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The Impact of 3D Virtual Laboratory on Engineering Education

Prof. Pnina Ari-Gur, Western Michigan University

Dr. Pnina Ari-Gur is a professor of Mechanical and Aerospace Engineering at Western Michigan University. Her research focuses are materials science and engineering. Dr. Ari-Gur earned her doctor of science in Materials Engineering from Technion, Israel Institute of Technology. Dr. Ari-Gur has been faculty at Western Michigan University since 1985. Her experience also includes R&D in the aerospace industry, post-doctorate at the University of British Columbia, and sabbatical at University of Auckland in new Zealand. She has been working on magnetic shape memory alloys as smart materials and for alternative energy. She has years of experience working on a variety of materials. Her research has been funded by NSF, the Air-Force Office of Scientific Research, NASA, CRDF Global, and industry. Her research projects also benefit society such as her NSF grants where nano-ceramics were used as photocatalysts for cleaning contaminants from water and air or for developing ferromagnetic alloys for alternative energy. She has used grants from HP and NSF to develop virtual laboratory to enhance student learning. She is also engaged in a number of outreach activities. A regular presenter in math and science events geared toward females and underrepresented groups of middle and high-school students, Dr. Ari-Gur regularly mentors students from the Kalamazoo Area Math and Science Center. She has strong ties and outreach programs with community colleges and hosts students from HBCUs in her lab.

Peter Thannhauser, Western Michigan University

Laboratory supervisor Mechanical and Aerospace Engineering

Dr. Pavel Ikonomov, Western Michigan University
Dr. Roman Rabiej, Western Michigan University
Dr. Daniel M. Litynski, Western Michigan University
Dr. Marwa M Hassan, Louisiana State University

Dr. Marwa Hassan is the Performance Contractors Distinguished Associate Professor in the Department of Construction Management, College of Engineering, at LSU. She is also the Graduate Coordinator for the department. Her area of expertise is sustainable material laboratory characterization and life-cycle assessment of infrastructure materials and systems. Dr. Hassan employed LCA to determine the impacts of photocatalytic pavements as well as asphalt construction operations including warm-mix asphalt. In 2003, she received the Architectural Research Centers Consortium King Medal for her work on sustainable technology at Virginia Tech. In 2008, she was awarded the Performance Contractors Professorship by the College of Engineering at LSU. Dr. Hassan has more than 17 years of industrial and academic experience in construction engineering and management, material science and characterization, and sustainable engineering. She have established a unique multi-disciplinary research and education program at LSU for undergraduate and graduate students focused on infrastructure sustainability and the use of advanced materials including nanomaterials in construction applications. This program has built a core foundation for sustainable development research and education within her department and LSU's College of Engineering. Dr. Hassan has attracted research funding that exceeded 2.3 million dollars, and has published with her students 45 refereed journal publications and 60 refereed conference proceedings. She has 10 invited presentations as well as a book chapter. She is currently a member of TRB Committee on Application of Emerging Technologies to Design and Construction, Pavement sustainability subcommittee, as well as the Design and Construction Group Young Member subcommittee (DCG YMS). She is also a member of the Construction Industry Institute academic committee and a friend of the Sustainable Pavement Technical Work Group (SPTWG). She supervised two female Ph.D. student and 8 MS thesis students to completion.

Mr. Jeff Johnston, Muskegon Community College

Mr. Jeff Johnston is an Instructor in the Applied Technology Department of Muskegon Community College. Mr. Johnston worked 25 years as a Product Developement Engineer for suppliers of engine components and heavy duty truck components. During his work as a Product Development Engineer, he worked as an adjunct instructor for 18 years. In his current position, he teaches Engineering Graphics, Engineering Statics, Metallurgy, Industrial Materials, and Mathematics. Mr. Johnston possesses a Masters of Science and Bachelor of Science in Mechanical Engineering from Michigan State University.

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Mr. Tyler Bayne

The Impact of 3D Virtual Laboratory on Engineering Education

Abstract

The virtual lab project aim was to address the need for a hands-on component in sophomore engineering classes, without the cost-prohibitive physical laboratory. The success rate in engineering courses at this level is pretty low, and the idea was to improve the comprehension of the material studied to lead to a better success rate. Computer simulations of experiments were developed by an international team of faculty and students with a clear goal of making it affordable at different sites (only a laptop is needed), and user friendly, so that the user does not need an instructor to successfully run the lab. At our home institution, the virtual lab is conducted in the physical lab space to make it possible to demonstrate samples/equipment and concepts. Priority in development was given to experiments that are essential for the sophomores, and to those that are based on very expensive equipment (e.g. X-ray diffraction). The experiments were developed and implemented at several sites, and assessment data shows positive impact on student learning. Simulations are also used in recruiting trips, attracting high-school students to STEM. The lab is distributed free of charge to individuals and institutions around the world. Assessment of student learning compared the use of virtual lab, to that without any lab, and to one with a *physical* lab experience was conducted.

Introduction

A recent report to the president[1] concludes that in order to maintain the current status of the US as a leader in science and technology, there is a need for about one million more STEM professionals than what is expected at the current rate of graduation over the next decade. What makes the situation worse is that most of the students who begin their undergraduate education in pre-engineering do not complete their degree[2,3]. To improve engineering learning effectiveness, a laboratory experience is highly beneficial; it reinforces the material comprehension, complements the theory, and provides an active, interactive learning. However, issues such as high cost and high credit-hour engineering curricula have resulted in elimination of many of the engineering teaching laboratories, especially at the sophomore level. Our project goal was to improve student success rate by providing them a set of virtual experiments that we develop to adequately simulate the physical laboratory.

Guiding Principles in Developing the Virtual Laboratory:

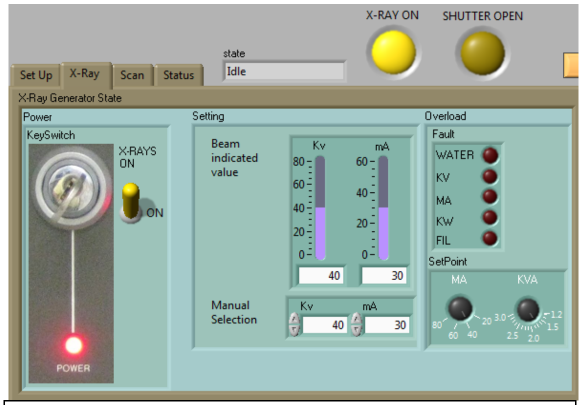
1. The virtual laboratory modules must mimic reality and the learning experience in the virtual environment needs to create an experience similar to manually manipulating laboratory equipment. This was accomplished by:
    a. Creating modules that are interactive; the student operates the simulated equipment in a similar way one would operate the physical equipment.
    b. Incorporating real data from physical experiments. Then, during the simulated experiments, the student collects data and later analyzes it.
    c. Emphasizing safety both as separate topics, such as general lab practices and radiation safety, as well as throughout the virtual experiments (such as a radiation badge is necessary to start the x-ray simulation.

   d. Understanding of statistical distribution of results is accomplished by incorporating measurements in the simulated laboratory which are based on real pre-recorded data with statistical distribution.
   e. Report writing is a requirement; it is graded and feedback is provided to the student for continued improvement.
   f. Familiarizing the student with equipment is accomplished in two ways; first the sight, motion and sound of the 3D simulated equipment are made very similar to the physical one. Also, the virtual lab at the home institution is located in the physical lab where examples of the equipment and samples are for the student to see.
2. The modules have to be able to run on low-cost equipment. The modules can be downloaded into any PC or laptop, so no special VR gear is needed. We have provided the modules to variety of educational institutions around the US and internationally.
3. Students should be able to conduct the experiments with no assistance. Every laboratory has an instructions file for the students that contains both theoretical background and links to the virtual module. The experiments themselves have embedded instructions.

Fig. 1 A six-year old in the lab running an experiment unassisted.

Methods Used In Developing Virtual Laboratory Modules

The virtual experiments were developed using several different tools. In common, though, the first step was performing the experiments in the physical lab, using existing procedures and collecting data. For example, the X-ray diffraction experiment was developed using LabVIEW (Laboratory Virtual Instrument Engineering Workbench), a system-design platform and development environment[4]. Part I of the lab is a mandatory X-ray training (that includes radiation safety), then the student takes a quiz to demonstrate sufficient knowledge to run the experiment. The student must put on a radiation badge to continue, select a sample, set the experimental parameters, and collect the data. Some of the data for the simulation was collected experimentally, and some was simulated



state: Idle

Beam indicated value: Kv 40, mA 30

Manual Selection: Kv 40, mA 30

Fig. 2 Virtual XRD experiment. The switch is on, the power light lit, and the voltage and current are set for the run.

using PowderCell[5] and noise was added to make it realistic. The last step is the use of the database (excerpts from ICDD)[6] to identify the sample and crystalline structure.

Some of the other experiments use Unity 3D, a game design engine[7]. We chose it because of its popularity with professional game designers. The Unity 3D scripts were programmed using C# and JavaScript. The virtual experiments development started with the creation of realistic 3D models of the equipment, furniture and environment. The 3D models were created using Adobe Photoshop and 3ds Max (formerly 3D Studio Max, a professional 3D computer graphics program)[8], then imported into Unity 3D and paired with the scripts. One example of a Unity 3D-developed experiment is the concrete compression test. The concrete experiment begins with a requirement to wear safety glasses (Fig. 3).

The simulation does not let the student continue until this is done. In the test, the student mixes different aggregates and cement and pour a bucket of water to create concrete cylinders. The simulation then guides the student through the process of mixing the different aggregates together for the concrete mixture. Now the mixture is poured into the mixing barrel, the barrel is spun, and the concrete is poured into the mold. The student then carries the cylinder to the curing chamber. Instead of lengthy curing time, the simulated experiment labels the sample with its "curing time" (7 days for the first sample) and it is ready for the compression test (tester is shown in Fig. 4). The student then presses the green button on the control panel to operate the tester. The cylinder is compressed until it breaks and the strength is displayed on the monitor. The student then goes back to the curing room and repeats the testing with a sample that was "cured" for 28 days.

Fig. 3 The safety glasses and mixing table in the concrete experiment

Fig. 4 The concrete compression tester and computer.

Other experiments developed with Unity 3D were asphalt and scanning electron microscopy (SEM).

Another tool used in several simulated experiments was EON reality (an interactive 3D software)[9]. EON Studio is a state-of-the-art VR development tool[10]. The development process of the EON modules was similar to that used for modules developed with Unity 3D. The development steps, after the physical experiments and testing procedure development, are illustrated in Fig. 5. For example, the tensile testing laboratory (Fig. 6), the student selects the sample, places it in the machine, and starts the test. The progression of the test is seen on the computer screen, the inset, and the machine itself. The sample continuous shape-change is watched on the inset. At the end, the student obtains the stress-strain data digitized.

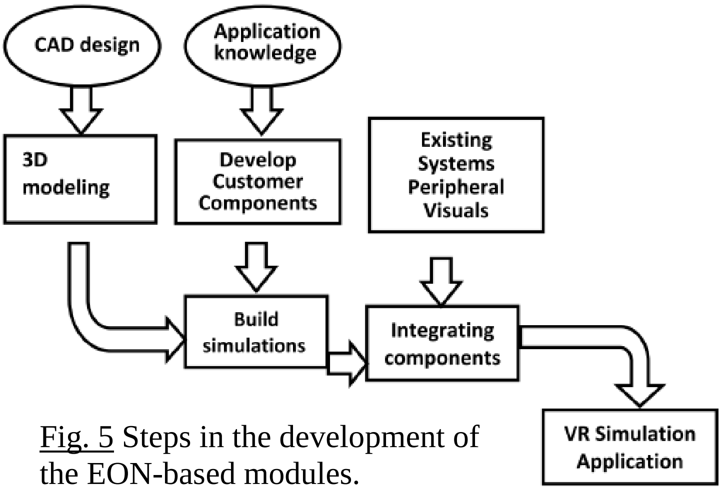
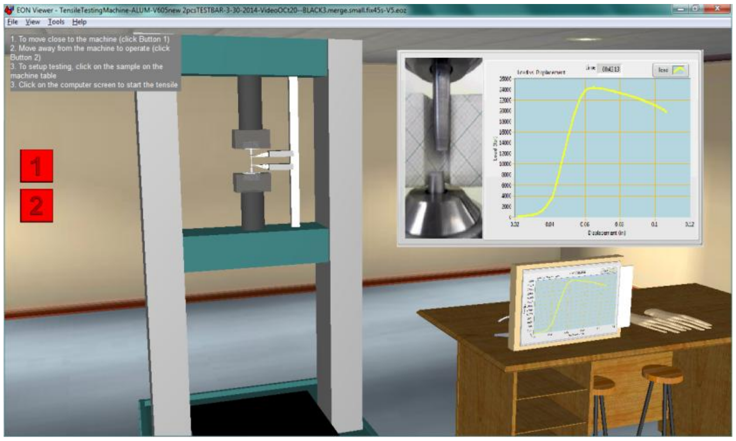


Fig. 5 Steps in the development of the EON-based modules.



1. To move close to the machine (click Button 1)
2. Move away from the machine to operate (click Button 2)
3. To setup testing, click on the sample on the machine table
3. Click on the computer screen to start the tensile

Fig.6 Tensile testing simulation. The machine, sample, and graph, are all synchronized.

All the modules, using the tools described, were developed in iterative process of feedback and improvement. The experiments are all launched from an html or PowerPoint that provide background and instructions for the lab. In addition, the continuous assessment of the lab, has led to constant improvement. In a way, the modules are never 'finished' but rather are subject to more modification and improvement.

Assessment

To ensure that the objectives are being met in the VR environment, the research team conducted a series of experimental studies to validate the usefulness of the developed module and to obtain feedback for further improvement of the simulations. Comparisons were made between a group of students that performed the virtual lab, a second group that conducted the same experiment in a physical laboratory, and a third group that did not have any lab component at all. Prior to conducting the experiment in the laboratory and immediately after submitting the lab report, all students were given multiple-choice tests to assess knowledge gain. Comparisons were made between the groups, as well as within the group (before and after the lab experience). Although the sampling is still relatively small, the assessment results at all three major sites, over a couple of semesters, were very consistent in demonstrating that the virtual laboratory was on par with the physical laboratory in improving student learning and both groups (virtual and physical labs) faired significantly better than the comparison group that performed no lab at all.

In addition, an on-going evaluation was used for a continuous improvement feedback loop between module developers, lab instructors, and pilot student users. External feedback was also obtained by providing lab modules to instructors at other institutions. Also, a very helpful critique was provided by lay people (with no science or engineering education) that were asked to run the lab.

We have provided the developed modules to a large number of individuals and institutions around the world. As their numbers grow, and our modules are improved, we will distribute the latest version of the labs and will seek further input.

Conclusions

Virtual laboratory modules were developed to mimic physical laboratory and provide students a valuable hands-on experience for better comprehension. The iterative process of developing, assessment, and improvement, proved to produce a good learning experience that is cost effective, attractive, and is not significantly time consuming as a traditional lab. Preliminary assessment results are compelling, but more assessment data will be collected.

References

[1] Olson, Steve, and Donna Gerardi Riordan. "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President." *Executive Office of the President* (2012).
[2] Seymour, E. and Hewitt, N. M. (1997). *Talking about leaving: why undergraduates leave the sciences*, Boulder, CO: Westview Press.
[3] Smith, T. (2001). *The retention and graduation rates of 1993-1999 entering science mathematics, engineering, and technology majors in 175 colleges and universities*. Norman, OK: Center for Institutional Data Exchange and Analysis University of Oklahoma.
[4] LabVIEW System Design Software http://www.ni.com/labview/
[5] PowderCell http://www.ccp14.ac.uk/tutorial/powdcell/
[6] International Centre for Diffraction Data (ICDD) http://www.icdd.com/
[7] Unity3D game design engine http://unity3d.com/
[8] 3ds Max® 3D modeling software http://www.autodesk.com/products/3ds-max/overview
[9] eon reality http://www.eonreality.com
[10] Sampaio, A. Z., Henriques, P. G., and Studer. P. Virtual Reality Technology Applied to Simulate Construction Processes. Computational Science and Its Applications – ICCSA 2004, Springer-Verlag Berlin Heidelberg, 817–826.

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