enable the integration of tools are widely found in the literature. A set of distance-learning tools (Shih, 2001a), including a shared whiteboard and a chat room tool, are integrated to a distance-learning environment, which provides a complete platform for distance education. Another distance lecture supporting system (Chen, 1999) for streaming video clips and dynamically loaded HTML course content is developed, based on a synchronization framework known as WSML (Web-based synchronized multimedia lecture). Huang (2000) also uses Windows media streaming technology to integrate a distance system, which supports both real-time communication and on-demand-based media production. A distance-learning system (Duran-de-Jesus, Villacorta-Calvo, & Izquierdo-Fuente, 2000) for real-time teaching and interactive course is proposed. Parameters for the measurement of QoT (quality of teaching) are also defined in Duran-de-Jesus et al. (2000). A distance-learning system (Lee, 1997) based on Java is implemented to facilitate communication, management, and the evaluation of distance learning. This system is designed to work on a heterogeneous environment to support PCs and workstations. Another Java-based network educational system (Foster & MacGregor,, 1999) is also developed to support tele-teaching applications. For communication, a mechanism to control who to speak in a distributed virtual environment is proposed (Keh, Shih, Deng, Liao, & Chang, 2001). The control mechanism can be used for multimodal, multichannel, and multi-user communications. A client-server distributed environment (Benetazzo, 2000) to support virtual lab, using commercially standard components, is discussed. The system is tested by a class of students learning electrical measurements in different connections and operating conditions. Another Web-based remote laboratory (Ko, Chen, Jianping, Zhuang, & Chen Tan, 2001) for the experiments on a coupled tank apparatus was developed at the National University of Singapore. Video conferencing technique is used to provide audio and video feedback. A Web-based interactive simulation tool for electronics was developed in Scotland (Masson, 1999).

In a larger scale, a number of distance projects (Castro, 2001) to improve the technology of collaboration and communication were discussed. Experiences of building a virtual community for enriching e-learning experience and humanizing learning process are discussed in Carver (1999). In addition, Multimedia Micro-University (Chang, Hassanein, & Hsieh, 1998) is a project arms to support the management and operation of distance education of a small academic institution. A virtual library tools and an intelligent system are implemented to support online tutoring. Skill requirements to build efficient virtual community are presented. The experience of using satellite-based digital video, Web technology, and Internet-based interactions is also discussed in Brackett (1998). Lecture recording and playback systems using video and PowerPoint presentation are presented (Deng & Shih, 2002a; Latchman, Salzmann, Gillet, & Kim, 2001). A suite

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

of Internet multimedia tools support both synchronized and asynchronized collaboration is presented in Peden, Burleson, and Leonardo (2000). The SimulNet (Anido et al., 2001b) distance-learning platform includes a few tools, such as authoring and communication tools. A set of synchronous distance education tools is also proposed in Pullen and Benson (1999). A system supports both synchronous and asynchronous mode of collaboration is proposed in Peden (2000). The system is used in a VLSI chip design course. A system allows video conferencing, interactive classroom, Web-based instruction, and traditional lecture is proposed in Siddiqui and Zubairi (2000). Mobile agent technologies were used in a distributed distance-learning system (Deng, 2002b), which allow students to have persistent personal data while they are accessing a centralized distance-learning server from different locations.

In addition to the communication tools used in a virtual community, Virtual Reality (VR) is a good medium, in distance learning, for making abstract concepts concrete, for example to touch or to manipulate virtual geodesic domes and to observe theirs symmetries (Sala, 2002). The difficulty of understanding scientific concepts is well-researched (Garnett & Treagust, 1999). Zoller (1990) has affirmed: *"Students' misunderstandings and misconceptions in school sciences at all levels constitute a major problem of concern to science educators, scientist-researchers, teachers, and, of course, students"* (p. 1054). Virtual reality can also help constructivist learning (Winn, 1993). Virtual reality modelling language (VRML) can help to create virtual objects in the cyberspace.

Intelligent Technologies

Artificial intelligence (AI) has been studied since many decades ago. In general, there are two directions of AI research: computational logic and neural network. The former has symbolic representation of knowledge. Using deductive reasoning and searching techniques, the former method tries to compute conclusions, which may represent new knowledge. On the other hand, there is intelligence which is hard to have a symbolic representation. The use of neural network relies on network of nodes, which encapsulate the second type of intelligence. Training is applied to the network, with modification to thresholds among these nodes. The resulting network is able to recognize the subsequent queries with proper suggestions. Whether the intelligent technology has a symbolic representation, it is possible to build autonomic systems, which help or guide students in an online learning session. Research issues of these systems include intelligent tutoring (Shih, 1997), individualized learning (Ha, Bae, Sung-Min, & Park, 2000), behavior analysis, auto-reply to frequently asked questions, and so on. We give some examples of intelligent technologies in distance education.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

IMMPS (Shih, 1997) is an integration of a multimedia presentation design system and a back end intelligent system. The author is able to design rule-based knowledge for each presentation window, with different layout and multimedia references. An instructor can use the system to design individualized course materials. A learning control strategy based on neural network is presented in Si and Yu-Tsung (2001). The mechanism learns from mistake of user through the reinforcement signal, and tries to improve the user's future performance. Positive reinforcement is also learned by the system. A path analysis technique (Ha et al., 2000) is used for customized education. The discovery of Web page association rues is also used to analyze knowledge structure. The information collected will help the designer to develop a more efficient courseware. Another system and framework for Web content customization is proposed in Ochi, Yano, and Wakita (2000). The system supports resource customization, sharing, and searching. Using personal agents, a virtual classroom environment (Trajkovic, Davcev, Kimovski, & Petanceska, 2000) serves as a bridge between students and a virtual professor. An active video control and selection mechanism is proposed in Kameda, Ishizuka, and Minoh (2000). The mechanism is based on dynamic object detection, and a human intrinsic time constraint. The implemented system is used in distance-learning courses between UCLA and Kyoto University. An online assessment mechanism using Web technology is presented (Chetty, 2000). The system is for students of control engineering, in the practice of answering several questions, before an experiment is actually carried.

Educational Technologies

Educational theory and technologies has a great impact to the development of distance-learning systems. A software system will be useless if no one use it. Relying on educational theories and experiences for professionals, the design of any distance-learning system should consider its usability as the first step. A few articles look at distance-learning system from both educational (Jun & Gruenwald, 2001; Schar & Krueger, 2000) and engineering (Shih, 2000) perspectives. A formal model that evaluates interactivity and motivation of students is proposed in Jun et al. (2001). The model is tested on several Web-based instruction courses. And, experiences are discussed. In addition, five major factors for the development of computer-aided learning were proposed in Schar et al. (2000). The factors include theories for learning, multimedia didactic, learning technologies, information models in human-computer interaction, and user acceptance. Criteria of how distance education software systems are developed are presented in Shih (2000). The discussion includes administration, communication, and assessment tools that should be developed for distance education.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

In addition to these guidelines, educational and software technologies were used to build distance education systems. Educational theory such as student-problem chart is used in the development of an assessment system (Chang, 2002), which supervise students via automatic generated Web tutorial. The system is able to incorporate user interactions. Thus, each tutorial generated is based on the individual behavior of student. On the other hand, to develop better courseware, a revised influence diagram method is proposed in Shih (2002) for courseware designs. The diagram helps the designers to construct a more efficient learning topology for students. A quantitative analysis is given to each course topology designed. Thus, comparison is made between different course structures. Moreover, a paradigm supports the development of Web documents is proposed in Shih, Chang, Tsai, Ma, and Huang (2001b). The paradigm can be extended to support courseware designs. Metrics of Web documents are also defined.

Summary

We point out challenges of distance education, as well as important research issues in this article. Experiences in the literature show that, distance education has a great impact not only to high-level education, but also to industrial training. A study report and the discussion of a distance-learning center established in MIT are discussed in Penfield and Larson (1996). A complete report of this study is available at http://www-evat.mit.edu/report/. The impact of information technology to high-level education is also discussed in Beckett (1996). Experiences of using multimedia and distance education tools in online teaching and conventional classrooms are discussed in Latchman, Salzmann, Gillet, and Bouzekri (1999). The analysis of distance-learning issues in U.S., UK, Canada, Australia, and New Zealand is reported in Stein and Harman (2000). The "learning-by-doing" (Anido, Llamas, & Fernandez, 2001a) paradigm for distance leaning in traditional university and life long training was also proposed. The access of real equipments using Internet and the use of Java-based simulation tools are compared, with several analytical parameters presented to the readers. But, what are the basic requirements to make a successful system? Two factors make instructors and students to use online distance-learning tools, such as video-based lectures are, firstly, the production process must be easy, and secondly, there must be advantages to overcome in-class teaching. The paper (Anderson et al., 2000) points out these reasons. A comparison of two sections of students enrolled in technical writing class, one in a conventional class and the other in a Web-based environment, is presented in Mehlenbacher, Miller, Covington, and Larsen (2000). Although no significant difference of student

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

performance is found, there are small differences of learning style and attitudes. Moreover, a complete report known as "The No Significant Difference Phenomenon" (http://teleeducation.nb.ca/nosignificantdifference/) collects a set of quotations back to 1928. The report surveys 355 references.

The above reports and experiences show that, distance learning seems to be promising. But, what will be the future of distance education? Will e-learning be another "dotcom" issue? That is, will the impact of e-learning decreases or even vanishes? Perhaps we do not have an answer today. However, from the development of new technologies, we see a few issues of future distance education:

- **Bring outdoors to indoors:** Virtual reality-based communication and situated learning use augmented panorama and real-time communication technologies in a distance-learning CAVE. Students can feel and experience with outdoor facilities inside the classroom.
- **Bring indoors to outdoors:** Wireless communication for encyclopedia and E-books will be available. Outdoor students can participate to a lecture, use online references, or read class notes.
- **Edutainment:** Education will be easier and more interesting. It is possible to use game technologies in education, to attract students and to increase their motivation.
- **E-commerce:** E-learning will be a commercial activity. Knowledge is for sale in the future.
- **E-inequality:** Each virtual university has its own uniqueness and focus. But, it is possible that a virtual university dominates a particular area of distance-learning courses.
- **E-problem:** It will be a less people-centric natural of learning. With a large number of project-oriented courseware available, an individual student will choose a focus for training. That is, students will adapt to course sequences more as compared to course sequences are designed for students.

The expected great success of distance learning and the virtual university paradise is still not coming. Even if technology can support such an operation, there still remains some sociological and methodological problems. It is questionable, whether it is political, or technical, for the society to approve virtual university degrees. However, distance learning is now very active in mission-based instruction, and in community-based lifelong education. We hope the academia, the government, the engineers, and the society can work tightly toward the great success of distance education.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

References

Anderson, D., Harvel, L., Hayes, M., Ishiguro, Y., Jackson, J., & Pimentel, M. (2000). Internet course delivery — Making it easier and more effective. *2000 IEEE International Conference on Multimedia and Expo, ICME 2000*, *1*(1), 84-87.

Anido, L., Llamas, M., Caeiro, M., Santos, J., Rodriguez, J., & Fernandez, M. J. (2001b). An update on the SimulNet educational platform. Towards standards-driven E-learning. *IEEE Transactions on Education*, *44*(2), 194.

Anido, L., Llamas, M., & Fernandez, M. J. (2001a). Internet-based learning by doing. *IEEE Transactions on Education*, *44*(2), 193.

Bai, J., He, X., Liao, Q., & Lin, X. (2000). An ATM-based multimedia communication system and its application in distance learning. *Proceedings of International Conference on Communication Technology (WCC-ICCT 2000)* (Vol. 2, pp. 1383-1386).

Beckett, J. (1996). The impact of IT on education. *Engineering Science and Education Journal*, *5*(4), 185-189.

Benetazzo, L., Bertocco, M., Ferraris, F., Ferrero, A., Offelli, C., Parvis, M., & Piuri, V. (2000). A Web-based distributed virtual educational laboratory. *IEEE Transactions on Instrumentation and Measurement*, *49*(2), 349-356.

Brackett, J. W. (1998). Satellite-based distance learning using digital video and the Internet. *IEEE Multimedia*, *5*(3), 72-76.

Carver, C. (1999). Building a virtual community for a tele-learning environment. *IEEE Communications Magazine*, *37*(3), 114-118.

Castro, M., Lopez-Rey, A., Perez-Molina, C. M., Colmenar, A., de Mora, C., Yeves, F., Carpio, J., Peire, J., & Daniel, J. S. (2001). Examples of distance-learning projects in the European Community. *IEEE Transactions on Education*, *44*(4), 406-411.

Chang, F. (2002). Intelligent assessment of distance learning. *Information Science: An International Journal* (Special Issue on Interactive Virtual Environment and Distance Education), *140*, 105-126.

Chang, S., Hassanein, E., & Hsieh, C. (1998). A multimedia micro-university. *IEEE Multimedia*, *5*(3), 60-68.

Chen, H., Chen, G., & Hong, J. (1999, June). Design of a Web-based synchronized multimedia lecture system for distance education. *IEEE International Conference on Multimedia Computing and Systems*, *2*, 887-891.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Chetty, M. (2000). A scheme for online Web-based assessment. *Engineering Science and Education Journal*, *9*(1), 27-32.

Chu, K. C. (1999). The development of a Web-based teaching system for engineering education. *Engineering Science and Education Journal*, *8*(3), 115-118.

Deng, L. Y., & Shih, T. K. (2002a, July 2-4). Implementing a distributed lecture-on-demand multimedia presentation system. *Proceedings of the 4th International Workshop on Multimedia Network Systems and Applications (MNSA2002)*, Vienna, Austria.

Deng, L. Y., Shih, T. K., Huang, T., Liao, Y., Wang, Y., & Hsu, H. (2002b, July). A distributed mobil agent framework for maintaining persistent distance education. *Journal of Information Science and Engineering* (Special Section on Parallel and Distributed Systems)*, 18*(4), 489-506.

Deshpande, S. G., & Jenq-Neng, H. (2001). A real-time interactive virtual classroom multimedia distance-learning system. *IEEE Transactions on Multimedia*, *3*(4), 432-444.

Dodds, P. (2002). *ADL sharable courseware object reference model (SCORM), advanced distributed learning*. Retrieved from http://www.adlnet.gov/scorm/index.cfm

Duran-de-Jesus, J., Villacorta-Calvo, J. J., & Izquierdo-Fuente, A. (2000). Complete system for distance learning over IP. *IEEE International Conference on Multimedia and Expo (ICME 2000)*, *1*(1), 27-30.

Fernandez, D., Garcia, A. B., Larrabeiti, D., Azcorra, A., Pacyna, P., & Papir, Z. (2001). Multimedia services for distant work and education in an IP/ATM environment. *IEEE Multimedia*, *8*(3), 68-77.

Fong, A. C. M., & Hui, S. C. (2001). Low-bandwidth Internet streaming of multimedia lectures. *Engineering Science and Education Journal*, *10*(6), 212-218.

Foster, A., & MacGregor, K. J. (1999). The use of a Java implementation of SLP in a tele-teaching application. Distributed computing systems. *Proceedings of the 7th IEEE Workshop on Future Trends* (pp. 273-278).

Garnett, P. J., & Treagust, D. F. (1999). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (Galvanic) and electrolytic cells. *Journal of Research in Science Teaching*, *29*(10), 1079-1099.

Ha, S., Bae, S., & Park, S. (2000). Web mining for distance education. *Proceedings of the 2000 IEEE International Conference on Management of Innovation and Technology (ICMIT2000)* (Vol. 2, pp. 715-719).

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Harris, D. A., & DiPaolo, A. (1996). Advancing asynchronous distance education using high-speed networks. *IEEE Transactions on Education*, *39*(3), 444-449.

Huang, S., & Hu, H. (2000). Integrating Windows streaming media technologies into a virtual classroom environment. *Proceedings of International Symposium on Multimedia Software Engineering* (pp. 411–418).

Jun, W., & Gruenwald, L. (2001). An evaluation model for Web-based instruction. *IEEE Transactions on Education*, *44*(2), 9.

Kameda, Y., Ishizuka, K., & Minoh, M. (2000). A live video imaging method for capturing presentation information in distance learning. *2000 IEEE International Conference on Multimedia and Expo (ICME 2000)*, *3*(3), 1237-1240.

Keh, H., Shih, T. K., Deng, L. Y., Liao, I., & Chang, R. (2001, April 16-19). Using the floor control mechanism in distributed multimedia presentation system. *Proceedings of the 3rd International Workshop on Multimedia Network Systems (MNS2001)*, AZ.

Ko, C. C., Chen, B. M., Jianping, C., Zhuang, Y., & Chen Tan, K. (2001). Development of a Web-based laboratory for control experiments on a coupled tank apparatus. *IEEE Transactions on Education*, *44*(1), 76-86.

Latchman, H., Salzmann, C., Gillet, D., & Kim, J. (2001). Learning on demand-a hybrid synchronous/asynchronous approach. *IEEE Transactions on Education*, *44*(2), 208-214.

Latchman, H. A., Salzmann, C., Gillet, D., & Bouzekri, H. (1999). Information technology enhanced learning in distance and conventional education. *IEEE Transactions on Education*, *42*(4), 247-254.

Lee, K., Chang, K., Yu, S., Chang, I., Shia, C., Chen, W., & Huang, J. (1997). Design and implementation of important applications in a Java-based multimedia digital classroom. *IEEE Transactions on Consumer Electronics*, *43*(3), 264-270.

Maly, K., Abdel-Wahab, H., Overstreet, C. M., Wild, J. C., Gupta, A. K., Youssef, A., Stoica, E., & Al-Shaer, E. S. (1997). Interactive distance learning over intranets. *IEEE Internet Computing*, *1*(1), 60-71.

Masson, A. M. (1999). Web-based simulations for computer-assisted learning in the higher education sector. *Engineering Science and Education Journal*, *8*(3), 107-114.

Mehlenbacher, B., Miller, C. R., Covington, D., & Larsen, J. S. (2000). Active and interactive learning online: A comparison of Web-based and conventional writing classes. *IEEE Transactions on Professional Communication*, *43*(2), 166-184.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Ochi, Y., Yano, Y., & Wakita, R. (2000). Development of Web customize system for sharing educational resources. *Proceedings of the 1st International Conference on Web Information Systems Engineering* (Vol. 2, pp. 173 -178).

Parnes, P., Synnes, K., & Schefstrom, D. (2000). mStar: Enabling collaborative applications on the Internet. *IEEE Internet Computing*, *4*(5), 32-39.

Peden, J., Burleson, W., & Leonardo, C. (2000). The multimedia online collaboration architecture: Tools to enable distance learning. *2000 IEEE International Conference on Multimedia and Expo (ICME 2000*) (Vol. 2, pp. 593-596).

Penfield, P. Jr., & Larson, R. C. (1996). Education via advanced technologies. *IEEE Transactions on Education*, *39*(3), 436-443.

Pullen, J. M., & Benson, M. (1999). ClassWise: Synchronous Internet desktop education. *IEEE Transactions on Education*, *42*(4), 19.

Sala, N. (2002). Virtual reality as an educational tool. *Proceedings International Conference on Computers and Advanced Technology Education (CATE)* (pp. 415-420). Cancun, Mexico.

Schar, S. G., & Krueger, H. (2000). Using new learning technologies with multimedia. *IEEE Multimedia*, *7*(3), 40-51.

Shih, T. K. (2000). Criteria of virtual university operation. The *24th Annual International Conference on Computer Software and Applications, COMPSAC 2000* (pp. 284-285).

Shih, T. K. (2001a, September 30-October 5). Software systems for virtual university operations. *Proceedings of the 2001 ACM Multimedia Conference*, Ottawa, Ontario, Canada.

Shih, T. K., Chang, S., Tsai, J., Ma, J., & Huang, R. (2001b, December) Supporting well-engineered web documentation development — A multimedia software engineering approach toward virtual university courseware designs. *Annals of Software Engineering* (Vol. 12, 139-165). Special Volume on Multimedia Software Engineering.

Shih, T. K., & Davis, R. E. (1997, April-June). IMMPS: A multimedia presentation design system. *IEEE Multimedia, 4*(2), 67-78.

Shih, T. K., & Hung, R. (2002, August 26-29). Multimedia courseware development using influence diagram. *Proceedings of the 2002 IEEE International Conference on Multimedia and Expo (ICME2002)*, Lausanne, Switzerland.

Si, J., & Yu-Tsung, W. (2001). Online learning control by association and reinforcement. *IEEE Transactions on Neural Networks*, *12*(2), 264-276.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.

Siddiqui, K. J., & Zubairi, J. A. (2000). Distance learning using Web-based multimedia environment. *Proceedings of Academia/Industry Working Conference on Research Challenges* (pp. 325-330).

Stein, S., & Harman, B. (2000). Distance learning — The global challenge. *Proceedings of International Workshop on Advanced Learning Technologies (IWALT2000)* (pp. 197-200).

Trajkovic, V., Davcev, D., Kimovski, G., & Petanceska, Z. (2000). Web-based virtual classroom. *Proceedings of 34th International Conference on Technology of Object-Oriented Languages and Systems (TOOLS 34)* (pp. 137-146).

Vouk, M. A., Bitzer, D. L., & Klevans, R. L. (1999). Workflow and end-user quality of service issues in Web-based education. *IEEE Transactions on Knowledge and Data Engineering*, *11*(4), 673-687.

Wang, Y., & Su, C. (2000). Synchronous distance education: Enhancing speaking skills via Internet-based real time technology. *Proceedings of the 1st International Conference on Web Information Systems Engineering* (Vol. 2, pp. 168-172).

Winn, W. (1993). *A conceptual basis for educational applications of virtual reality*. (HITL Tech. Rep. No. TR-93- 9). Seattle, WA: Human Interface Technology Laboratory. Retrieved from http://www.hitl.washington.edu/publications/r-93-9

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and organic). *Journal of Research in Science Teaching*, *27*(10), 1053-1065.

Endnotes

1 Except the first author, the co-authors are sorted by last names.

2 Answers for each question are cited by the last name of authors in between brackets, to distinguish the answers from paper citations.

Copyright © 2007, Idea Group Inc. Copying or distributing in print or electronic forms without written permission of Idea Group Inc. is prohibited.