Web-Based Virtual Torsion Laboratory

PEEYUSH BHARGAVA,[1] JOHN ANTONAKAKIS,[1]
CHRISTINE CUNNINGHAM,[2] ALAN T. ZEHNDER[1]

[1]*Department of Theoretical and Applied Mechanics, Cornell University, Ithaca, New York 14853*

[2]*Research, Museum of Science, Science Park, Boston, Massachusetts 02114*

Received 14 October 2004; accepted 8 June 2005

ABSTRACT: An emerging change across the science, technology, engineering, and mathematics curriculum is the implementation of online, or virtual laboratories as supplements or replacements to both homework assignments and laboratory exercises. To test the effectiveness of such labs, a web-based virtual laboratory on the topic of torsion of engineered and biological materials was developed. The lab contains extensive data sets, videos of experiments, narrated presentations on lab practice and theory and assignments. Flexibility of use is built into the lab by providing the capability for the web-pages to be tailored to the needs of a particular institution. The lab was implemented and evaluated in a standard, sophomore level statics, and strength of materials course. Results of the evaluation show that the virtual lab is clear, helped students with their understanding of torsion concepts, and offered a number of benefits. However students also rated hands-on labs to be more fun and more interesting. © 2006 Wiley Periodicals, Inc. Comput Appl Eng Educ 14: 1–8, 2006; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20061

Keywords: mechanics of materials; strength of materials; evaluation; biological materials; torsional experimental data

INTRODUCTION

Hands-on laboratory experience is a key element in engineering and technology education. Laboratory sessions provide examples that students can see, feel, and hear, and provide an alternate mode of learning to those for whom reading the textbook or hearing lecture is insufficient. Labs are also used to introduce data analysis, to hone report writing, to find empirical correlations between experimental variables and data, and to validate theory. However, hands-on laboratories are not always an option due to space, cost, and time constraints. Many college students work part- or full-time jobs and/or have families, making it difficult to spend great amounts of time in lab classes during working hours. Providing sophisticated, in-person physical laboratories is nearly impossible in distance learning courses. Finally, some of the most interesting laboratory tests require instruments that

Correspondence to A. T. Zehnder (atz2@cornell.edu).

are prohibitively expensive for most colleges; to observe these tests, students may need to interact with the experiment in another way. Thus alternate means of providing laboratory experience and of making labs accessible at any time and from any location are desirable.

One solution is virtual labs [1]. These can be used in many ways: to replace physical labs, to help students prepare for a physical lab, or to expand upon a physical lab by providing data that students are unable to collect themselves. Virtual labs could also be used to supplement or replace pencil and paper homework assignments and as demonstrations and starting points for in-class discussions. For example, a simple in-class or homework exercise might ask students to explain the physical features of brittle and ductile fracture using the virtual lab described herein. Virtual labs can be classified broadly into three categories: (1) Simulation based virtual labs provide a software mockup of an experiment, sometimes including controls, meters, and other ''instruments'' to emulate the physical lab [2–4]. By changing parameters of the simulation, students can observe changes to the system. (2) Remote but physical labs allow students to view, control and acquire data from a physical experiment through a web-based interface [5–7]. (3) Recorded experiments allow students to view actual experiments and work with real data [8–10]. As these three concepts for virtual labs are developed, tested, used, and refined, best practices will emerge and we may see a confluence of ideas with new labs that combine aspects of the virtual and physical labs [11,12].

The few research results concerning the design and effectiveness of virtual labs generally show positive results. Budhu [13] examined whether ''modern simulation and communication technologies enhance delivery, learning, and retention'' and concluded that they were effective, especially for difficult topics. Others have shown that virtual laboratory experiences can reinforce concepts from lecture material, convey practical issues associated with actual experiments [14,15] and illustrate applications absent from textbooks [16]. In tests comparing students who performed physical labs to those who performed virtual labs, Hall [17] found that ''There were no statistically significant differences in posttest scores between the groups of students...'' General principles for successful virtual labs can be gleaned from previous research. [5,18,19]. These papers point out that the labs must have a high visual content and that students must be able to run the labs with a regular web-browser. Ogot et al. [5] suggest that an integrated environment must also be provided. Budhu [18] suggests that virtual labs be based on methods that include ''gaining attention, informing students of the objective, stimulating recall of prior knowledge, presenting the stimulus, providing learning guidance, eliciting performance, providing feedback, accessing performance, enhancing retention, and transfer of learning.''

OVERVIEW OF THE VIRTUAL TORSION LAB

The web-based virtual lab described here is of category (3), recorded experiments, with data and video. We chose the topic, torsion of shafts of engineered and biological materials, because it is one for which we had no physical, student lab equipment, hence the virtual lab expands our lab capabilities. The lab is designed for use in classes on mechanics of materials but could also be used for upper level solid mechanics courses or for courses focusing on biological materials. Contents include: (a) narrated ''chalk talks'' on basic theory, test equipment, and data reduction procedures, (b) ''virtual experiments,'' videos of the tests, including live plotting of twist-torque data, (c) extensive sets of data for engineered and biological materials, and (d) a lab manual with suggested exercises and questions. Reference materials, graphing software, an on-line quiz and a discussion board are also provided. The lab is designed to be modular and to be useful for labs, homework, in-class demonstrations and self-study. From the instructor's page, Figure 1, instructors choose elements that suit their own curriculum to create a custom starting page. Students see only the elements chosen by the instructor, allowing the lab to be adapted for use by students from high school to graduate school.

At the beginning of physical labs at Cornell, the instructor generally introduces the experiment, the equipment, procedures, and goals of the lab with a brief chalk talk. This is emulated in the virtual lab by a series of professionally recorded and edited narrated presentations, ''chalk talks,'' that review basic torsion theory, test equipment, and procedures, data reduction for engineered materials, and data reduction for biological materials. The chalk talks were written in PowerPoint and then captured as image files for incorporation into the website. All of the talks include text for hearing impaired students and all are available in .pdf format for easy printing. An example is shown in Figure 2, which describes the functioning of the rotary servo-hydraulic actuator.

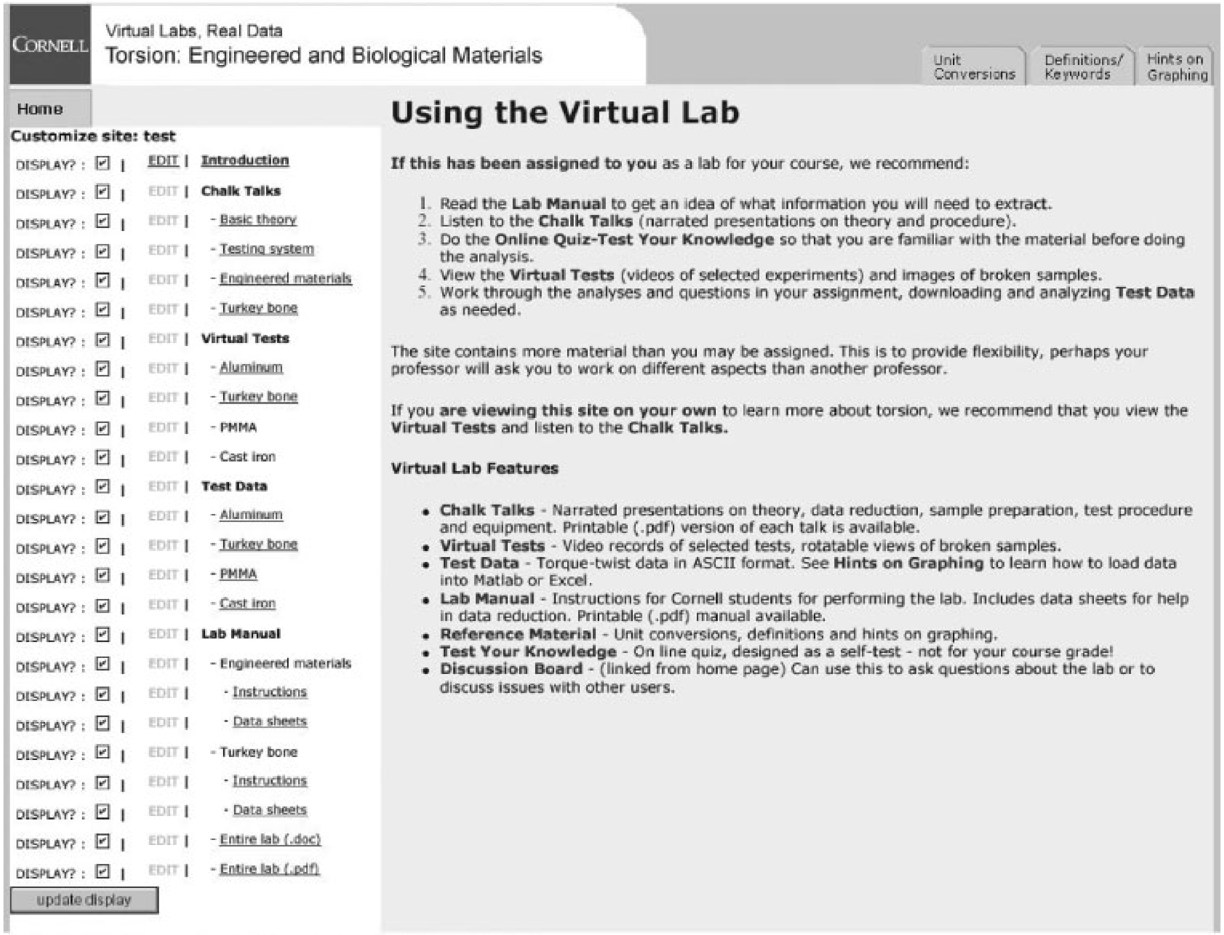


Figure 1 Password protected, instructor customizable information page used to create a custom wed site so that students at a particular institution see only the features selected by their instructor. Student page only, with all options selected, may be viewed at http://instruct1.cit.cornell.edu/courses/virtual_lab/intro.shtml.

The heading ‘‘virtual tests’’ contains videos of actual experiments. These include audio and were professionally recorded, then converted to QuickTime movies. As the test is played back, the torque-twist curve is plotted, emulating a physical experiment in which the data would be plotted in real-time. A sample frame and graph from the virtual experiment on the Turkey bone are shown in Figure 3. Also included are rotatable images of the fractured samples, allowing students to examine the broken pieces much in the same way they would in physical laboratories.

Data from real experiments with aluminum, PMMA (Plexiglas), cast iron and wet and dry turkey tibiotarsus bones are provided under the ‘‘test data’’ heading. An example of test data and images of broken samples is shown in Figure 4. Several repeats of each experiment are provided to allow instructors to ask students to examine statistical variations in data. This is particularly important when dealing with biological materials. Results provided include time, torque, twist-angle, force, and elongation, both in plain text form and spreadsheet (Excel) format. Our research showed that for many students, graphing, and analyzing the data took considerable effort. Thus a Matlab program for plotting and fitting of data, (e.g., to determine the elastic modulus or yield stress of a material) is provided to the students. However, should an instructor wish to have students learn and practice using software for data analysis, the instructor could choose to not display the link to the Matlab program. The Excel data include plots of the data and a utility for drawing the offset line to determine yield stress.

Under the heading ‘‘lab manuals’’ data sheets and suggested exercises for students are found. This section was tailored to Cornell students; however instructors at other schools can write their own manuals and upload them through the instructor page

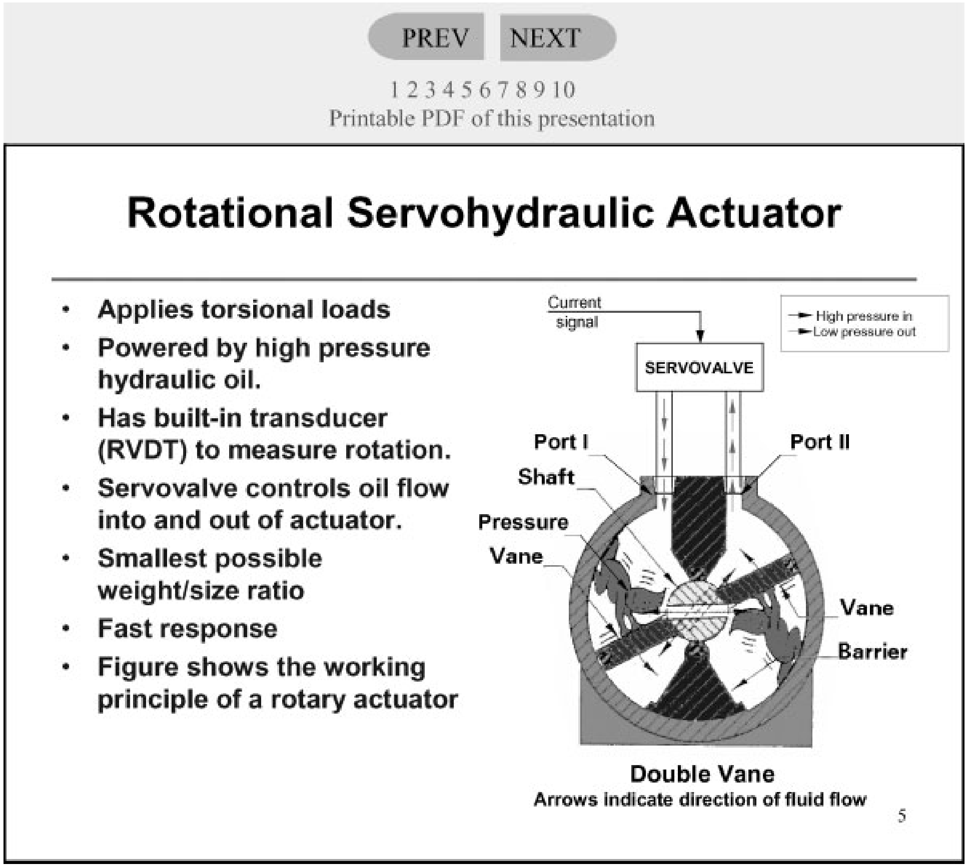


Figure 2 Example page from narrated chalk talk. Text of narration and printable file containing all slides and text is available in .pdf form.

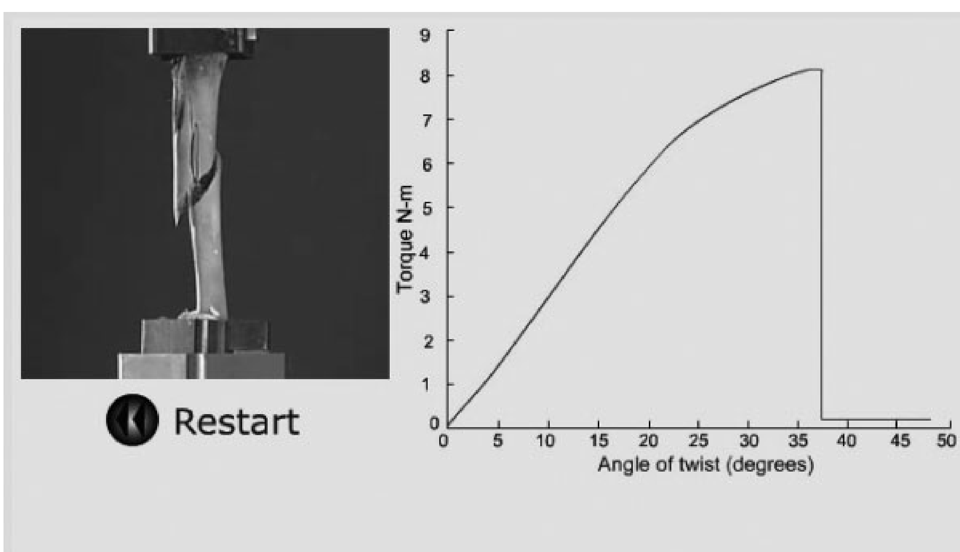
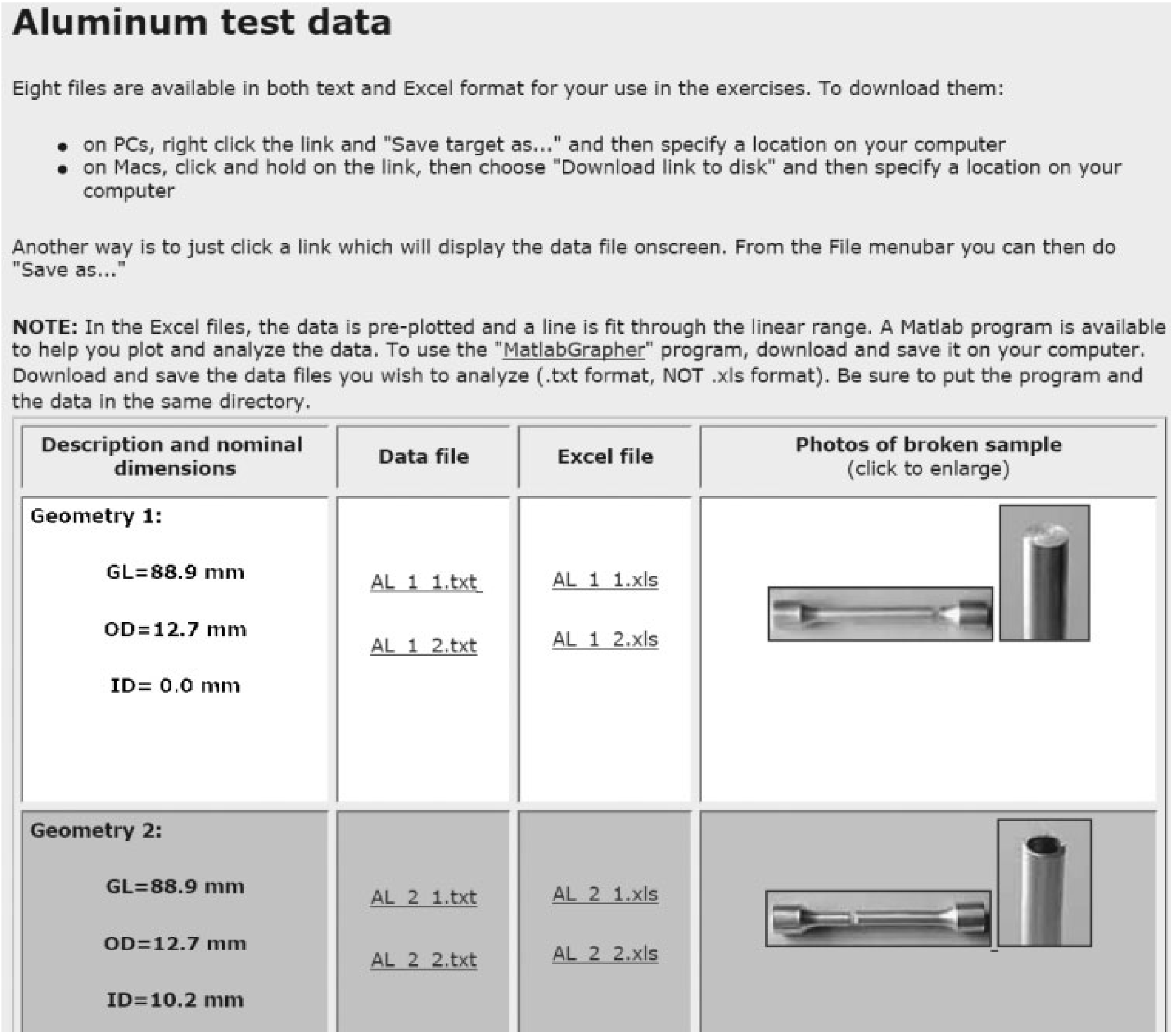


Figure 3 Example of virtual test of torsion of a turkey tibiotarsus bone. Results are plotted live as video of test is played.



Aluminum test data

Eight files are available in both text and Excel format for your use in the exercises. To download them:

- on PCs, right click the link and "Save target as..." and then specify a location on your computer
- on Macs, click and hold on the link, then choose "Download link to disk" and then specify a location on your computer

Another way is to just click a link which will display the data file onscreen. From the File menubar you can then do "Save as..."

NOTE: In the Excel files, the data is pre-plotted and a line is fit through the linear range. A Matlab program is available to help you plot and analyze the data. To use the "MatlabGrapher" program, download and save it on your computer. Download and save the data files you wish to analyze (.txt format, NOT .xls format). Be sure to put the program and the data in the same directory.

Description and nominal dimensions	Data file	Excel file	Photos of broken sample (click to enlarge)
Geometry 1: GL=88.9 mm OD=12.7 mm ID= 0.0 mm	AL_1_1.txt AL_1_2.txt	AL_1_1.xls AL_1_2.xls	
Geometry 2: GL=88.9 mm OD=12.7 mm ID=10.2 mm	AL_2_1.txt AL_2_2.txt	AL_2_1.xls AL_2_2.xls	

Figure 4 Sample listing of test data. Included are results in spreadsheet and plain text format. The spreadsheet results include graphing tools. A Matlab program is available to assist the analysis of the plain text format data. Photos of the broken sample are also provided.

to replace those provided. A link in the reference section provides guidelines on the procedures for importing, plotting, and analyzing the data. Other reference materials include the definition of terms, and relevant unit conversions.

The virtual lab is a cross-platform application written in PHP, a widely used, general-purpose scripting language that is especially suited for Web development, can be embedded into HTML and does not require specialized database software. Modules covering other topics could easily be added because the site is based on reusable templates and a text-based hierarchical representation, so that the overall storage requirements are much less than would normally be required of static web sites this size. It can scale to accommodate an arbitrary number of modules.

USE AND EVALUATION OF THE LAB

The virtual torsion lab was used in the Fall and Spring 2002 semesters at Cornell, replacing one of four physical labs in a sophomore statics and mechanics of materials course taken by about 100 students per semester. Students were given 2 weeks to complete the lab. The assignment entailed analyzing the data provided to determine yield and fracture strengths, to calculate shear moduli, and to deduce relationships between stiffness, strength, and dimensions of the test samples. Students wrote and submitted a 10-page report. The questions, types of analyses and length of report were similar to the three physical labs that the students performed. The lab was also used by small numbers of students at Tompkins Cortland Community College (a 2-year college) and at The California Institute of Technology.

To assess the effectiveness of the torsion lab, a web-based evaluation survey was integrated as part of the online lab. To encourage completion of the evaluation students were given 1 point on their final grade point average if they completed the survey; 193 students did so.

Analysis of the results shows that of the reference material, only the hints on graphing were used by most students. Only one student used the discussion board, and few took advantage of the online, ‘‘Test Your Knowledge’’ quiz.

Students were asked to rate several aspects of the lab. The results in Table 1 show that the virtual lab was easier to use than the physical labs, that it was easier to understand the concepts, but that it was somewhat less interesting, less fun and more time consuming than the physical labs. Over 80% of the students agreed that it was clear how to navigate through the site. Only 10% of students reported technical problems with the site.

If given a choice between a virtual and a physical lab, 65.0% of students would prefer doing labwork, 19.2% online, and 14.5% do not have a preference. Students enjoy having the hands-on experience (72 students mentioned this) and being able to see the experiments in person (44 students mentioned this). The other common reason that 25 students gave for preferring physical labs is a teaching assistant or other people are present who can answer questions.

The students who preferred the online experience cited a few reasons. The most common one (25 students) is that it is more convenient, you can do it when and where you want to, and at your own pace. They also thought that the online lab was more clearly presented than physical labs and enjoyed knowing that they had more accurate data. A few students mentioned that they liked not having to spend time setting up and performing the experiments and a few others indicated that the virtual lab allowed them to focus more on the theory and the data. ‘‘The quality of the actual experiment is much higher than we have ever done in a 1.5 hr lab block. Better simulation of research.’’ ‘‘Less time consuming, able to go back and redo experiment as many times as I want, able to go through slides multiple times.’’

Suggestions for improving the lab included: ‘‘making the lab shorter, with less number crunching, improving the online videos, more engaging voices on the narrations and include an FAQ section.’’

CONCLUSIONS AND RECOMMENDATIONS

Virtual labs offer several distinct advantages over real labs. Most notably, virtual labs reduce equipment needs, and thus cost, by providing ‘‘virtual access’’ to equipment and accompanying materials. In addition, virtual labs are available to students at anytime, from any place. They also offer more information to students than can be covered in a single laboratory period. Students can navigate the website at their own pace, speeding through familiar material and more carefully exploring difficult or interesting sections. As the experiments have been expertly performed, students have more confidence in the data than that from some traditional labs. The clarity and quality of explanations for the virtual lab were highly rated, suggesting that well crafted virtual labs are effective for teaching mechanics concepts and theory. A striking outcome is the strong student preference for physical laboratories. This suggests that in schools where virtual and physical labs are both options the physical labs may be preferred. Proper placement of virtual labs in the curriculum is critical to their success. Replacing an interesting physical lab is probably not a good idea, but replacing static, textbook homework assignments with a more

Table 1 Compared to Other Physical Labs You Have Conducted This Year in This Course, How Would You Rate the Virtual Torsion Lab on the Following Scales? (Values Are Percentages)

	Much	Moderately	Slightly	Neutral	Slightly	Moderately	Much	
Easier to use	13.3	26.1	3.8	20.7	14.8	7.9	3.4	More difficult to use
Easier to understand the concepts	12.8	20.7	18.7	22.7	16.7	7.9	0.5	More difficult to understand the concepts
Less interesting	8.4	14.3	24.6	29.1	12.8	6.9	3.9	More interesting
Less time consuming	7.9	10.8	17.7	20.2	19.7	10.3	13.3	More time consuming
Less fun	12.8	13.8	24.1	27.1	9.9	8.9	3.4	More fun

visual and dynamic virtual lab would help to engage the students and to allow them to explore some of the concepts and principal results of the topic at hand.

ACKNOWLEDGMENTS

The support of the National Science Foundation, Division of Undergraduate Education (DUE), CCLI program, through award DUE-01227434 is gratefully acknowledged. We would also like to acknowledge valuable discussions with Prof. Elliot Eisenberg of the Pennsylvania State University at Hazleton and the contribution of Michael Tolomeo and his colleagues at the Cornell University Academic Technology Center who did most of the web-programming and media recording and editing.

REFERENCES

[1] M. Mannix, The virtues of virtual labs, prism online, September 2000, teaching toolbox. Available: http://www.prism-magazine.org/sept00/html/toolbox.cfm

[2] C. E. Hailey and D. E. Hailey, Evaluation of instructional design of computer-based modules for a manufacturing processes laboratory, J Eng Educ 89 (2000), 345–352.

[3] M. E. Haque, Web-based visualization techniques for structural design education, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002. Available: http://www.asee.org/conferences/proceedings/search.cfm

[4] C. C. Ngo, M. J.-F. Voon, and F. C. Lai, A web-based measurement lab for thermal sciences, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[5] M. Ogot, G. Elliott, and N. Glumac, An assessment of in-person and remotely operated laboratories, J Eng Educ 92 (2003), 57–64.

[6] M. Ogot, G. Elliott, and N. Glumac, Hands-on laboratory experience via remote control: Jet thrust laboratory Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[7] M. Naghedolfeizi, S. Arora, and S. Garcia, Survey of LabVIEW technologies for building web/internet-enabled experimental setups, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[8] L. R. Chevalier, J. N. Craddock, P. C. Riley, and B. J. Trunk, Interactive multimedia labware for strength of materials laboratory, Comput Appl Eng Educ 8 (2000), 31–37.

[9] P. Bhargava, C. Cunningham, M. Tolomeo, and A. T. Zehnder, Virtual labs, real data for statics and mechanics of materials, Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, Nashville, Tennessee, June 22–25, 2003.

[10] A. R. Kukreti, M. Zaman, K. Gramoll, and J.-H. Lee, Virtual laboratory modules for undergraduate strength of materials course, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[11] D. G. Alexander and R. E. Smelser, Delivering an engineering laboratory course using the internet, the post office and a campus visit, J Eng Educ 92 (2003), 79–84.

[12] E. C. Eckhoff, V. M. Eller, S. E. Watkins, and R. H. Hall, Interactive virtual laboratory for experience with a smart bridge test, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[13] M. Budhu, Enhancing instruction using interactive multimedia simulations, Simulation 76 (2001), 222–231.

[14] M. E. Marias Gracia, V. M. Cazared, and E. E. Ramos, A virtual laboratory for introductory electrical engineering courses to increase the student performance, Proceedings of the ASEE/IEEE Frontiers in Education Conference, October 2001.

[15] S. E. Yarbrough and R. Gilbert, Development, implementation, and preliminary assessment of virtual laboratory, J Prof Issues Eng Educ Pract 125 No 4 (1999), 147–151.

[16] S. Spanias, S. Urban, A. Constantinou, M. Tampi, A. Clausen, X. Zhang, J. Foutz, and G. Stylianou, Development and evaluation of a web-based signal and speech, Processing laboratory for distance learning, 2000 IEEE International Conference on Acoustics, Speech and Signal Processing, Vol. 6, June 2000.

[17] T. M. Hall Jr. EET laboratory courses: From the classroom to the web–from research to practice, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montréal, Quebec, Canada, June 16–19, 2002.

[18] M. Budhu, Virtual Laboratories for Engineering Education. Proceedings of the International Conference of Engineering Education, Manchester, UK, August 18–21, 2002.

[19] D. Gillet, et al., Hand-on laboratory experiments in flexible and distance learning, J Eng Educ 90 (2001), 187–191.

BIOGRAPHIES

Alan Zehnder received his PhD from Caltech in 1987 and his BS from the University of California at Berkeley in 1982. He joined the Cornell faculty in 1988, where he is an experimentalist with interests in fracture and thermomechanical coupling. He was a visiting professor at Caltech in 1996−1997. In the summer of 1998 he was a senior faculty fellow at the Naval Surface Warfare Center, Carderock, Maryland. He was a visiting professor at the Technical University of Vienna in 2004. He was awarded the 1988 Rudolf Kingslake Medal and Prize from the Society of Photo-Optical Instrumentation Engineers.

Christine Cunningham works as the vice president of research at the Museum of Science, Boston. In her work, she oversees research and evaluation efforts related to learning and teaching in the museum and in K−12 classrooms; the Engineering is Elementary: Engineering and Technology Lessons for Children project; and a number of teacher professional development programs. Her projects focus on making science and engineering more accessible to marginalized populations, especially women, underrepresented minorities, and people with disabilities. Christine received a joint BA and MA in biology from Yale University and a PhD in science education from Cornell University.

John Antonakakis was born in Hanover, New Hampshire. At age 6, his family moved to Kalamata, Greece, where he attended elementary and high school. He moved back to the United States to study at SUNY Binghamton, where he earned a BS in mechanical engineering. He earned an MS from the Department of Theoretical and Applied Mechanics at Cornell University in 2005, with an emphasis on experimental mechanics. In 2005 he joined General Electric as a performance engineer. His main focus is on evaluating the performance of steam turbines in large fossil fuel power plants and of wind turbines in wind farms around the world.

Peeyush Bhargava received his BTech in mechanical engineering from Indian Institute of Technology, Roorkee (India), in 2001. He is currently working towards his PhD in the field of solid mechanics in Department of Theoretical and Applied Mechanics at Cornell University under Professor Zehnder. His research interests include solid mechanics, experimental mechanics, and composites.