AC 2009-1446: A WEB-BASED VIRTUAL LABORATORY FOR WATER RESOURCES ENGINEERING EDUCATION

Steven Burian, University of Utah

Alfred Kalyanapu, University of Utah

Dasch Houdeshel, University of Utah

David Judi, University of Utah

Christine Pomeroy, University of Utah

Web-Based Virtual Laboratory
for Water Resources Engineering Education

Abstract

This paper describes a virtual laboratory website used in water resources engineering courses at the University of Utah. The prototype virtual lab provides access via the Internet to digital video, visualization, an interactive calculator, and a written summary of key lab points. The content available for review is delivered and additional web links are provided to create a bridge from the lab experiment to classroom examples and professional practice. Movies have been created for eight laboratory sessions in an undergraduate Hydraulics course and one session of a graduate Open Channel Flow course. Animated visualizations have been created for two laboratory sessions in the Hydraulics course. A complete virtual lab website has been developed for one lab session of the Hydraulics course. The effectiveness of the content and delivery methods employed was assessed using a quiz and student surveys. The quiz results suggest students given access to the virtual lab components were able to recall key concepts better than those not having access. Feedback through surveys highlighted the benefits of the virtual lab and indicated an area of need relating lab content to classroom examples and professional practice.

Introduction

Traditional experimental-based learning is constrained by several factors. Laboratory resources are expensive, space is limited, and lab sessions often conflict with other student commitments (e.g., courses, work, personal). In addition, traditional on-site laboratory experiments have a short-term exposure. After leaving a traditional lab, students may not be able to easily recall equipment, procedures, or key observations. And it is impossible to review and repeat experimental procedures to investigate concepts. Virtual laboratory environments provide the opportunity for asynchronous, on demand, and repetitive interaction, which may be a potential solution to these challenges, especially during tough economic when resources for traditional lab improvement are at a premium or nonexistent.

Numerous approaches to create a virtual laboratory environment have been introduced in engineering education by (1) permitting lab experiments to be performed remotely[6], (2) providing time flexible lab experiences, (3) providing capture of lab content for later recall, and (4) creating opportunities for lab experiences for impaired students. There have been virtual laboratories created using 3D rendering technologies[1,5], Java[3] and other web-based programming languages, live video, web services[4], integrated digital camera and LabView[6], and multi-media[8].

In civil engineering education, virtual laboratory environments have been developed to serve the geotechnical[2,7], structural, earthquake engineering (http://cee.uiuc.edu/sstl/java/), and materials[4,5] sub-disciplines. The initial literature search uncovered no instances of the use of virtual laboratories focused on water resources engineering.

The literature review and our experience suggest there is also a need to create a better linkage among laboratory concepts, classroom content, and professional practice. For example, end of course student surveys in the undergraduate Hydraulics course at the University of Utah has highlighted the need to specifically improve the linkage of lab experiments to class examples and professional practice. The virtual laboratory concept may be configured to meet this need in addition to facilitating distance education and providing review of laboratory procedures and concepts.

The idea of a virtual lab environment to aid teaching and learning makes sense, but to be effectively integrated into an existing course it must not substantially increase student time commitment to the course. The laboratory core objectives related to data analysis and communications (writing) must remain the focus of the report writing outside of the lab session. A virtual lab environment must be streamlined to provide efficient delivery of content without requiring extensive student time outside the lab.

This paper describes the development and assessment of the components of a virtual laboratory website recently introduced to water resources engineering courses at the University of Utah. The virtual lab components are designed to meet several educational objectives including reinforcing key concepts, stimulating critical thinking, and linking lab experiments to professional practice.

Virtual Laboratory Website Components

The virtual lab website presented in this paper includes digital video of the laboratory procedures with interactive questioning, animated visualizations reinforcing key concepts, and an interactive calculator helping students link the laboratory topic to example and homework problems and to explore "what if scenarios" not studied in the laboratory. The virtual lab website components and prototype have been developed for initial application in two courses at the University of Utah – Hydraulics (an undergraduate required course) and Open Channel Flow (a graduate technical elective). The long-term plan is to build upon the initial development, incorporate student feedback, and eventually extend to other courses in water resources and the broader civil engineering curriculum.

Hydraulics

The undergraduate Hydraulics course at the University of Utah is a junior level required course. The course has a required 1-credit hour laboratory session that meets once per week for 3 hours. Given the large size of the class (~80 students per class on average) and equipment limitations the 3-hour session must be divided into a 1.5 hour session, effectively reducing the number of students in the lab session at a time. The limited lab time available prevents linking lab concepts to class content and professional practice during the session.

The initial development of the virtual lab website for the Hydraulics course focused on the individual components. Short digital video movies were created for eight lab sessions:

- Hydrostatic forces
- Bernoulli theorem
- Orifice and free jet flow

- Friction loss in pipes
- Minor losses in pipes
- Centrifugal pumps
- Weirs
- Hydraulic jumps

The movies were strategically scripted to provide a review of the essential procedures and to link the lab topic to the classroom content. Materials introduced in the classroom were embedded directly into the movies in the form of still shots, equations, and graphics. In addition, queries are presented to encourage critical thinking and to offer potential for using the videos as a remote laboratory experience.

Prototype visualizations were also created for two laboratory sessions: Bernoulli Theorem (Fig. 1) and Centrifugal Pumps (Fig. 2). We focused on these two lab topics because they were serving as the basis for developing the prototype website and for conducting the assessment. We identified the confusing or counterintuitive concepts to visualize in the animations created with Macromedia Flash. The Bernoulli Theorem animation shows water flowing through a tapered pipe that changes the energy distribution illustrating conservation of energy and energy loss in the pipe system. The laboratory objective is to test Bernoulli's theorem in a tapered duct. The visualization clearly illustrates the flow losing energy as it traverses the pipe. The conclusion of the animation is a summary of points to observe in the animation. The animation loops to permit students to watch it several times and view the key points several times. The Centrifugal Pump lab animation illustrates the change in pump capacity in response to adjustments in resistance (head loss introduced to system). There are three visualizations to capture the different pump configurations (series, parallel, single). All animations are short (approximately 1 minute) and packaged such that they are web accessible.

An online calculator was also created to complement the Bernoulli Theorem lab. The calculator presents students with the common problem of a pipe changing diameter along its length. The student enters the pipe sizes and watches the calculator automatically change the system characteristics (pressure, velocity) in two pipe sections. Students may interactively adjust pipe sizes to manipulate the results. The value of the calculator is the ability to conduct "what if" experiments based on the laboratory, experiments encouraged through required discussion points included in the student laboratory report.

The prototype virtual lab website was created for the Bernoulli Theorem lab.

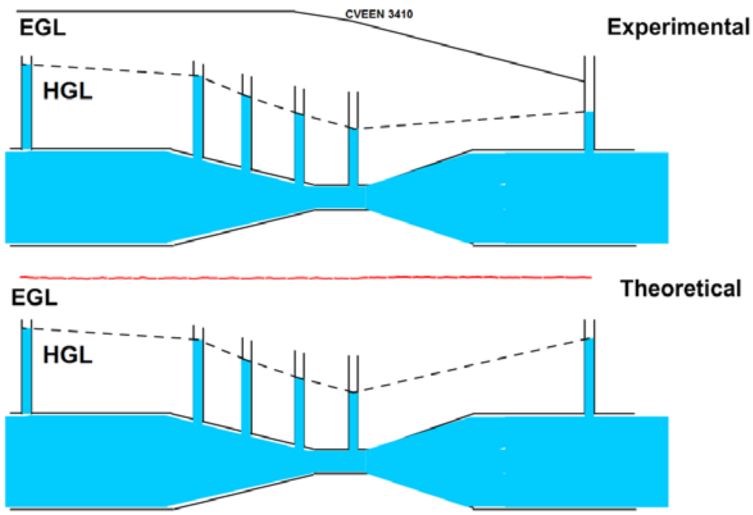

Figure 1. Screen capture of Bernoulli Theorem laboratory experiment visualization.

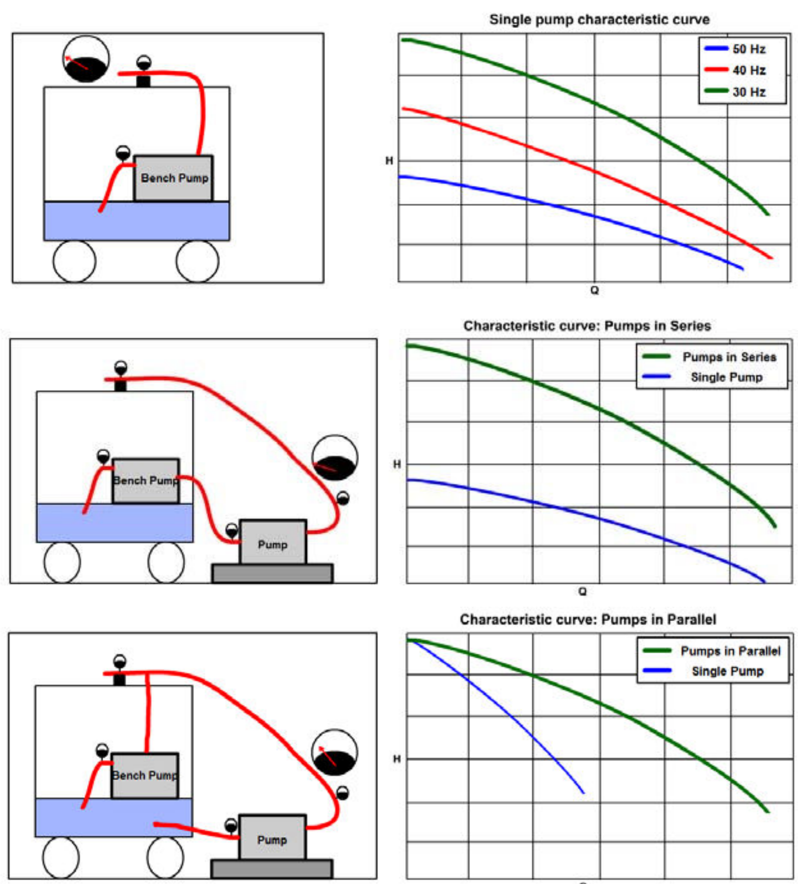

Figure 2. Screen captures of Centrifugal Pump laboratory experiment visualizations (top – single pump, middle – series pump, bottom – parallel pump).

Open Channel Flow

The Open Channel Flow course is an introductory graduate course that may be taken by eligible undergraduate students as a technical elective. Historically at the University of Utah the course has not had a laboratory component. Student feedback through end of course surveys suggested the need to provide clearer explanation of concepts through the use of demonstrations or laboratory experiments. The class is fairly large (approximately 40 students on average) making it challenging to conduct in-depth classroom demonstrations stimulating critical thinking. To meet the need, selected classroom periods were replaced with laboratory experiment sessions. The virtual lab concept is being developed for this course to help integrate the lab sessions with the classroom content and professional practice. One movie was completed to capture the rapidly varied flow experiments working with a hydraulic jump (Fig. 3). The 8-minute digital video incorporated coverage of the procedures and clear linkage to classroom content. The video was scripted in such a way to permit students to remotely "conduct" the experiment by watching the video and being keyed to questions and points important for the lab. Students watching the movie are led through the experimental setup, data collection, and observations and given time to reflect on important points. This approach was used to stimulate critical thinking, but also as the next step in the development of our virtual lab website concept towards a remote laboratory experience. We envision a remote laboratory experience using the virtual lab website if data recording can be incorporated. This is not the focus of this paper, but is a goal of the overall effort.

Resources and funding were not provided to help create the virtual laboratory components or website. This will likely be the case for most professors seeking to implement web-based laboratory content. The effort devoted to developing the resources for the virtual lab and to create the website has been kept as small as possible. Two teaching assistants assigned to the courses for one semester created the movies and animations with a small amount of instructor oversight. The teaching assistants contributed approximately three hours per lab during their normal 15-hr per week assignment. In addition, one student involved with the TA Scholars program at the University of Utah contributed another two hours per week to help refine the resources and conduct the assessment. This amounted to approximately 65 person-hours of teaching assistant effort devoted to develop and implement the preliminary components of the virtual lab and to create the prototype website described in this paper.

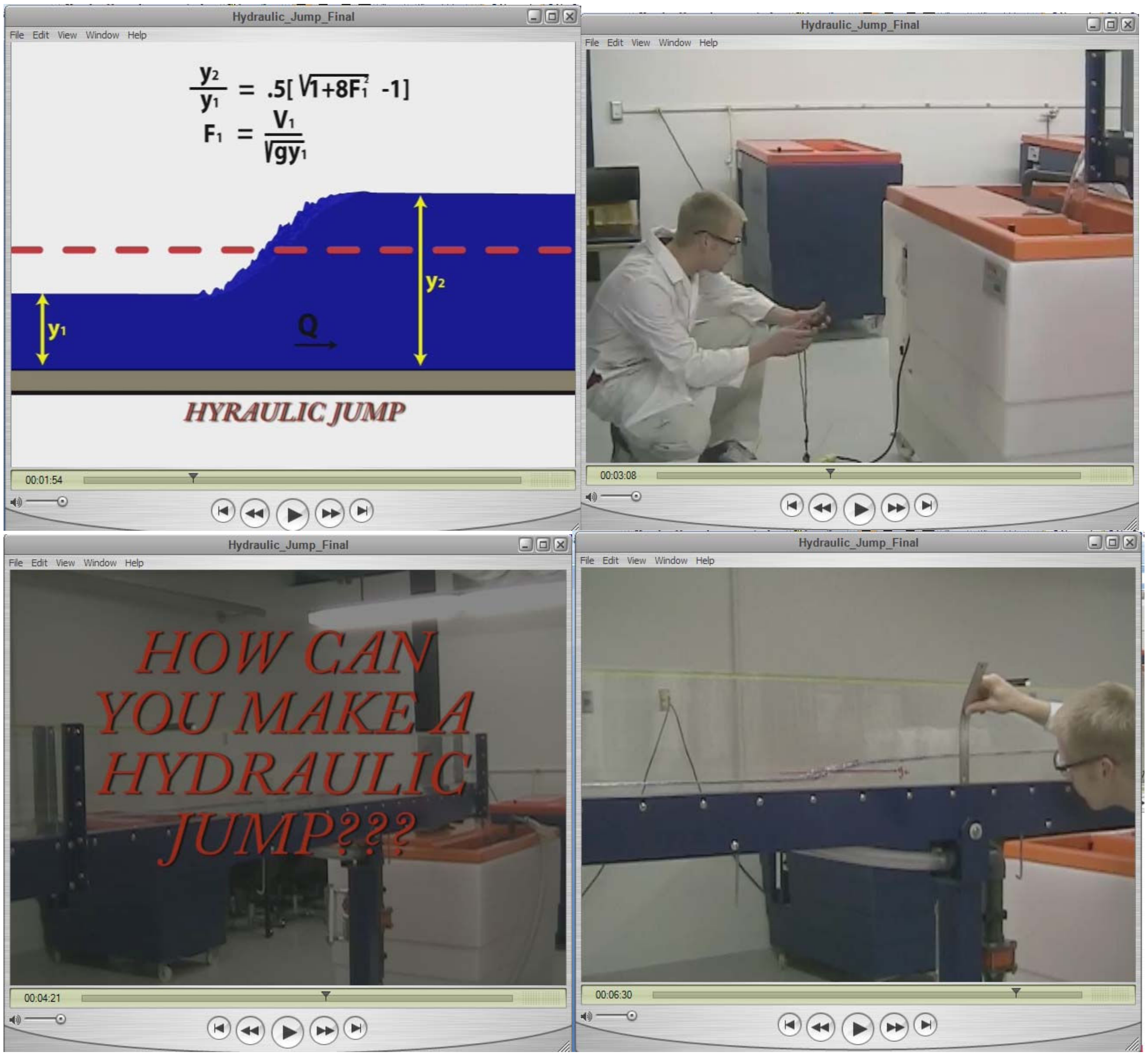

Figure 3. Screen captures of rapidly varied flow inquiry-enabled movie for a graduate open channel flow class.

Assessment

The components of the virtual lab website were developed in 2008 and implemented in the Hydraulics course in the fall 2008 and spring 2009 semesters. The Bernoulli lab was chosen for the introduction of the virtual lab and the assessment of effectiveness. For the Bernoulli Lab, all students experienced the traditional experiment and report writing exercise. Approximately two weeks after the experiment was completed and the report had been submitted and graded, students were notified of an upcoming quiz covering the Bernoulli Lab content. Students were not alerted to the existence of a virtual lab or to the purpose of the quiz being an assessment of the virtual lab components. As far as they knew it was one of the frequent (~ one quiz per week) quizzes they were given in the course. The objective of the quiz was to determine if recall of key concepts could be enhanced by providing access to the virtual lab components. After announcing the quiz, a random sample of students was selected to receive access to the virtual lab web page. A control group of 20 students (59 students in the course) were selected. The control group was sent an email through WebCT reminding them of the quiz and providing a written summary of the key objectives and conclusions of the experiment. One test group of 19 students was sent a similar email reminding them of the quiz and containing a link to the animated visualization summary of the key lab concepts and conclusions. A second test group of 20 students was sent an email reminding them of the quiz and containing a link to the movie. To ensure the random selection was not biased, we adjusted the three sample groups by exchanging eleven students to make the average, range, and standard deviation of grades on the first exam approximately the same for the three groups. The objective behind using three groups of students was to first compare the quiz performance of students that had access to the virtual lab components versus students that did not have access, and second to determine if there was a difference in performance for students that viewed the movie versus students that viewed the animation.

One week after announcing the quiz and providing student access to the virtual lab movie and visualization the quiz was administered to the 59 students in the class. The quiz was comprised of four questions. One required students to describe a concept, another asked them to answer a question interpreting the results, a third asked them to sketch what would happen if conditions not tested in the laboratory were recreated, and a fourth asked if they had viewed the movie or visualization. The final question was included to identify students that may have been alerted to the virtual lab website content by other students and to identify those notified that did not access the resources. Those that did not access the resources were included in the results as if they were not notified.

The quiz results were interesting. A small number of students missed the class and did not take the quiz. Somewhat surprisingly no sharing of virtual lab website existence was reported by the students. And of the 39 students notified of the virtual lab website content and took the quiz, all accessed it. The tally of correct questions answered by the three groups (not notified, movie access only, visualization access only) is shown in Fig. 4. The first observation of the results is the improvement on the quiz if students accessed the virtual lab website resources. More than 40% of the students accessing content (digital video or visualization) provided correct responses to the three questions, while less than 20% students of the students that did not access the resources scored perfect quizzes. Students that did not access the resources also had lower frequency of 2 out of 3 questions answered correctly (0 compared with ~20%). Some students that did not access the resources scored 0 out 3, while all students that accessed the resources answered at least 1 question correctly.

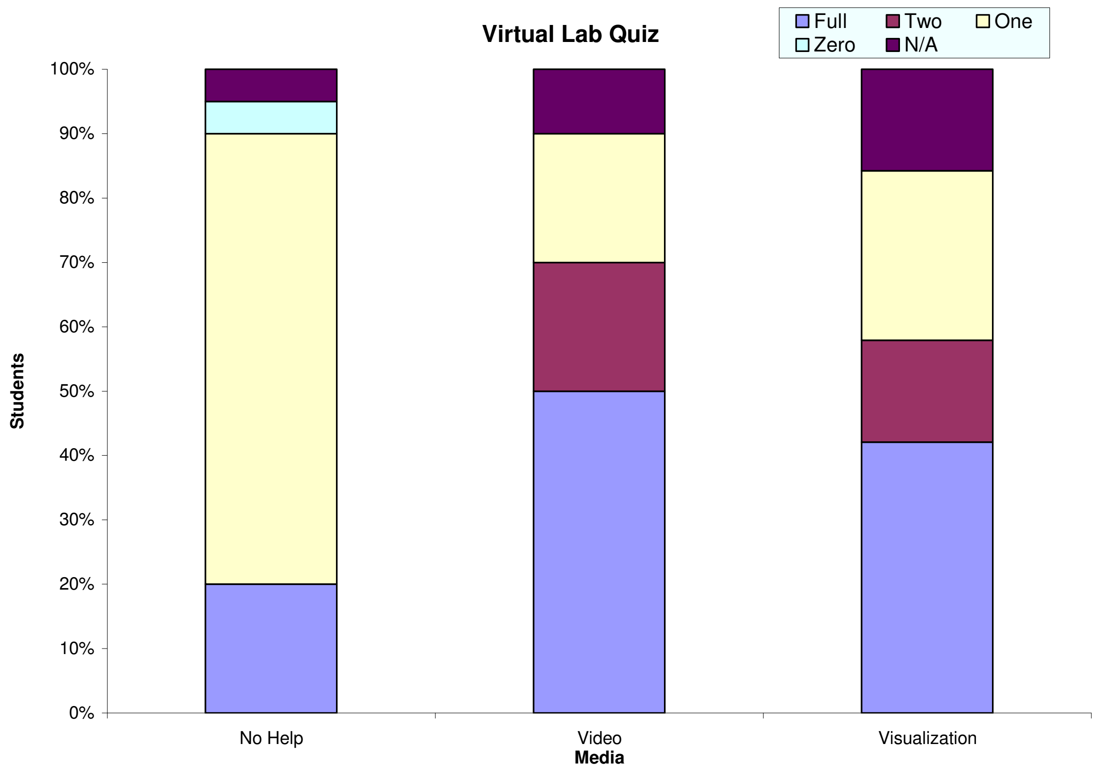

Figure 4. Results of quiz assessing student learning for the three groups of students (those receiving no additional help, those viewing a video, and those viewing a visualization). The number of correct responses is shown and N/A indicates students that did not complete the quiz.

Another observation of the quiz results is the similar performance of the students exposed to digital video and visualization. Both seemed equally as effective, although the digital video students performed slightly better.

After the quiz was administered the instructor explained the virtual lab website components and made clear that the quiz would not count for credit. All students were then invited to view all components of the virtual lab website. From that point on the instructor posted virtual lab website resources for subsequent labs immediately after each lab session was completed. Surveys were distributed to the students after the Bernoulli lab quiz to collect their feedback regarding the benefits of the virtual lab website resources and the potential enhancements to the resources. In general, most students felt the resources were concise summaries useful for their learning. The key suggestion was to include greater linkage of the laboratory concepts to classroom examples and to professional practice, an area of current attention as the next step in the development of the virtual lab at the University of Utah.

Conclusion

This paper described the development of resources for a virtual laboratory website for use in water resources engineering courses at the University of Utah. The virtual lab concept is being developed to facilitate asynchronous and remote laboratory experiences, to help students retain and review content introduced in the laboratory experiment, and to help students relate laboratory concepts to classroom content and professional practice. Movies, visualizations, an interactive calculator, and references and links to the classroom content and professional practice were created for the lab sessions in the undergraduate Hydraulics and graduate Open Channel Flow courses. The content was packaged in a prototype virtual lab website for one experiment in the undergraduate Hydraulics course. Digital video resources were developed for seven Hydraulics lab experiments and one experiment in the Open Channel Flow course. Animated visualizations were developed for two Hydraulics labs.

The initial assessment of the virtual lab components indicated student recall and understanding of concepts was enhanced if they were given access to the concise summaries provided by the virtual lab website. Survey results suggested students appreciated the concise, clear summaries and found them useful for review of the key concepts. Several suggestions were also provided (and continue to be provided) to improve the resources and the virtual lab website. Overall, the development effort presented in this paper has been well within the normal teaching assistant expectations for an undergraduate course.

Although an initial set of virtual lab resources have been developed, much more work is needed. More visualizations are needed, more interactive components are needed, and clearer linkages of lab concepts to classroom examples and professional practice is needed. These will be areas of continued attention for future teaching assistants assigned to the water resources engineering courses at the University of Utah.

Acknowledgments

Special thanks are extended to Nicholas Augustus for his help acting in the movies and to the students in the fall 2008 and spring 2009 Hydraulics courses at the University of Utah for participating in the assessment and providing useful suggestions for improvement.

Bibliography

1. Adamo-Villani, N., Richardson, J., Carpenter, E., and Moore, G. (2006). "A photorealistic 3d virtual laboratory for undergraduate instruction in microcontroller technology." *Proceedings of the International Conference on Computer Graphics and Interactive Techniques*.
2. Budhu, M. (2001). "Enhancing geotechnical education using interactive multimedia simulations." *Proceedings of the Eighth International Conference on Civil and Structural Engineering Computing*, 19-21 Sept. 2001, Vienna, Austria, 257-258.
3. Goa, Y., Yang, G., Spencer, B.F. Jr., and Lee, G.C. (2008). *Java powered virtual laboratories for earthquake engineering education*. Downloaded from http://cee.uiuc.edu/sstl/java/.

4. Koenders, E.A.B., Schlangen, E., Dado, E. (2008). "Virtual testing of compressive strength of concrete." *Proceedings of the 4th International Structural Engineering and Construction Conference*, ISEC-4 – Innovations in Structural Engineering and Construction, 613-618,
5. Koenders, E.A.B. and Dado, E. (2004). "A virtual lab for composite materials." Proceedings, *2004 ASME International Mechanical Engineering Congress and Exposition*, IMECE, 13-19 Nov 2004, Anaheim, CA, 53-58.
6. Steidley, C. and Bachnak, R. (2005). "Developing a prototype virtual laboratory for distance science and engineering education." *Proceedings of the Information Technology Based Higher Education and Training Conference*.
7. Wyatt, T.R., Arduino, P., and Macari, E.J. (2000). "Assessment of a virtual laboratory for geotechnical engineering." *Computers in Education Journal*, 10(2), 27-35.
8. Yarbrough, S.E. and Gilbert, R.B. (1999). "Development, implementation, and preliminary assessment of virtual laboratory." *Journal of Professional Issues in Engineering Education and Practice*, 125(4), 147-151.