Virtual Labs, Real Data for Statics and Mechanics of Materials

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Introduction

Hands-on laboratory experience is a key element in learning the concepts of engineering mechanics. 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, report writing, finding empirical correlations between experimental variables and data, and to validate theory.

We are strong proponents on hands-on laboratories; they must never be eliminated from engineering education, however, hands-on laboratories are not always an option due to space, cost and time constraints. Thus other means of providing laboratory like experience are often desirable. There are currently a number of projects to develop virtual laboratories. These can be classified broadly into three categories. (1) Simulation based virtual labs that provide a software mockup of an experiment, sometimes including controls, meters and such to emulate the physical lab [1]. By changing parameters of the simulation, students can observe changes to the system. (2) Remote but physical labs in which students view, control and acquire data from a physical experiment through a web-based interface [2]. (3) Recorded experiments where students can view actual experiments and work with real data [3]. As these various concepts for virtual labs are built, tested and refined, best practices will emerge and we may see a confluence of these ideas into new virtual labs that combine aspects of the categories above with physical labs [4].

The virtual lab we are developing is of category (3), recorded data and videos of experiments. Our lab focuses on torsion of shafts of engineered and biological materials.

Project Description

The lab is designed for use in classes on mechanics of materials. In this proof of concept stage of the project we are focusing on torsion as this was the one topic for which we had no physical lab equipment available to students at Cornell. The lab is web-based and consists of (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, and (d) a lab manual with suggested exercises and questions. An on-line quiz and a discussion board are also provided. The instructions page is shown in Figure 1. The lab is designed to be modular so that instructors can pick and choose from elements that suit their own curriculum, perhaps writing their own manual to direct students to specific aspects of the lab and to specific tasks and so that additional material can be readily added.

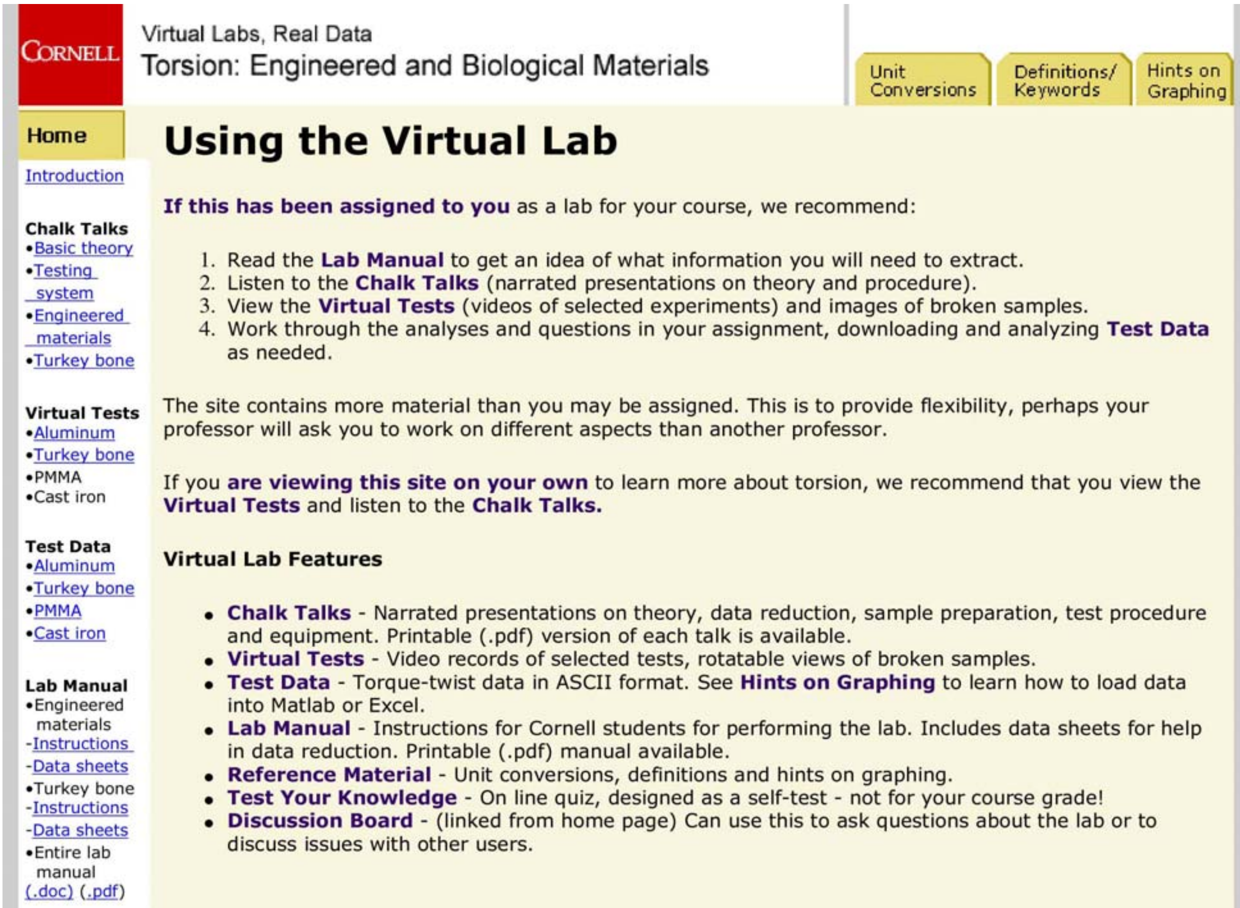


Figure 1, Instructions on using the web-based virtual lab. Students can select from different pages on left hand menu bar. Reference material on tabs in upper right open in separate window. http://instruct1.cit.cornell.edu/Courses/virtual_lab/index.html.

At the beginning of physical labs at Cornell, the instructor generally gives the students a brief chalk talk introducing the experiment, the equipment, procedures and goals of the lab. This is emulated in the virtual lab by a series of narrated presentations, herein called "chalk talks" on 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 chalk talks are also available in .pdf form for printing. The narrations were professionally recorded and edited. Text of the narrations is shown at the bottom of the presentations. An example is shown in Figure 2, where an example of the shear failure of ductile materials is presented.

Under the heading "virtual tests" in Figure 1 we have 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.

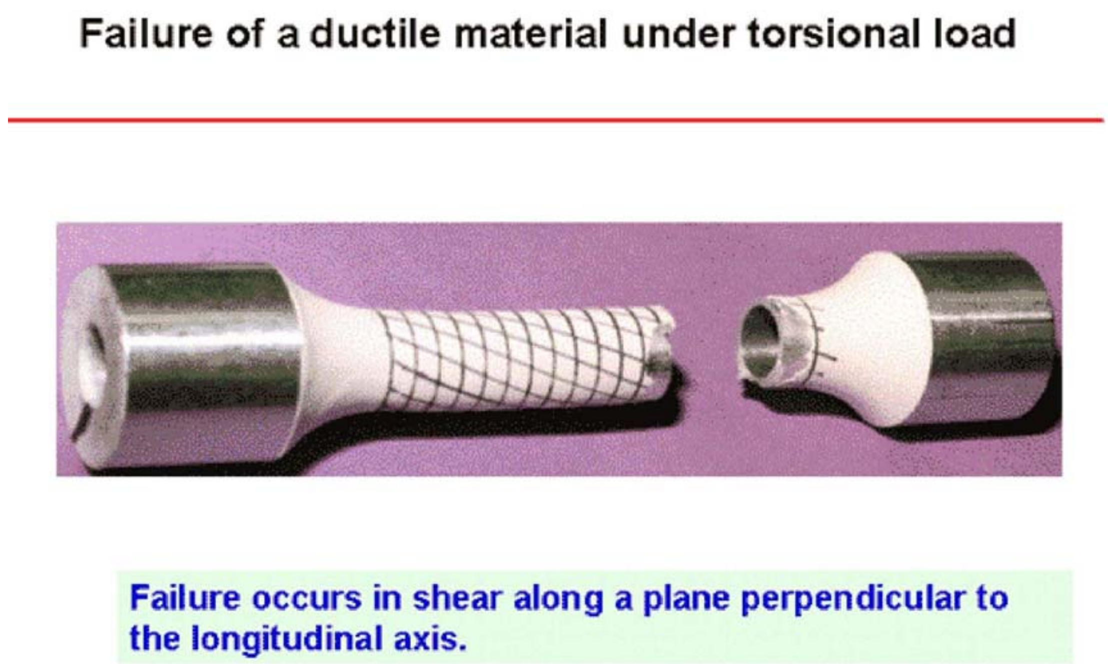


Figure 2, Example slide from chalk talk on basic torsion theory.

Data from real experiments is provided under the "test data" heading. Here we have performed torsion tests on aluminum, PMMA (Plexiglas), cast iron and turkey tibiotarsus bones. Data provided include time, torque, twist, force and elongation, all in plain text form and easily imported into Excel, Matlab or other analysis programs. A link in the reference section provides guidelines on the procedures for importing, plotting and analyzing the data. A sample listing of test data and images of broken samples is shown in Figure 4.

Under the heading "lab manuals" we have provided data sheets and suggested exercises for students. This section was tailored to Cornell students, however instructors at other schools could tailor the use of the lab by writing their own manuals to replace those provided.

Use and Evaluation of Lab

The virtual torsion lab was used in the Fall 2002 semester at Cornell as one of four labs in a sophomore course that combines statics and mechanics of materials. The course was taken by about 120 students. The lab will be used in the Spring 2003 at Cornell and other schools including two-year and engineering technology programs.

Students were given two weeks to complete the lab. The work entailed analyzing the data provided to determine yield and fracture strengths, shear moduli, and to deduce relationships between stiffness, strength and dimensions of the test samples. A report of about ten pages length was written and turned in. The questions, types of analyses and length of report were all similar to the three physical labs that the students performed.

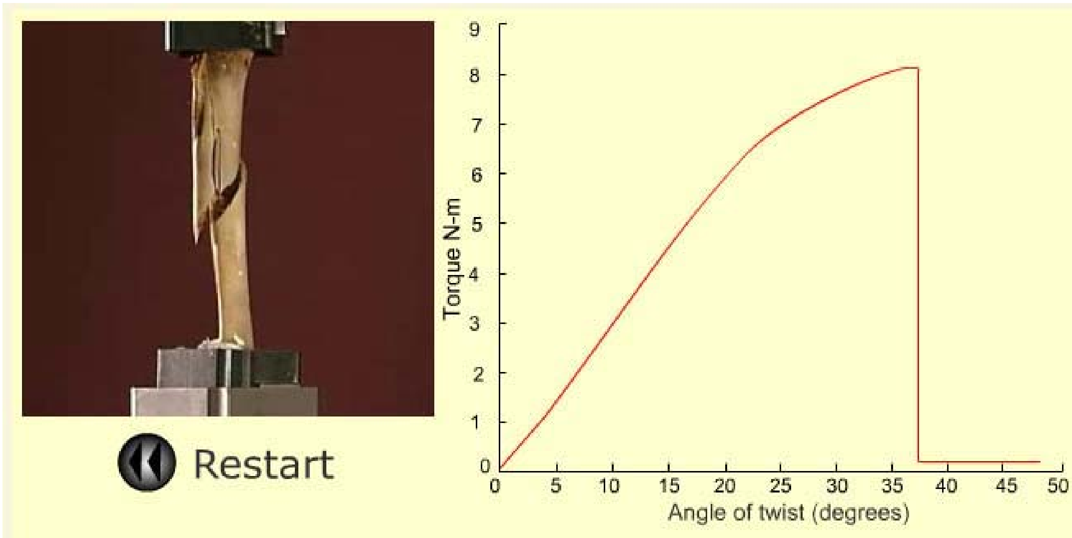
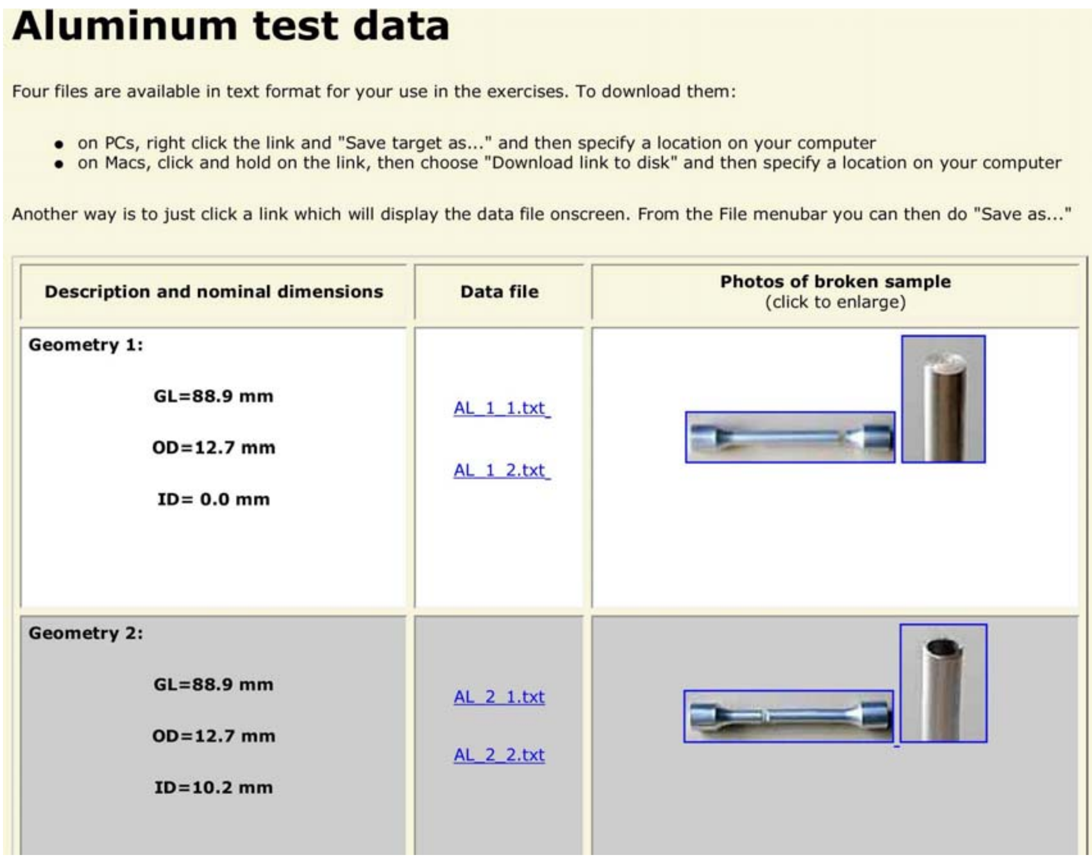


Figure 3, Sample frame from virtual test of turkey tibotarsus. Torque-twist curve is plotted in real time as virtual test is played back.



Aluminum test data

Four files are available in text 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..."

Description and nominal dimensions	Data 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	
Geometry 2: **GL=88.9 mm** **OD=12.7 mm** **ID=10.2 mm**	AL_2_1.txt AL_2_2.txt	

Figure 4, Sample listing of test data and images of broken samples.

Each student was required to complete a password protected, web-based survey on their experiences with the lab. For completing the survey students were given a 1% bonus to their semester grade.

Preliminary 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 on-line, test your knowledge quiz.

Students were asked to rate the lab on several aspects. The results given below, 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 was clear how to navigate through the site. Only 10% of students reported technical problems with the site.

	Much	Moderately	Slightly	Neutral	Slightly	Moderately	Much	
Easier to use	17 14.4	27 22.9	19 16.1	23 19.5	21 17.8	6 5.1	5 4.2	More difficult to use
Easier to understand the concepts	14 11.9	24 20.3	25 21.2	27 22.9	19 16.1	8 6.8	1 0.8	More difficult to understand the concepts
Less interesting	11 9.3	18 15.3	26 22.0	33 28.0	18 15.3	8 6.8	4 3.4	More interesting
Less time consuming	6 5.1	13 11.0	17 14.4	24 20.3	26 22.0	15 12.7	17 14.4	More time consuming
Less fun	16 13.6	21 17.8	31 26.3	28 23.7	10 8.5	8 6.8	4 3.4	More fun

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? Top set of values are number of responses, bottom are percentages.

Students were asked if given a choice to do laboratory exercises online or in the laboratory which would you prefer? The responses were:

- o In the laboratory 67.8 %
- o Online 17.8 %
- o Don't have a preference 14.4 %

These results clearly show that students would prefer physical laboratories. Some of the reasons students gave for preferring physical labs include: "*gaining hands-on experience, opportunity to see the experiments and results in person, the availability of people to ask questions to, don't have to stare at a computer, and easier to focus in a physical lab*." One student stated that they "*pay a lot for school so should use resources*," presumably meaning that they should get to use the testing equipment themselves. Some of the reasons students gave for preferring the virtual labs include: "*know you have the right data/Less human error, clearer presentation of lab, can focus more on theory and data, more convenient (can do where and when you want) and easier to focus online*." Suggestions for improving the lab included: "*making the lab shorter, with less number crunching, improving the on-line videos, more engaging voices on the narrations and include an FAQ section*."

Discussion

The most 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. Note that the clarity and quality of explanations for the virtual lab were highly rated, suggesting that well crafted virtual labs might be quite effective for teaching mechanics concepts and theory. Additional evaluations comparing student performance on the virtual torsion lab to performance on the three physical labs are in progress.

In the coming semester we will have the opportunity to use the virtual lab at schools where physical labs are not an option. This will allow us to judge the acceptance and effectiveness of virtual labs in a setting where they may be better than no lab at all. Future work will involve improvements to the lab, addition of material aimed at both engineering technology and advanced students, incorporation of additional data on biological materials to appeal to biomedical engineering students, more in-depth evaluation and extension of the lab to other topics in engineering mechanics.

Summary and Conclusions

A web-based virtual lab, focusing of torsion theory has been developed and implemented in a sophomore mechanics class taken by over 120 students. Initial evaluations show that students find the virtual lab easy to use and informative, but not as much fun as physical laboratories.

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