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A web-based, interactive virtual laboratory system for unit operations and process systems engineering education: issues, design and implementation

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Abstract

The development of real educational content and customized virtual education systems satisfying the needs of a specific engineering education domain is getting more and more research attention in this era of ubiquitous Web and virtual technologies. By analyzing the characteristics of computer-based educational methods and adopting the rapidly changing Internet and object component technologies, we have developed a Web-based, interactive virtual laboratory system for unit operations and process systems engineering education, and validated its effectiveness by surveying student users of the implemented prototype system. In this paper, we also discuss many technical issues in building Web-based interactive virtual education systems and share the experience obtained. The proposed system is expected to overcome many obstacles in performing the unit operations laboratory in the current setting. More teachware and experiment suites are being added for more extensive, quantitative evaluation of educational efficiency of the proposed methodology and the system. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Advances in the Internet and emerging tools for virtual reality modeling language (VRML) and eXtra markup language (XML) now make it easier and cost-effective to develop Web-based virtual educational or laboratory systems. As reflected in the current explosion in the use of the Web for teaching and learning, the ultimate realization of on-line higher education is the Virtual University (VU), which supplies all the services of a conventional university but is supported and interfaced through Web- and Internet-based technologies (Westhead, 1999). Though most engineering schools are already surrounded by numerous building tools for VU and there is much promise for improving the quality, flexibility and effectiveness of the education in general, these tools rather handle administrative tasks and will never supply the necessary educational content, which all of us are interested in teaching and sharing in those virtual universities. Thus the development of the real content (what to teach), customized virtual education systems (how really to teach 'virtually'), and new teaching models satisfying the needs of each specific domain is getting more and more research attention in every engineering discipline.

Ubiquitous Web and associated Internet technologies are becoming increasingly important in engineering education. Computer-based educational environments have existed for many years. However, the recent explosion of the World Wide Web (WWW) has provided a new system designed for network use and supporting high-quality software demonstrated to be popular and intuitive to use. As an effort to make an advance in computer-aided engineering education tools and to solve problems in performing the engineering laboratory in the current setting, we are conducting a multi-

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disciplinary, collaborative research to design, implement and distribute successfully virtual engineering laboratory systems on the Web. In the interactions of the whole collaborative research, our part of the research is focused more on the design of a framework for chemical engineering education through the integration of the virtual plant and Web technologies. The effectiveness of the proposed system architecture and new education methodology has been demonstrated by implementing a prototype system for a more flexible, self-paced approach in the operations and control experiments of distillation and drying processes. Some of the technical issues, related standardizations and tools emerging in this broadening research area are also discussed in this paper.

The next section introduces some basic concepts of computer-based education while the sections following will describe (1) the whole interdisciplinary research effort; (2) how our system has been designed, implemented and validated; and (3) how the prototype system delivers user-adaptive, interactive virtual labs on the Web.

2. Review of computer-based education technologies

2.1. Comparison of various computer-based education systems

If we think of learning, Web-based or otherwise, in the context of 'learning formats,' i.e. how and when a learner encounters and undertakes the content, there are at least three general formats in which learning occurs (Jackson, 2000): directed study (asynchronous 'self study'), instructor-led events (synchronous 'live, real-time' learning), and small group collaboration. Depending on the main functionality and research focus, computer-based educational systems are classified as follows—each system architecture pursues its own way of cost-effectiveness but in different perspectives.

- Computer-aided instruction system: most educational systems using computers belong to this general category. It developed with the advances of computer and computing technologies and is being used broadly. Systems of this category are more interested in and satisfied with transferring educational content efficiently even if the implemented system and interfaces are quite different from the real counterpart.
- Multimedia/virtual laboratory (e.g. Bell & Fogler, 1996; Montgomery, 1996): using computers, advanced graphics, and multimedia technology, e.g. head-mounted displays, 3-D sound, and artificial sensory devices, they are focused on developing a mockup of the real part as closely as possible. The visual part is especially emphasized by using advanced graphics and improved user interfaces.
- Distance learning system/instruction on the Web: on the Internet or intranet, education is performed by connecting learners and instructors, who may be in different time and/or spatial locations. Less direct interventions between the instructor and the trainee are achieved by downloading and installing the necessary computer programs and/or connecting to the education server. The instructor becomes much more free from directly managing the education session compared with general computer-aided instruction systems. With the connectivity of the Internet and a new generation of software applications, distance learning has evolved into a new model, which provides higher quality and more flexibility in an anytime/anywhere fashion, and is more appropriately called distributed learning (Jackson, 2000).
- Intelligent tutoring system (e.g. Shin & Venkatasubramanian, 1996): in the three systems above, the delivery rate and the content of educational material are still controlled by humans. However, the intangible education method itself, especially the role of a human instructor who is controlling adaptively the information transfer rate, is replaced by computer components in this kind of system. How to evaluate and react and proact to the trainee's changing knowledge level and how to deliver interactively the user-adapted necessary feedback are the main focus of the research and development in this area.

2.2. Open standards for learning technology

There are two types of standards we need to consider in designing Web-based virtual lab systems. Web and Internet-related technologies will be considered in the later implementation section; in this section let us briefly look over what standards for education are being proposed inside the education research community. Since open standards tend to guide technology development, it seemed to be prudent to carefully consider them in designing and implementing our system. Accompanying the transition of learning technology from the LAN or CD-ROM based onto the Web is the transition from a closed to the open environment. In a closed environment, proprietary solutions are acceptable, on the Web they are not.

Several organizations are attempting to establish open standards to permit interoperability and free exchange of the content developed in various software packages (Jackson, 2000; Richards, 1998). These standards cover a wide range of systems, including computer-based training (CBT), computer-assisted instruction, intelligent tutoring, metadata, etc. They promote interoperability and portability by identifying critical system interfaces (Farance & Tonkel, 1999).

Airline Industry CBT Committee (AICC)[2]'s computer-managed instruction (CMI) specification defines the tracking data exchanged between management systems and interactive lessons. It also defines an interchange format for course structure so that entire courses can be exchanged between management systems made by different vendors. Instructional Management Systems (IMS) Project[3] is a consortium of academic, commercial and government organizations, developing a set of specifications and prototype software for facilitating the growth and viability of distributed learning on the Internet. The architecture encompasses platform-independent interfaces for metadata, aggregated content, management services, user profiles and external services such as databases. The IMS architecture anticipates the widespread availability of emerging technologies such as XML and provides an excellent vision for the future of online learning (Richards, 1998). Within IEEE, the Computer Society is sponsoring the development of 'Standards for Computer-based Learning.' The IEEE Learning Technology Standards Committee (LTSC)[4] hopes to develop a broad suite of de jure technology standards that will support the component development of computer-based learning tools and courseware. Both the AICC and IMS initiatives are furthering their goals in the IEEE LTSC. The AICC has submitted its CMI specification, and IMS has jointly submitted a metadata specification with the European ARIADNE project.

After analyzing the characteristics of the aforementioned education methods and the rapidly changing Internet, Internet2 (Lange, 1997) and object/component technologies, we have designed and implemented a virtual laboratory system for unit operations and process systems engineering education. In this research, we are not developing leading-edge, computer-based education technologies, but are more concerned with developing a suitable system architecture and libraries to be used right away, efficiently, for real education. The developed system should also be affordable in low-budget engineering schools, although computing technology development coming in a few years is considered as well for future easier expansion and enhancement of the system.

Table 1
The Web as a distribution medium of educational material (compared with paper, CD-ROM and tape recordings)

Widely accessible (in multi-platforms): freely accessible if network access is available
Low cost for providers and users: delivery of the educational material, including motion pictures, through already available, reusable equipment
Maintainability: single-source control—maintenance of a Web site on a reliable server is only required without worrying about client sites
Easy updating of the content (though all changes should be made through electronic document publishing)
Easy to get users' feedback

3. Interdisciplinary collaborative virtual lab (VLab) development

The whole research work started as an interdisciplinary initiative to make innovative and useful computer-aided engineering education tools. We wanted to develop cost-effective, powerful, reusable learning modules by investigating a new education methodology on the Web. The Web has now about a 10-year history and there are numerous reports on its usage in education in general (Lewis, Snow, Farris, Levin, & Greene, 1999; Urdan & Weggen, 2000). However, their conclusions do not give us enough practical help that we need in developing running systems for engineering education. Our Web-based, simulation-oriented engineering lab for general students is the first attempt of this sort, and it would give us more specific views on the Web's capability in engineering education. Physical laboratories are still an important component of an engineering education. Our objective is to enhance or augment traditional labs, not to replace hands-on equipment experience when it is handy.

This Web-integrated system presents common Internet-based tools within a unified interface accessed by using a Web browser. Accessing text, graphics, multimedia, and other course resources in a virtual system environment involves using the familiar Web browser interface. The Web's advantages and disadvantages as a distribution medium of educational material are summarized in Table 1.

To make its effort more worthwhile and the resulting system widely accepted and distributed, it is being conducted as a multi-disciplinary, government-supported research to design, implement and distribute successfully a virtual, distance engineering laboratory system, independent of computer platforms. Many obstacles were considered in performing the engineering laboratory at the current setting (Shin et al., 1998): space and time limitations, experiment-related hazards and safety concerns, and decreasing resources for exercising actual experiments, especially in low-budget universities. These obstacles also hold in performing the unit operations lab at the current setting.

With participation from all engineering disciplines belonging to the college of engineering, the research efforts consist of the development of virtual measuring

[2] AICC home page: http://www.aicc.org/.
[3] IMS home page: http://www.imsproject.org/.
[4] IEEE LTSC home page: http://ltsc.ieee.org/.

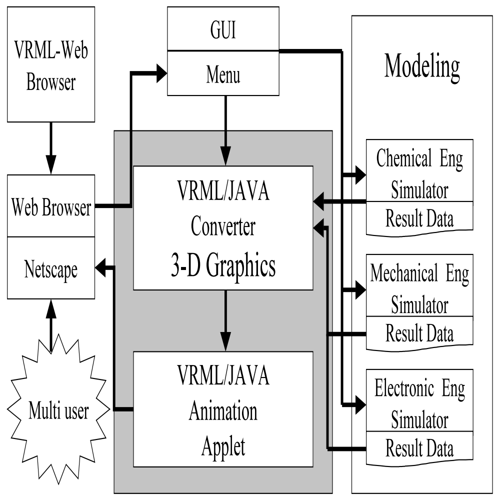

Fig. 1. Interdisciplinary collaborative development effort in 3-D graphics and visualization.

devices (including remote observation of real-time laboratory experiments—this one is comparable to Henry's distance experiment[5] which is a Web-based replay of the recorded real experiment output generated to the user's request), various simulators and related software libraries, laboratory administering scheme, 3-D graphics and visualization, virtual manufacturing process models, and virtual laboratory building tools. Fig. 1 shows a part of the cowork in developing the common 3-D graphics and visualization module. The research and development cooperations are organized in the common, core component development and the applications development for individual engineering discipline.

In our part of the research, we focused more on the design of the system framework through the integration of the virtual plant and Web technologies. We would demonstrate its effectiveness through an implementation of a prototype system for the unit operations lab and control experiment of separation processes, including distillation and drying. Our affordable system and developed components will be suitable for wide distribution in the chemical engineering education community. As in Kurooka, Yamashita, and Nishitani (2000), there is research on more direct measurement of a human operator's thinking state, estimated from EEG data. Reading and having an accurate knowledge of a student's thinking state is important also for user-adaptive tutoring, but in our system we estimate those states based on more cheaply obtainable data, e.g. user inputs and interactions. Even if more advanced technologies are already available to us, we limit their use to only when the cost is justifiable and affordable for higher educational institutions.

[5] See its home page: http://chem.engr.utc.edu.

4. Proposed system architecture

By analyzing the characteristics of each computed-based educational method and considering the rapidly changing Internet and object technologies, we have designed a virtual laboratory system for unit operations and process systems engineering education. The proposed system encourages high-order thinking (Miller, Ely, Baldwin, & Olds, 1998) and overcomes the aforementioned obstacles in performing the unit operations laboratory at the current setting. Routinely converting lecture notes for the Web or transforming conventional lab sessions as slide shows on the Web has been avoided by developing an interactive virtual lab system, best suited to the characteristics of the Web and the surrounding environment. Bringing together a user's interests and active participation in the lab was also one of the main concerns of the development.

4.1. Requirements and needs analysis

To design a system satisfying our research needs, necessary system components are analyzed first. As emphasized in Miller et al. (1998), the unit operations lab should enhance students' higher-order thinking skills and familiarity with many aspects of chemical engineering professional practice, including data collection and analysis, evaluation and interpretation of results to draw meaningful conclusions, and effective communication to a variety of audiences. Beyond data reporting and simple comparisons, students should be encouraged to develop inferences about what the results actually mean.

Current practices of the unit operations lab have also been analyzed. In addition to converting conventional lab components into the corresponding on-line virtual parts, we also investigated a new education methodology for on-line lab education. Through the analysis of available lab manuals and the records of conventional lab sessions, the usual lab sequence and the objectives of what we want to teach at each lab have been identified and revised based on the feedback from instructors and students.

In addition to high-order thinking, there are four types of knowledge we would like to teach and transfer successfully to the students through the lab, viz. qualitative knowledge such as causal relations; internal/external mechanisms; operation methods and procedures; and knowledge of the equipment. Students can learn actively and acquire such knowledge through interactions with the system, at any time and place over the Internet. Tracking a student's progress and performance is especially important in making the any time, self-directed, self-paced lab possible, with reduced face-to-face (synchronous) contacts with the students.

The proposed virtual lab system consists of five modules as shown in Fig. 2. Modules for process simulation, lab-related knowledge, user interactions, and session management are self-explanatory and already summarized in Shin et al. (1998). In this section, we will only discuss the lab-tutoring module in detail.

4.2. Helping students build correct mental models

Routine lab management is handled by the lab session management module. In our system design, we are not satisfied with just replacing the hardware part of the unit operations lab with its virtual counterpart. We also need to have replacements for the involving software part, e.g. help of TA's, to run the lab effectively any time, any where on Web. That is where the intelligent tutoring system (ITS) component fits in. The role of ITS module is maximizing an individual's learning efficiency through the student model-based, user-adaptive instruction. At the start of each lab session, it determines what the learner already knows and compiles only the required learning objects necessary to fill particular learning gaps. Based on the standard tutoring scenarios, it supplies adaptive interactive feedback to the student as well. At the end of a laboratory session, it also measures, through tests, and records what the student learned from that lab.

As the total amount of supplied information increases, called the 'information sea' on the web, the user may waste much time in deciding which information and knowledge should be mastered first. Through this module, teaching material and the corresponding lab sessions that the user does not fully understand will be especially emphasized based on the continuously updated user profile (this module signifies the proposed system's difference from many commercial operator training systems (Morgan, 1994; Nicholas, 1995; Wozny, 1994)). Rather than being hardwired directly in a document, hyperlinks to the referential material are attached selectively in the generated hypermedia help file, according to the user's level of understanding on the chosen topics — this is one example of user adaptation using the learner profile.

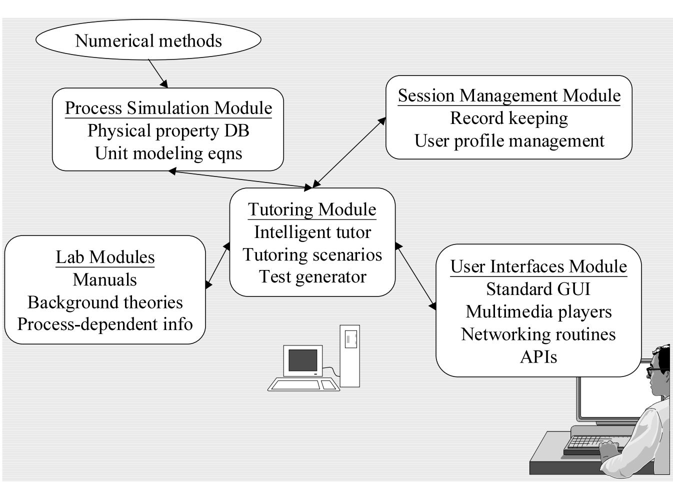

Fig. 2. Proposed system architecture.

Students make their own meaning of what they are learning by relying on mental models of the world. Using the user interaction data and direct questioning techniques, this intelligent tutor helps students understand complex technical phenomena by constructing mental models that reflect reality as perceived by acknowledged experts while minimizing models containing significant misconceptions (Miller et al., 1998).

4.3. Evaluation of student's performance

Report writing, quizzes, and tests are common ways of evaluating a student's performance: they ensure that students achieve mastery of the learning material. Test and assessment mechanisms, both formative and summative, are crucial aspects of the learning experience particularly if accreditation is involved (Westhead, 1999). They provide essential feedback mechanisms, to both instructors and learners, on progress. To provide students instant, immediate feedback in the everywhere-accessible lab, automatic test generation and evaluation is also required as well as pre-built user aids, now popular in every software package. Multiple-choice problem types are already available on the Web for this purpose, but we are concerned about developing more advanced test generators with built-in user adaptation. However, at the current system design, we are not yet considering severely imposing classroom test conditions in the on-line environment.

4.4. Comparison with the general model of technology education

Compared with the general model of Sandberg (1994) for the components of a technologically rich learning environment, our system architecture only lacks a 'fellow learners' module. According to Sandberg, these components must all be in place in order to optimize learning: school, teacher, learner, monitor, learning materials, tools, information sources, and fellow learners. For the support of collaborative learning and the communication between students and staff, one or several methods are combined for use in the proposed system, including e-mails, bulletin boards, white boards, on-line chats, and audio/video conferencing depending on the hardware availability. Though some research tries to implement artificial ones to improve the learning process of involving fellow learners, we encourage a user's interactions with other students by only supplying the necessary communication tools.

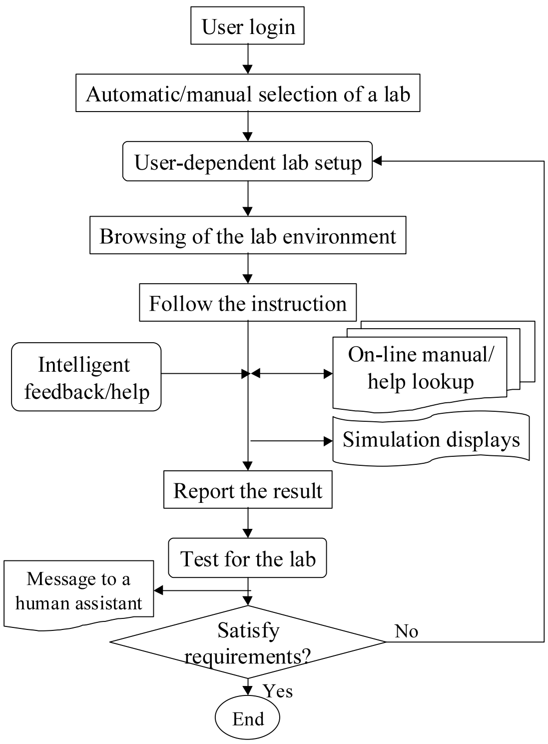

Fig. 3. System's working procedure in cooperation with the lab server.

4.5. Lab execution procedure

A unit operation lab session using the proposed system is performed in three steps: prelabs for mainly obtaining necessary background information on the project; the interactive real lab session executed by operating the virtual equipment to collect data and reporting of the result after analysis, synthesis, and evaluation of the data (there would be some time delays in this step); and the rectification and diagnosis of mistakes. After a lab session is finished with a student test about the project, if necessary, the student is guided to appropriate on-line materials for more complete explanations and review of the subject. The whole procedure of the system's working steps on the Web in cooperation with the lab server is shown in Fig. 3.

5. System implementation and validation

In this section, we will take a look at some technical issues in more detail. In the implementation of a prototype system, we adopted open system architecture to employ still developing Internet and related technologies. Using already available (public-domain) libraries the prototype system has been quickly implemented for the test and evaluation and the following modifications, adaptations, and improvements. For example, Netlib and public-domain math libraries were mostly used for numerical methods, and usages of commercial packages have been limited for wider and limitless distribution of the developed system. Many routines of the program have been borrowed and reused if already available as source code, and only the necessary parts programmed by our development team. So as not to create from scratch all the necessary components, and to achieve interoperability with them, we developed translators and wrappers to adapt existing program resources.

5.1. Standards and technology consideration

Though there already are a few groups developing standards for education, including IEEE LTSC and IMS, we have not incorporated much of their proposed standards at this early stage of development. However, following de facto, de jure or other emerging standards would be important at the next stage of our development for wider acceptance and easy integration with existing systems. While the world wide web consortium (W3C) does not focus on learning, it does define basic technologies that are assumed by many learning technology specifications. It is not necessary to evaluate all the Web server and client technologies in this section, but we must have a vision of their progress so that our selected implementation technologies do not go to sudden death in the market. Debates are still open on what are the best solutions, and let us briefly think about what options we have in this core element of Web development.

Since Web- and Internet-related technologies are still changing and being developed rapidly, we are facing many choices of tools and technologies in implementing our proposed system. The developed system is to be run on major Web browsers like Netscape Navigator and Internet Explorer, and the programming solutions that work on both Web browsers have been mainly used. Programming in mixed languages was not avoided: some simulation codes were already developed and existing in C + +, and the programming team favored visual basic (VB) and Java for various user interface development. Java provides platform-independent support for rapid development of graphical user interfaces, as well as for building programs that are network aware.

Since the main medium of teaching and learning in our system is the Web, when the implementation part is concerned, we cannot ignore the on-going 'Web browser war.' We are not yet in a position of choosing one over the others, and every user has his/her own preference on this matter. So our development has been based on widely accepted Web technologies, especially publicly available technologies. Implementing the system for one dominant Web server and client is the easier task, but for wider adoption of the system, we took the approach of cross-platform development.

5.2. Load balancing between server and client sides

Depending on the configuration and capabilities of the server and the connecting clients, the optimal way of executing the lab is quite different from the perspective of program running and the network load for communication. In our first generation of the implementation, we emphasized the client side program running with reference material on the Web. In the second-generation implementation, we took the intermediate approach of equal load balancing between the server and the client. In the third generation of current implementation, we are trying to push the server capability to the limit.

The easiest way of session management is to do all the jobs on a powerful server and only return and display the result to the client side when necessary. The server can watch over all user interactions, so user adaptiveness programming can be more easily achieved. However, this may too much increase the network traffic if high interactivity is required. Server overload may happen if more clients are trying to connect to the server than the number we expected in the design of the system. We may also be wasting a client's computing power by not using it enough. This way of configuration is perfect for the clients of NetPC-level. The other extreme is to do all the jobs on the client after downloading necessary widget programs from the server. The user does all program executions on his/her own client computer and only reports the result to the server. Program development for this configuration is easy since this is not much different from the conventional stand-alone programs. However, in this configuration, user-adaptiveness programming cannot be achieved effectively, and the client-side computer needs to be powerful and be loaded with all necessary tools and programs, which may not be free. Needless to say, with low-bandwidth network connection this approach may be the only option we may choose. In the intermediate approach, the programs running on the client requests necessary data from the server and also returns data that are required for the functioning of programs running on the server side. In this case, we need to develop more Web plug-in programs.

Various computing environments are considered for the widespread distribution and porting of the developed system: users are recommended to choose the best suitable one out of the many available configurations. At the current implementation of the prototype system, for example, the virtual laboratory server and clients can be connected by using one configuration out of the three available methods: using common gateway interface (CGI) or the like, as helper or plug-in, and as Java applets.

5.3. Overview of current implementations

The current version of the prototype system has a control lab like PCM (Doyle, Parker, & Gatzke, 1998) and Virtual Control Lab[6] and distillation and drying labs developed as helper and plug-in programs in VB/active server pages (ASP), C++ and Java (see Fig. 4 for one of those helper programs).[7] Dynamics simulation codes developed in consideration of the execution speed have been validated in comparison to the results of commercial simulators and conventional real labs. On-line lab manuals of the first generation of the implementation, partly shown in Fig. 5, are browsable through the Web during and before the lab session. Browser applets provide interactive demonstrations to clarify the material presented. Standardized laboratory scenarios with more educational value are the main focus of the development at the current stage. Using multimedia, legacy lab manuals are being converted as on-line documents and interfaced with the developed program. The student profile module for adaptive teaching is being developed based on the overlay model by borrowing a standardized component from the ITS research community. Button clicks, sequence of operations, direct user inputs, user response time, and information requests are being used as input data for the student profile updates.

Figs. 6–10 show the most recent, third generation of the implementation runs for a lab session. User login; browsing of introductory material, including essential terminology and definitions; study of experimental objectives, background knowledge and lab-related theories as part of the prelab; selection of lab conditions and execution are all shown. Various test forms supported in the current implementation are also shown in Fig. 11. In the long run, this system should be integrated with, and work as part of the VU system of an individual institution, not as a stand-alone system of current implementation. Thus, modules that are generally supported and supplied by the VU system, e.g. session management, user authentication, and administrative report generation, have not received much attention in our development efforts. Only minimal parts of them were developed for the test of the prototype system.

The working system may also use the powerful computational engine of legacy software packages if available, e.g. Matlab/Simulink and commercial simu-

[6] Virtual Control Lab 2 home page: http://www.esr.ruhr-uni-bochum.de/VCLab/index.html.

[7] Our prototype system is running under the project home page, http://no1.dongguk.ac.kr/vlab.

lators, for extensive simulations and real-time interactive animations on laboratory plants modeled in VRML. More teachware and experiment suites are being added for extensive, quantitative evaluation of the educational efficiency of the proposed system. To provide guided exercises as well as to help students build expertise in process control, the control lab modules are being extended by incorporating the three categories of questions (check your reading, study questions and thought questions) approach described in Hough & Marlin (2000).

XML, under development by the W3C, is a simple, very flexible text format that falls between the HTML and SGML. It aims to capture much of the power of SGML without all its complexity. XML has been designed to reach beyond text formatting and provides a suitable language for the interchange of metadata. In the next version of our system implementation, XML will be used heavily, replacing HTML. We are also developing more flexible tools for authoring teaching materials to be run on this system. A valid username and password check is the only way we are using for the user authentication, but an improved way of ensuring that we are testing the person we think we are must be developed if the test score would be used to grade the individual performance.

5.4. System validation

Educational systems and materials have their value only when they benefit instructors and/or students. The effectiveness of the proposed system may only be validated by directly testing against the eventual users of the system, i.e. teachers and students who are involved in the operation of the lab course. Table 2 summarizes the survey questionnaire and the results obtained; the surveys were collected by using the forms adapted from the test forms shown in Fig. 11. We received very high praise on the efficient use of the lab time, accessibility of the virtual lab and the possibility of its replacing some real labs. The initial feedback has been positive and quite encouraging for further development of our entire system.

6. Conclusions

To overcome the obstacles in performing the unit operations laboratory in the current setting, we designed and implemented a Web-based interactive virtual laboratory system for unit operations and process systems engineering education. This virtual lab system helps students understand the fundamentals of unit

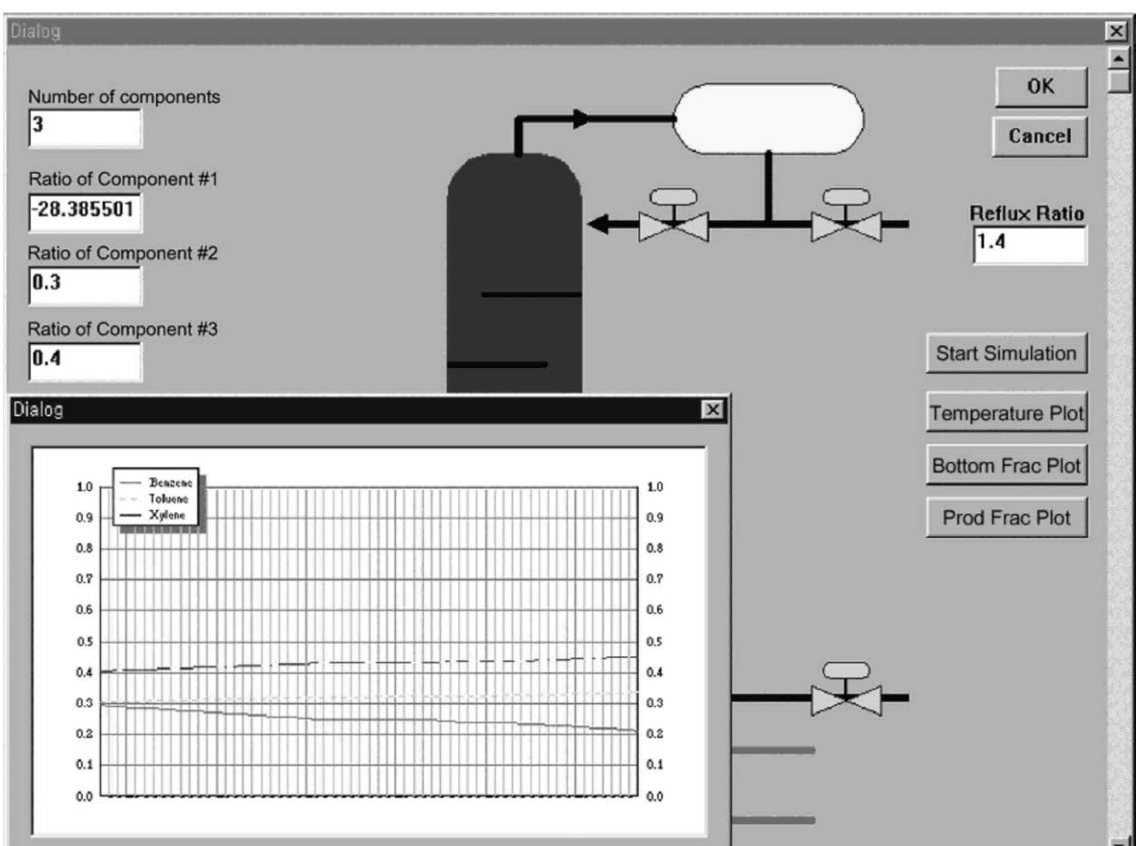

Fig. 4. Screenshot of a main client program of the second generation of the implementation.

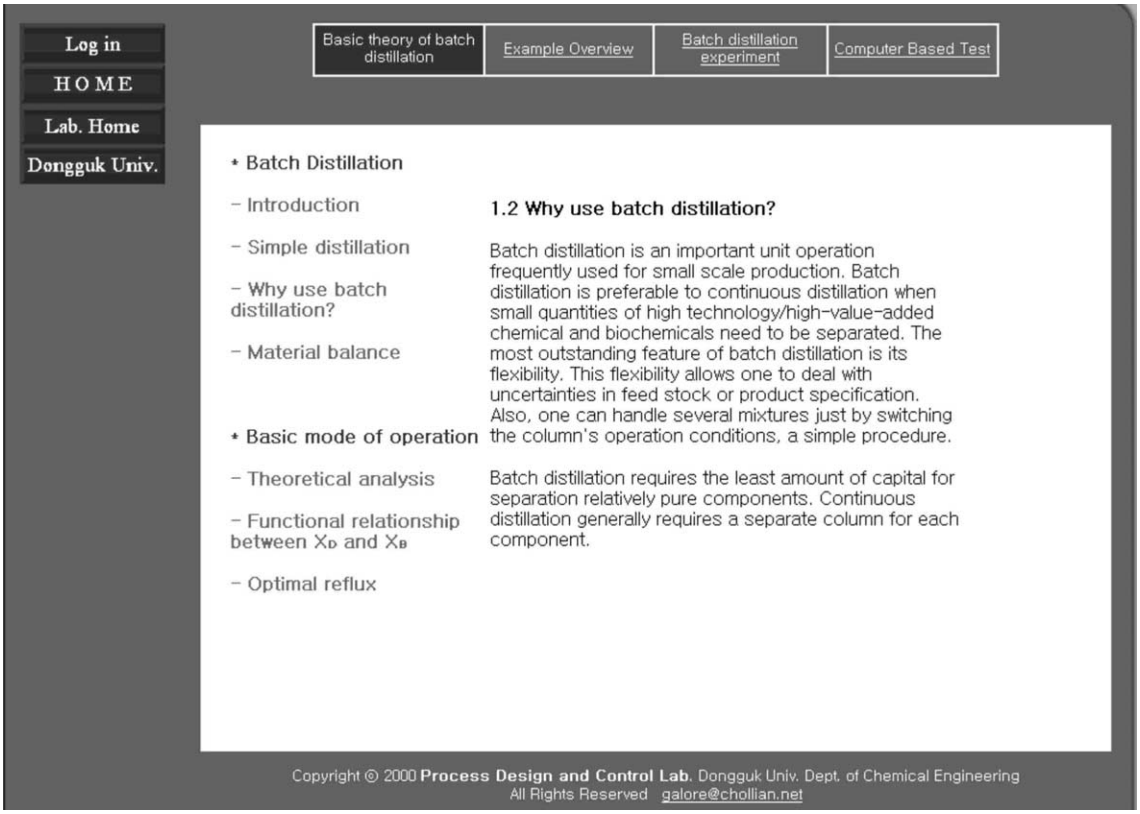

Fig. 5. Part of the on-line manual (help text converted from Korean).

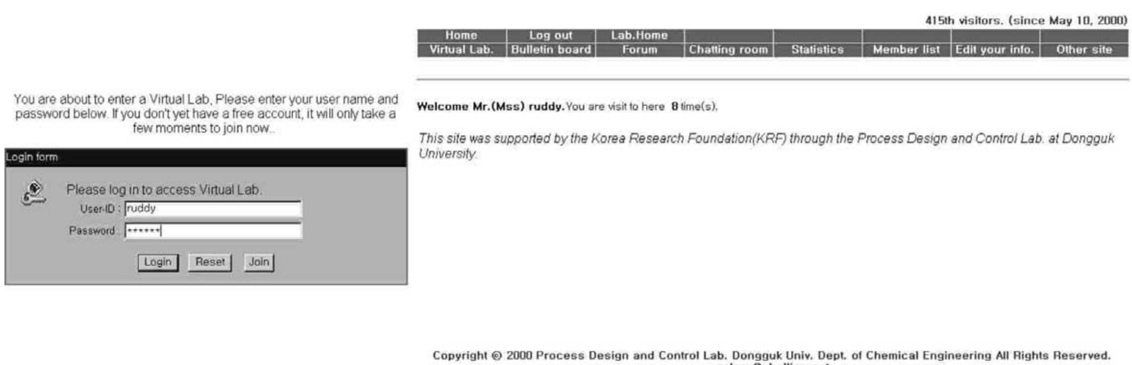

Fig. 6. User login and start page of the lab, including a bulletin board.

operations and increases educational efficiency with significantly less operating cost for the lab. It is also expected to contribute to increasing students' adaptability to working in real process plants after graduation. In this paper, we focused more on showing that the hard parts of a time-consuming real lab could be replaced, without loss of educational effect, with their virtual counterpart on the Web to make the lab more accessible any time, in any place. The effectiveness of the proposed system was evaluated through direct experimentation and survey with students taking the unit operations lab course. For extensive quantitative evaluation on the educational efficiency of using the proposed system and the new teaching model, more teachware and experiment suites are being added to the whole virtual lab system. Based on the success of this study and other parts of the research, we are developing, in cooperation with all engineering disciplines, a dedicated virtual engineering lab course, which will be offered starting from the Fall 2001 semester at Dongguk University.

Acknowledgements

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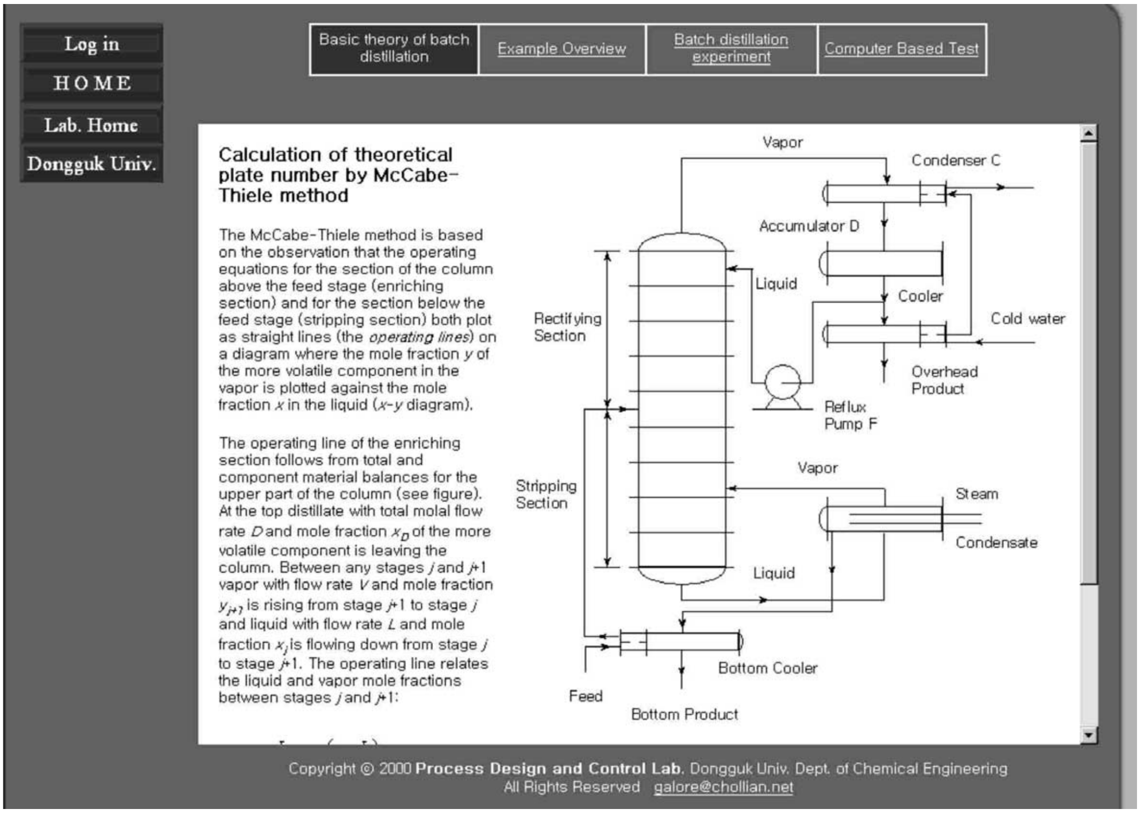

Fig. 7. Introduction and summary of basic theories related to the lab.

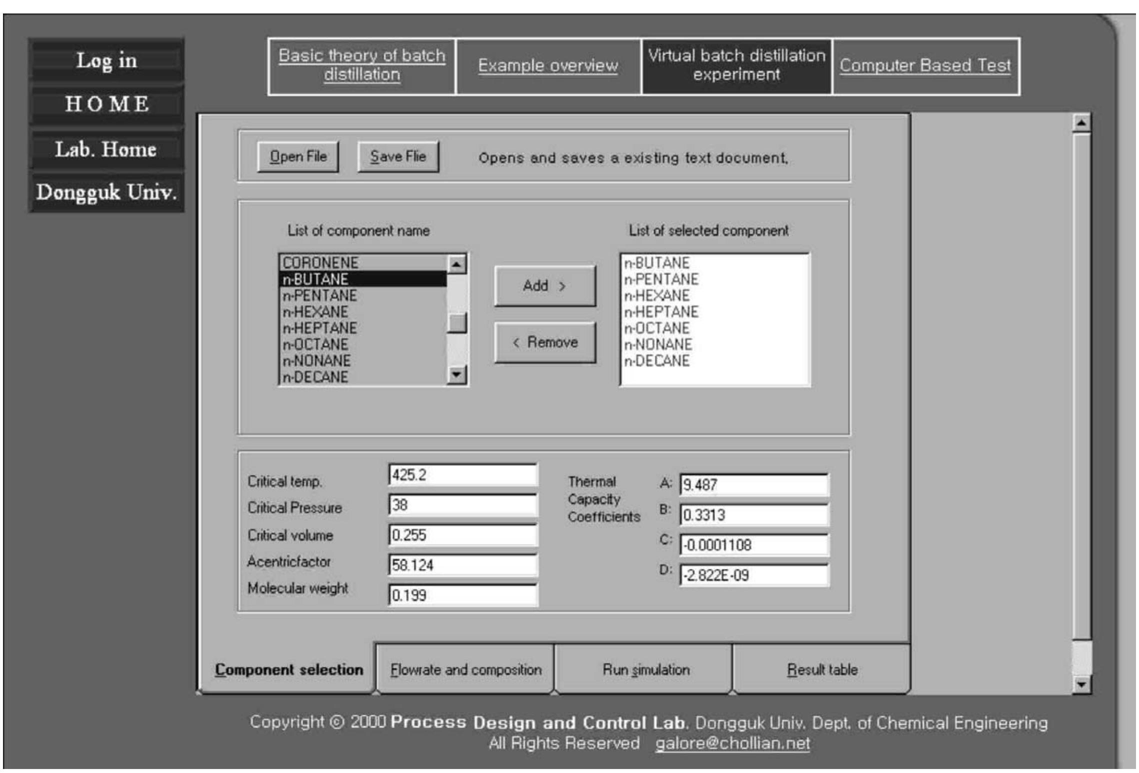

Fig. 8. Selection of a lab setting I: compositions.

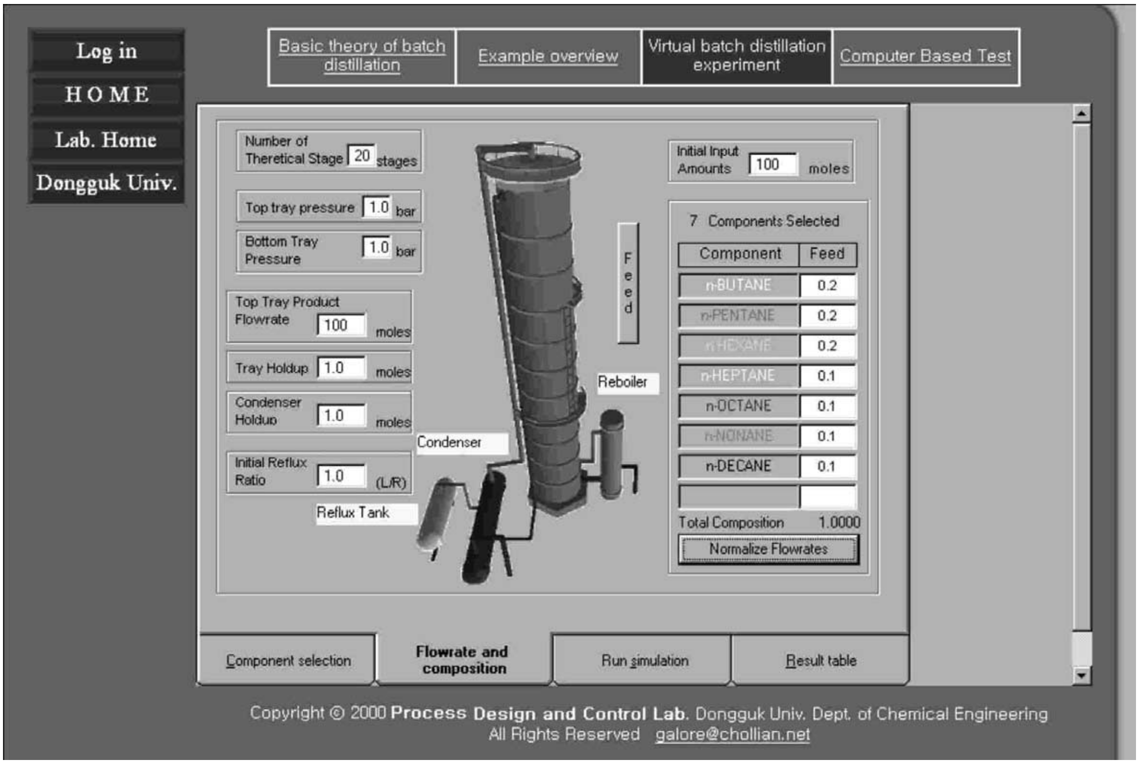

Fig. 9. Selection of a lab setting II: operating conditions.

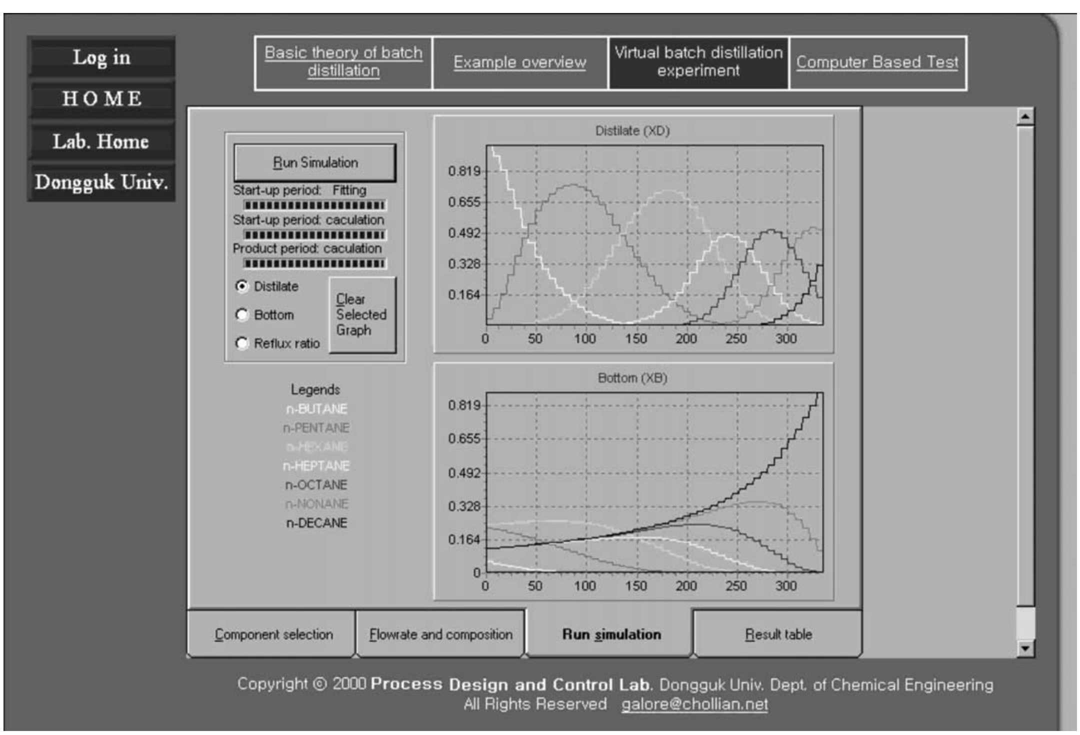

Fig. 10. Run and execution of a lab session.

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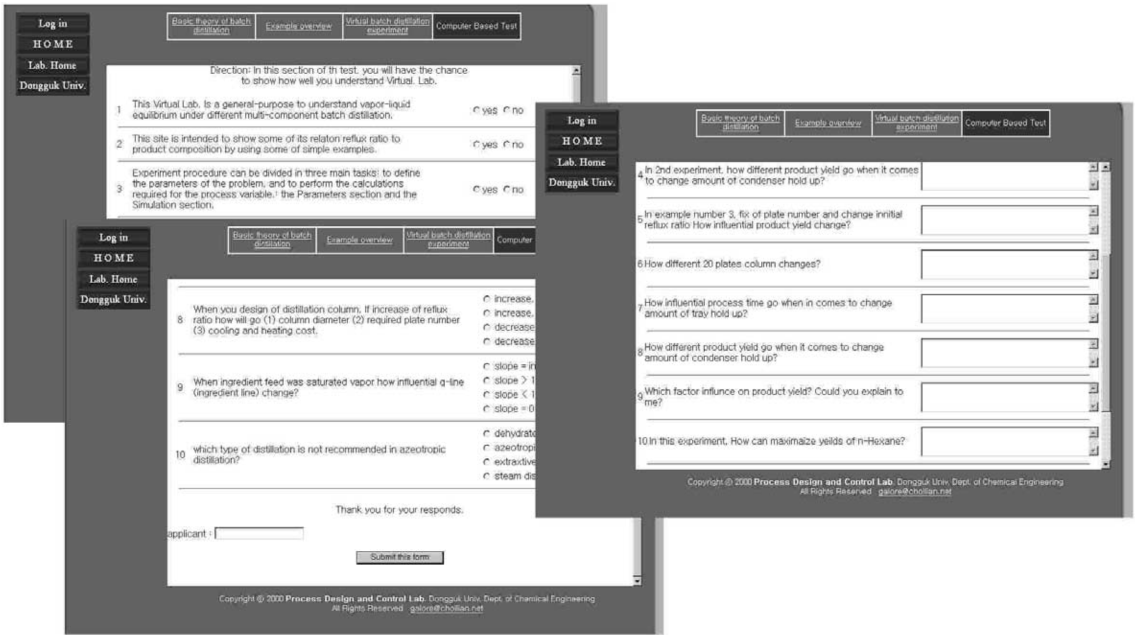

Fig. 11. Various test forms: true/false, multiple choices and short answers.

Table 2
Summary of the survey questionnaire and the result returned from the 15 new users of the system

Very high on	Points received (five points maximum)
Savings in the lab time	4.5
Accessibility: any time, anywhere	4.1
Possibility of acceptance as a substitute of the real lab	3.5
High on	
Achievement of educational objectives	3.3
User environment	3.4
Satisfied on	
Savings in the lab cost	3.2
Easy to use	3
Requested improvements: (% reviewers suggested that point)	
Diverse contents of more labs (80)	
After-lab test questions (30)	
Should be easier to use (20)	

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