VIRTUAL LABORATORIES FOR ENGINEERING EDUCATION

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Abstract ⎯ This contribution deals with the application of modern technologies to develop virtual laboratories for civil engineering education. These virtual laboratories allow students to conduct laboratory experiments anytime and at anyplace. Students can conduct tests as if they were in a real laboratory, interpret the results and apply the results to practical situations using 3-D simulated apparatus. Each student has his/her own virtual apparatus to conduct not only the standard tests but also a variety of tests that existing, real equipment cannot accommodate. These virtual laboratories can enhance learning, retention and transfer of learning, extend the range of testing and allow for exploration of what if situations without the need for laboratory space (real estate), equipment and associated human resources. Interactions are coded in the virtual laboratories courseware to recall prior knowledge, to stimulate learning and to test learning outcomes. Virtual laboratories for a geotechnical engineering course are used to demonstrate how they can be used for engineering education.

Index Terms ¾ Engineering education, geotechnical, interactive multimedia, virtual lab

INTRODUCTION

Laboratories are important components of engineering education. With the advent of modern computer technologies, web-based laboratories are used as an alternative or a supplement to physical labs. Physical laboratories are the traditional labs occupying real estate, have real equipment and require technical expertise to function effectively. Web-based laboratories, also known as virtual laboratories, or simply virtual labs, or cyberlabs, have become complementary and, in some cases, alternatives to physical labs. Web-based labs are used in the "anytime, anyplace, online learning" world of engineering education. They are also increasingly being used to supplement traditional learning.

Virtual laboratories have been developed in a number of engineering and scientific disciplines [1-9, 17, 19] using a variety of simulation technologies. Mannix [15] documented the virtues of virtual labs. The virtues of virtual labs are not spread equally. They are not equal in terms of creation, development and maintenance costs. The educational benefits are also not the same. Asynchronous interactivity or high degree of interactivity by geographically separated learners is a key aspect [17] and not offered by all virtual labs. The degree of reality simulated and the software used differ. Some virtual laboratories show two-dimensional images of the laboratory devices and stop at demonstrating the principles [1, 2, 17] while others used Virtual Reality Modeling Language interfacing with MATLAB/SIMULINK/MAPLE [19] to simulate a real laboratory.

The virtual laboratory with 3-D simulation of the apparatuses developed by the author is based on the instructional methods proposed by Gagné [16] and Clark [11] and provides opportunities for exploration. These methods include: gaining attention, informing students of the objective, stimulating recall of prior knowledge, presenting the stimulus, providing learning guidance, eliciting performance, providing feedback, assessing performance, enhancing retention and transfer of learning. A summary of some of the major differences among virtual labs and physical

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TABLE 1
DIFFERENCES AMONG VIRTUAL LABS AND PHYSICAL LABS

PARAMETER	VIRTUAL LAB WITH 2-D SIMULATION	VIRTUAL LAB WITH 3-D SIMULATION	SENSOR-ACTUATED & REMOTELY-CONTROLLED VIRTUAL LAB	PHYSICAL LAB
Space Needs	None	None	Yes	Yes
Equipment Needs	None	None	Yes	Yes
Scheduling Logistics	None	None	Yes	Yes
Safety concerns	None	None	Depends	Yes
Other Requirements	WWW & Computer	WWW & Computer	WWW & Computer	Chalkboard
Pre-requisites (Computing)	WWW & Computing skills	WWW & Computing skills	WWW & Computing skills + robotics control	None
Maintenance Cost Items & Frequency in parentheses	Software and lab content updating (annually or semester-based)	Software and lab content updating (annually or semester-based)	Sensors, software, room (at least weekly maintenance)	Equipment (Weekly, if not daily maintenance)
Educational Benefits	1) Variables can be changed; 2) Number-crunching can be hidden from students or performed for them if necessary and to promote concept learning; 3) teaching style can be adjusted mid-way; 4) learning can be continuously monitored; 5) anytime, anyplace learning	1) Variables can be changed; 2) Number-crunching can be hidden from students or performed for them if necessary and to promote concept learning; 3) teaching style can be adjusted mid-way; 4) learning can be continuously monitored; 5) anytime, anyplace learning; 6) provide opportunities for exploration	1) Variables can be changed; 2) Number-crunching can be hidden from students or performed for them if necessary and to promote concept learning; 3) teaching style can be adjusted mid-way; 4) learning can be continuously monitored; 5) limited distance learning	Feel and smells of real-time interaction have an indelible effect on learning (memory, cognition, etc.); limited (traditional) access to learning
Realism (extent to which reality is simulated)	Least realistic; 2-d simulations are often just line drawings	More realistic as the graphics are 3-d	It depends; May be more realistic or less depending on image basis	Most realistic
Relative cost	$	$	$$$$	$$$$$

labs is shown in Table 1.

DEFINITION OF A VIRTUAL LABORATORY

Virtual laboratories are defined here as one genre of interactive multimedia objects. Interactive multimedia objects are composed of heterogeneous formats and include text, hypertext, sound, images, animations, video, and graphics. They are complex objects and new digital genres (forms), with no print equivalent, and with an explicit or implicit learning goal. Prototypical examples of interactive multimedia objects are 3-D simulation virtual laboratories [3-9]. These types of virtual laboratories are complete learning units. They provide pointers to prerequisite material, additional materials, uses multimedia formats to provide the learning material, different types of interaction (asynchronous and synchronous) to motivate, engage, challenge, and test learning.

AVAILABILITY OF VIRTUAL LABS

Virtual labs are usually available from developers' web sites, some of which are not accessible by the general public. In addition, virtual labs are delivered through storage media such as CD and may accompany textbooks as for example "Soil Mechanics and Foundations" 10]. A digital

library (DL) is a potential avenue for easy, anytime, anyplace access. The Oxford English Dictionary 2nd edition, 1989, defines a library as a place set apart to contain books for reading, study, or reference; the books contained in a library; *(transf.* and *fig.)* especially used to denote (*a*) a great mass of learning or knowledge; (*b*) the objects of a person's study, the sources on which he depends for instruction.

A digital library is not a single entity. It requires technology to link the resources of many so that the links between digital libraries and information services are transparent to the users. Digital library collections are not limited to document surrogates, they extend to digital artifacts that cannot be represented or distributed in printed formats [14]. The promise and allure of a DL is that it can be a natural part of asynchronous learning networks; it may also enhance the scientific reasoning skills of students [12]. A DL offers a combination of usable, interactive, information technologies coupled with authoritative knowledge repositories in multimedia formats (text, video, graphics, and sound).

The United States National Science Foundation is developing a National Science, Mathematics, Engineering and Technology Digital Library (NSDL). NSDL (to be launched in late 2002) provides a set of integrated services to link a network of digital libraries with different collections that would be available to the public anytime-anyplace. One such digital library collections is GROW (Geotechnical, Rock and Water Resources Digital Library). GROW is phase I of a National Civil Engineering Digital Library (NCERL) that is being developed in the Department of Civil Engineering & Engineering Mechanics of the University of Arizona. One of the collections in GROW is a Virtual Geotechnical lab created by the author. These virtual labs allow not only for the virtual testing of soils as if the user were in a real lab but allow the user to explore other test situations that are often difficult to conduct in real labs. An example of a virtual lab in GROW is described below.

VIRTUAL GEOTECHNICAL LAB

Presently, GROW houses a series of virtual geotechnical labs that are normally required in undergraduate and graduates courses in Civil Engineering. Some virtual labs, for example, simple shear are not available in most physical labs because of costs and complexity. Figure 1 shows the currently available labs in GROW.
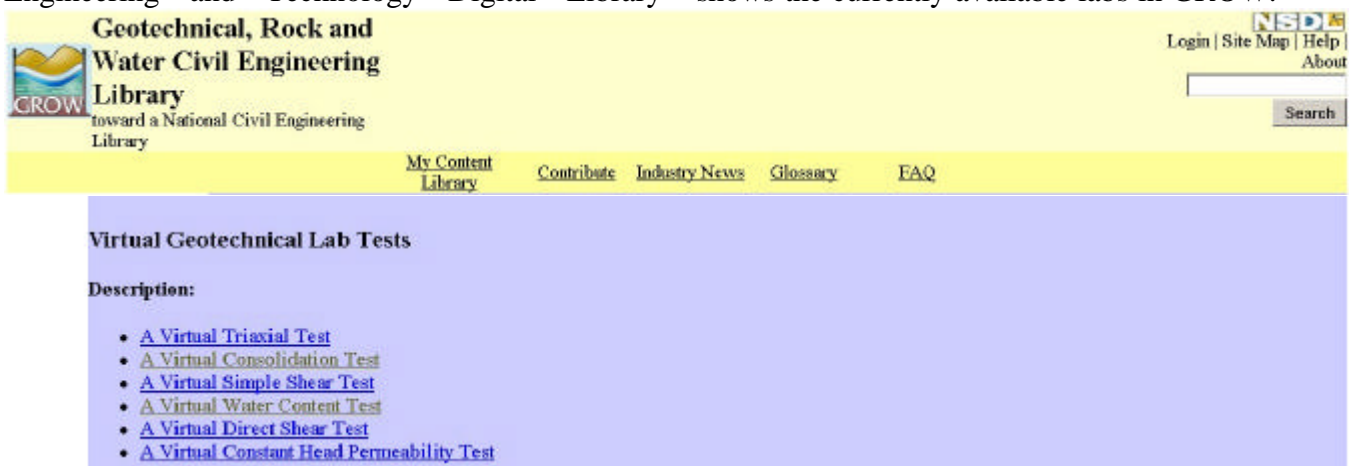

FIGURE 1
VIRTUAL GEOTECHNICAL LAB TESTS CURRENTLY IN GROW

The virtual labs were created with the following features.1. Informing the user (a) of the reason for doing the test by citing a practical scenario (b) on how to conduct the test (c) on the learning outcomes, (d) on the grading scheme and (e) on how to use the program

2. Testing of pre-requisite knowledge such as effective stress
3. Familiarity with the parts of the apparatus
4. Sample preparation and shoeing user how sample was taken in the field via a digital video
5. Setting up a specimen in the apparatus
6. Application of loading
7. Observation of results
8. Guiding the interpretation of the test results
9. Using the results, where applicable, in a practical scenario
10. Answer a quiz to test retention
11. Providing feedback throughout the testing

Soil parameters are randomly generated so that each student not only has his or her own virtual apparatus but also his/her own sample type. After informing the user of the test information, he/she proceeds to take a pretest to determine if the prerequisite knowledge is known for the understanding of the lab test and the interpretation of the test results. An example of a pretest question is shown in Figure 2.
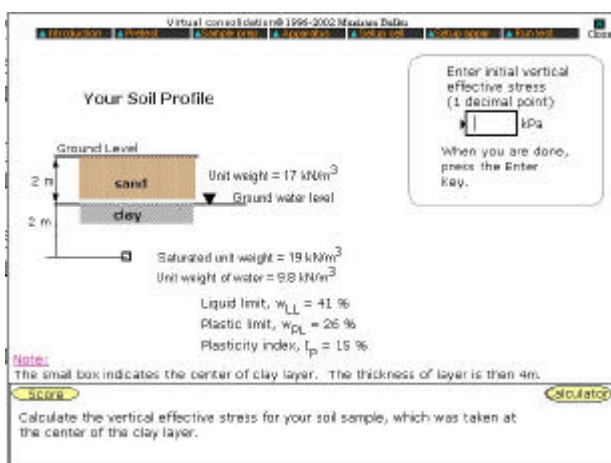

FIGURE 2
AN EXAMPLE OF A PRETEST QUESTION

The user is given three tries to answer the question correctly. If after three tries, the user fails to get the correct answer, the solution is then displayed. Each question is graded and a record kept of each user's progress, which the student can e-mail to his/her instructor at the end of the lab session. The soil profile shown in Figure 2 is randomly generated so that each student has a different soil type and stratigraphy. A digital movie is then displayed after the pretest to show the user how a soil sample for the lab test is taken from the field.
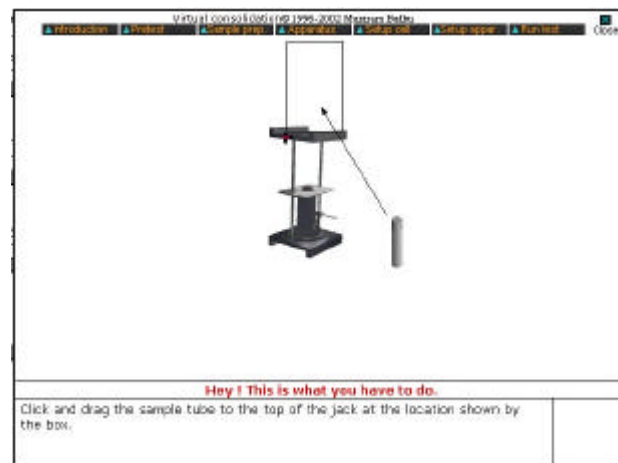

FIGURE 3
USER IS GUIDED TO INTERACTIVELY PREPARE A SOIL SPECIMEN

Subsequently, the user begins the lab test by preparing a soil specimen for the test through a guided interactive exercise. One frame of the interactive sample preparation exercise is shown in Figure 3, whereby the user drags a sample tube into a frame for jacking out a specimen and then trims a specimen to the desired size required by the test standards. In the case of the consolidation test described here, the user inserts a ring into the sample in the sample tube and then extracts the ring by jacking it out. The soil is then cut from under the ring to release it.
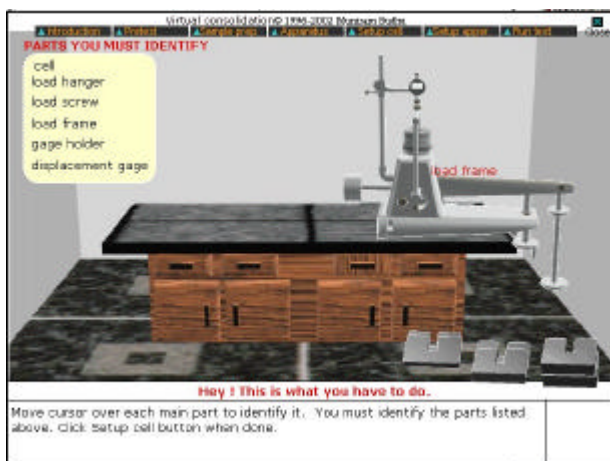
FIGURE 4
INDENTIFICATION OF VARIOUS PARTS OF
A CONSOLIDATION APPARATUS

The virtual apparatus is then displayed and the user is prompted to identify various parts of importance to the test as illustrated in Figure 4.

Following the identification of the various parts of the apparatus, the user is guided to set up the test specimen in the apparatus by dragging and dropping parts including any screws or bolts into their correct position. Once this is accomplished satisfactorily, the user begins the test by adding loads and switching on any motor that is part of the virtual apparatus
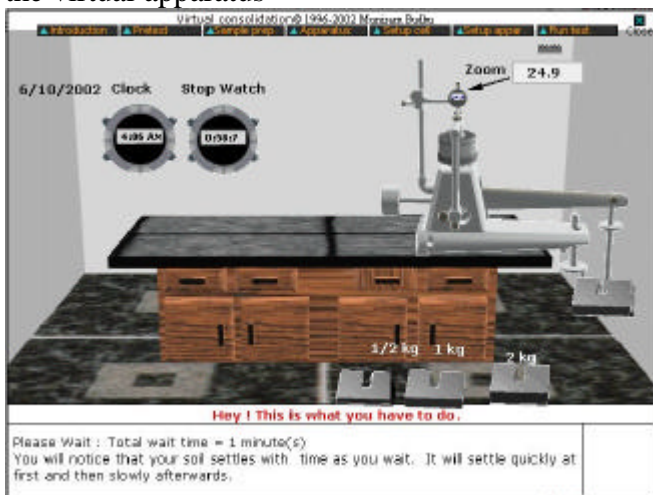

FIGURE 5
A VIRTUAL CONSOLIDATION TEST IN
PROGRESS

The user then observes the test results displayed on simulated panel meters and dial gauges. In Figure 5, a virtual consolidation test in progress is illustrated. The user observes how the soil settles with time. Usually this test would take about 24 hours in a physical lab but in the virtual lab this has been scaled to 1 minute.
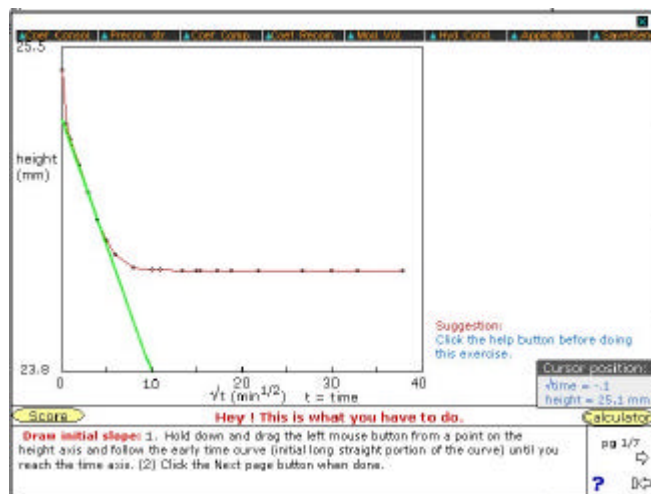

FIGURE 6
GUIDING THE USER TO INTERPRET THE
RESULTS

When the test is completed the user must now interpret the results. Guiding the user to perform interactive tasks and doing any calculations required accomplish this. A record is kept of the user's response and is available to his/her instructor. For example, in Figure 6, the user uses the results of the settlement over time to determine the coefficient of consolidation by following a series of steps prompted by the computer.

Once the results have been interpreted, the user is presented with a practical scenario to apply his/her results as illustrated in Figure 7. The soil layer is the same one given in the pretest and the building load varies for each student.

After this stage, the user can then explore other types of soils without setting up the virtual apparatus. This is a real advantage of virtual lab because in physical labs the user rarely can conduct any exploration because of time, equipment and space requirements.
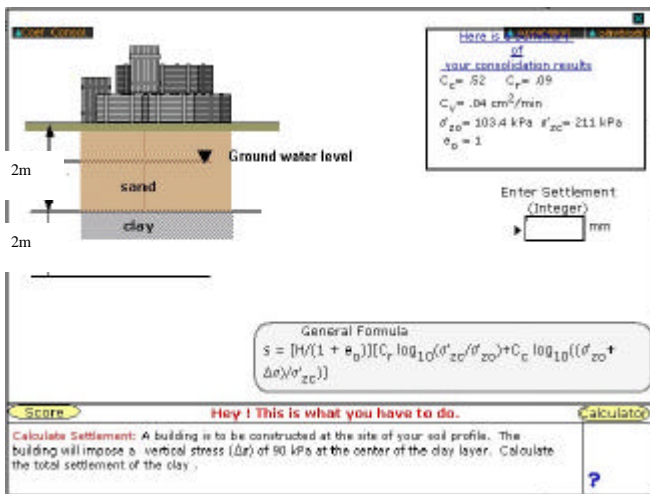
FIGURE 7
APPLICATION OF THE TEST RESULTS

In virtual labs, the user cannot break any equipment, he/she does not require space and can he/she can conduct a variety of tests that is beyond the scope of physical lab.

CONCLUSIONS

Virtual labs offer some advantages in engineering education and can supplement physical labs. Virtual labs can be an alternative to physical labs when such labs are unavailable because of lack of space or funds or equipment malfunction. For virtual labs to have a positive impact, the simulation must be as close to real situations as possible and be firmly grounded in rich pedagogy. Learning is also inextricably linked to usability and the user interface in virtual labs must be easy so that the user can spent time learning the discipline concepts rather than the navigation. Digital libraries now in development have the potential to deliver high quality digital information for public education.

ACKNOWLEDGEMENTS

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