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Transforming Undergraduate Engineering Education with 3D Virtual Reality Laboratory

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Dr. Pnina Ari-Gur is a professor of Mechanical and Aeronautical 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.

Dr. Pavel Ikonomov, Western Michigan University

Dr. Pavel G. Ikonomov has been working on virtual reality (VR) simulation for more than 20 years and in the area of micro/nano technologies for the past ten years. The main focuses of his works have been 3D modeling design and VR simulation in manufacturing and assembly, medical application. Dr. Ikonomov has participated in large scale dynamic simulations in research organizations in Japan such as Hokkaido University, TMIT and 3D Incorporated and Virtual Reality Center Yokohama, UCLA, and NIST. His most recent research contributions are related to use of VR for visualization and control of nanostructures and processes for assembly, and medical application including analysis of nanoparticles kinematics and dynamics modeling. Dr. Ikonomov has published over 100 papers as international journal and proceeding publications. He has given invited talks on his research at different institutions in USA, Japan, India, Russia, and Bulgaria.

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Dr. Hassan is the Performance Contractors Distinguished associate professor in the Department of Construction Management at LSU. Her areas of expertise are laboratory characterization and life-cycle assessment of sustainable infrastructure materials. Dr. Hassan employed life-cycle assessment techniques to determine the impacts of hot-mix 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 31 refereed journal publications and 40 refereed conference proceedings as well as a book chapter. She is currently a member of the Transportation Research Board Committee AFH30: Committee on Application of Emerging Technologies to Design and

Construction, AFD001: Pavement sustainability subcommittee, and the Design and Construction Group Young Member subcommittee (DCG YMS). She is also a member of the Construction Industry Institute (CII) academic committee and a friend of the Sustainable Pavement Technical Work Group (SPTWG). She supervised one Ph.D. student and five M.S. students to completion.

Dr. Daniel M. Litynski, Western Michigan University

Dan Litynski is the vice president for Research (VPR) for Western Michigan University (WMU) and professor of Electrical and Computer Engineering (ECE). Since joining WMU in 1999, he has served as dean of the College of Engineering and Applied Sciences (CEAS), provost and vice president for Academic Affairs, and interim president of WMU. Dr. Litynski completed three years at the National Science Foundation as physics program director and acting division director for Undergraduate Education. He has served in numerous international technical and advisory capacities including member of the International Faculty of Engineering Advisory Committee at the Technical University of Lodz, Poland where he served as their first visiting professor. Brigadier General Litynski (Ret.) served with armor and ordnance units in Asia and Europe and with several Department of Defense research and development organizations. Dr. Litynski served in the Physics and the Electrical Engineering departments at the United States Military Academy, and was head of the Department of Electrical Engineering and Computer Science. Degrees include a Ph.D. and B.S. in Physics from Rensselaer Polytechnic Institute and an M.S. in Optics from the University of Rochester. His national service education includes the Army Command and General Staff College, and the Industrial College of the Armed Forces of the National Defense University. He has been active in research and teaching in electrical engineering, optics, physics, and educational pedagogy for over thirty years. He is author or co-author of numerous international conference presentations, technical papers, book chapters, and a patent. Dr. Litynski is a senior member and past president of the IEEE Education Society, appointed to several honor societies, and a member of many professional societies. Honors include many military awards, the Polish Cavalier Cross of Merit, an NSF Director's Award, and the ASEE Meritorious Service Award.

Dr. Renee Schwartz, Western Michigan University

Dr. Renee Schwartz is an associate professor of Biological Sciences and Science Education at Western Michigan University in Kalamazoo, Michigan. She earned her Ph.D. in Science Education from Oregon State University, M.S. in Molecular Biology from Wake Forest University, and B.S. in Biology from Purdue University. Dr. Schwartz's research focus is teaching and learning about the nature of science (NOS) and scientific inquiry. She explores effective practices of embedding NOS and scientific inquiry within science content courses for pre-service science teachers, undergraduates, and for professional development. She seeks to understand contextual factors such as science disciplines, authentic science research, and classroom-embedded scientific inquiry; and their effects on learners' epistemological views of science. A current project engages pre-service secondary science education students in a science research internship, along with extended support structures to help translate the experiences into inquiry-based curricular materials and classroom practices for middle and high school students. She has been PI for an NSF-funded CCLI grant aimed at improving undergraduate level introductory biology and chemistry laboratory courses through curriculum and professional development. Dr. Schwartz has designed a course for college science teaching. This course emphasizes the integration of inquiry, nature of science, and subject matter through active learning strategies in STEM classrooms.

Transforming Undergraduate Engineering Education with 3D Virtual Laboratory

Abstract

We have been developing a unique set of 3D virtual laboratory experiments for use in an undergraduate materials science course, community college instructions, for demonstrations to the public and hands-on recruiting events for middle and high school students. The methodology and technology used is designed to make it possible to easily disseminate the laboratory to a large variety of institutions and locations. The fact that the laboratory is fully interactive makes for a realistic experience for the student.

Introduction

Despite a growing need for engineers in the workforce, there has not been a significant increase in engineering degrees awarded[1]. In fact, foreign-born engineers account for a significant portion of engineering and technology companies established in the last decades; e.g. according to[2], “companies founded by immigrants between 2006 and 2012 generated $63 billion in revenue and employed 560,000 workers in 2012." What makes the situation even worse is the so-called *reverse brain drain*; that is increasingly, foreign-born engineers are heading back home. Authorities estimate the number of foreign-born workers returning to India and China annually is in the tens of thousands[3,4]. The Chinese Ministry of Education estimates the number of Chinese who returned to China last year was a record 134,800, up 25% from 2009[4]. That makes the education of future US engineers and scientists a matter of national security.

Engineering is viewed by many as a very demanding curriculum. Even when students begin their undergraduate education interested in STEM majors, the completion rate is less than half[5,6]. One of the primary reasons undergraduates choose to leave science and engineering majors is the loss of interest in the field[5] prompted by inadequate motivation and background knowledge from school level. Among our sophomore engineering students, only about 50% are passing with the required C or better. Many of the unsuccessful students could become successful if teaching methods would better fit their different learning styles[7,8].

Students have different preferred learning styles[7-9]. These styles relate to the type of information accessed, the manner in which information is accessed (e.g., visual, verbal), the processes involved in accessing information (e.g. active, passive, reflective), and the sequence in which information is accessed. Understanding different learning styles can help instructors develop effective teaching strategies that target student diversities. Laboratory experiences can help address the needs of diverse learners as well as develop skills and emphasize the relevance and real-world application of course content[10]. Through engaging students in engineering investigations by means of a 3-D virtual laboratory, our goal has been to spark interest, excitement and the concomitant retention of engineering students[5].

Few engineering courses have a laboratory associated with them. One reason is that physical laboratory investigations are often limited by resources such as time and equipment. Further, the undergraduate engineering curriculum is already packed with credit hours. The virtual laboratory addresses these issues. For example, an experiment that would take days (e.g., heat treatment) takes just a few minutes in the virtual laboratory (VL) environment. As Felder and Silverman[8] conclude, “the virtual laboratory is used as an alternative mechanism for achieving the same learning outcomes as in the corresponding physical laboratory.”

Another challenge is providing laboratory experience to students enrolled in distance education. The virtual laboratory modules are portable, self-explanatory, and user-friendly. They enable distance education students to have lab experiences similar to those of their peers on campus[11]. They also address the needs of students with motion disability. Simulated experiments are more accessible to learners who often find it difficult or unsafe to use a real laboratory.

An issue of major concern is the recruitment of female and minority students[12]. Being portable, recruiting professors will be able to take the VL with them when going on recruiting trips.

Steps in the Development of Virtual Laboratory

The virtual laboratory development is composed of several phases as described in Figure 1. These are:

I. Development of lab modules
II. Instructor training
III. Dissemination
IV. Assessment

These tasks are interrelated and feedback was used regularly to improve the lab modules.

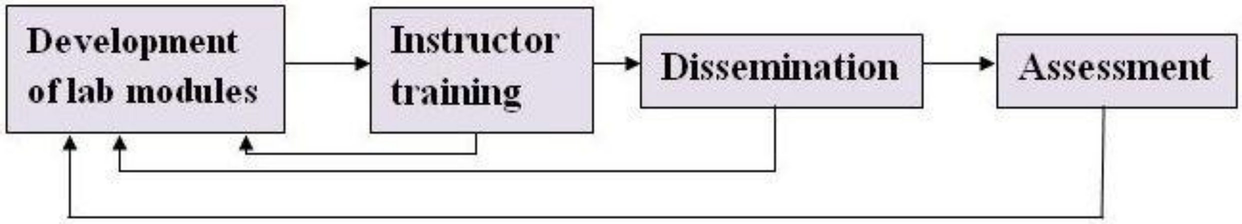


Figure 1. Flow chart of the project.

Virtual Laboratory Experiments

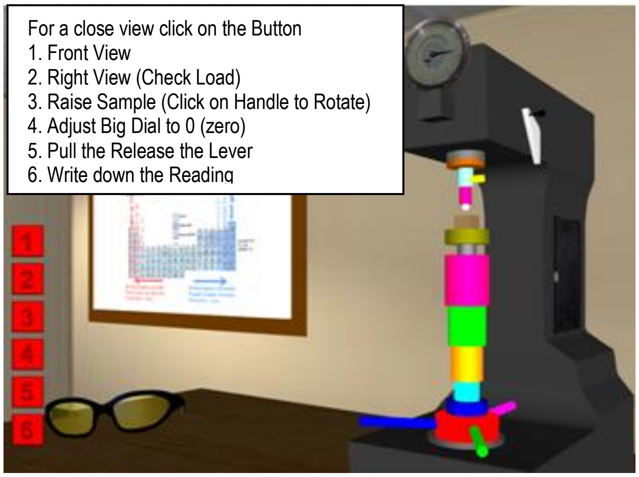
The simulated experiments are designed to address the needs at the participating institutions, where the sophomore courses are taught as a large lecture section with no associated laboratory experiences. They are designed also with collaboration of other institutions around the country and around the world to make them adaptable by diverse populations.

Preferred consideration for VL development was given to experiments that are of critical importance in the course (e.g. heat treatment of alloys). Other considerations include, for example, labs that require specialized, expensive, fragile, and potentially hazardous equipment, such as X-ray diffraction and electron microscopy.

The modules include: X-ray diffraction, scanning electron microscopy, heat treatment of alloys (steel, aluminum, and brass), concrete testing (compressive strength and modulus of rupture), and asphalt (rotational viscosity, and mechanical testing).

The guiding principles in the development of the virtual lab are:

1. A laboratory that enables the student to conduct experiments without an immediate need for an instructor. Figure 2 shows a simulated hardness tester. The instruction "balloon" directs the user to a step-by-step process using the red buttons.



For a close view click on the Button
1. Front View
2. Right View (Check Load)
3. Raise Sample (Click on Handle to Rotate)
4. Adjust Big Dial to 0 (zero)
5. Pull the Release the Lever
6. Write down the Reading

Figure 2 Simulated hardness tester. The instructions are designed for independent use by the student, and can be run anywhere using a laptop.

2. The simulated equipment provides a feeling of the "real thing" while clearly identifying components. For example, the cut-off disc (Figure 3a) has a vice to hold the sample, cooling water, light, and an abrasive disk. The sounds of the different phases of the cutting operations were recorded while operating a real machine and incorporated into the simulation.

3. As in a real laboratory, experimental results have to be recorded. Tables for data collection will be uploaded on the computers. Repeated experiments will yield subtly different values in order to make the virtual results more realistic.

4. To make the virtual lab user-friendly, PowerPoint was developed that can be used to easily navigate through the virtual lab environment and link to resources.

Figure 3. Virtual cut-off machine: (a) Virtual machine, and (b) A real one.

The PowerPoint files also include links to the theory behind the experiments and other useful information.

Development of laboratory modules

The laboratory modules have variety of characteristics that require different approaches to modeling. Still, all of them are interactive, making the student an active participant. Some of the simulated experiments (such as cold-work of brass) were developed using EON Studio, state-of-the-art VR development tool. Others (e.g. the asphalt and concrete laboratories) were developed using Unity3D, the most commonly used game design engine. For the X-ray diffraction experiment, LabVIEW with real video clips was used.

All the modules are built to run on Windows computer with basic graphics capabilities to make dissemination to wide and diverse audience feasible.

Creating the simulated experiments

The first step in the process was to conduct *physical* experiments. This was done for two reasons: first to collect data to be used in the simulation; second, to record the procedure to aid the simulation developer. Next, models of the objects and devices were created using CAD software and imported to a 3D modeling package. These 3D models were developed into components, based on the physical experiments. Subsequently, the enhanced 3D graphics models were imported into the VR simulation software to be used as objects or environment of the VR lab simulation. In order to make the object and devices react in response to student actions, a behavior model (cause/ action/ reaction intelligent engine) has been developed for the simulation.

Steps of testing and troubleshooting provided feedback in several sub-steps. First, the development team tested, identified problems, and improved the simulations. Then inexperienced students tested the modules to improve their user-friendly nature. Lastly, the laboratories were tested by “lay persons” and their feedback was used to further improvement. Some of the experiments were further tested by enthusiastic middle- and high-school students (Figure 4).

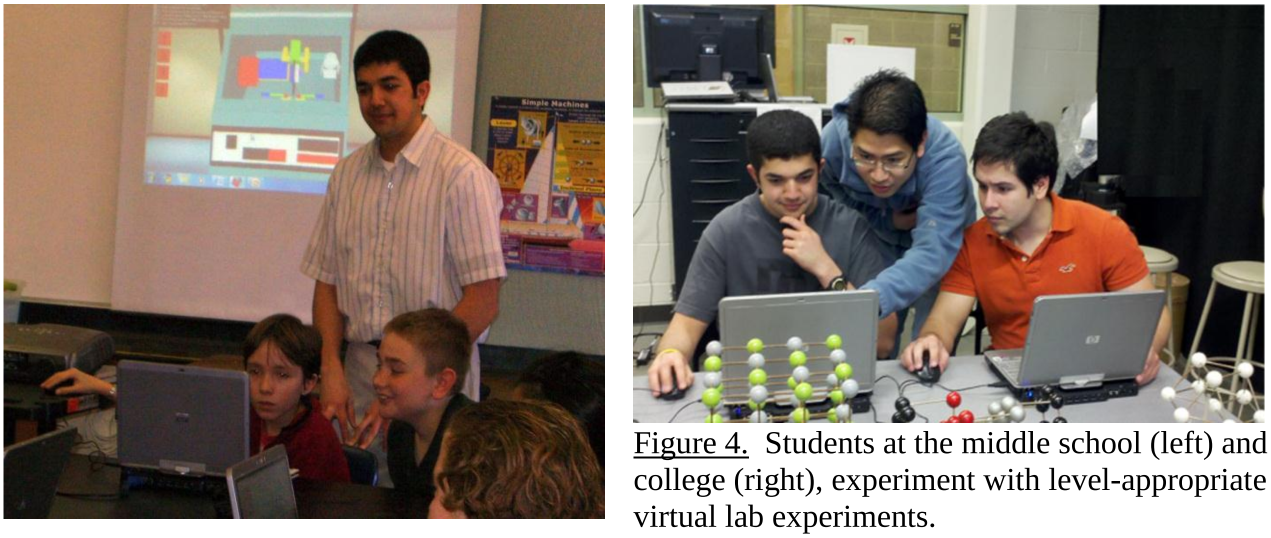


Figure 4. Students at the middle school (left) and college (right), experiment with level-appropriate virtual lab experiments.

The virtual laboratory development steps are described in Figure 5.

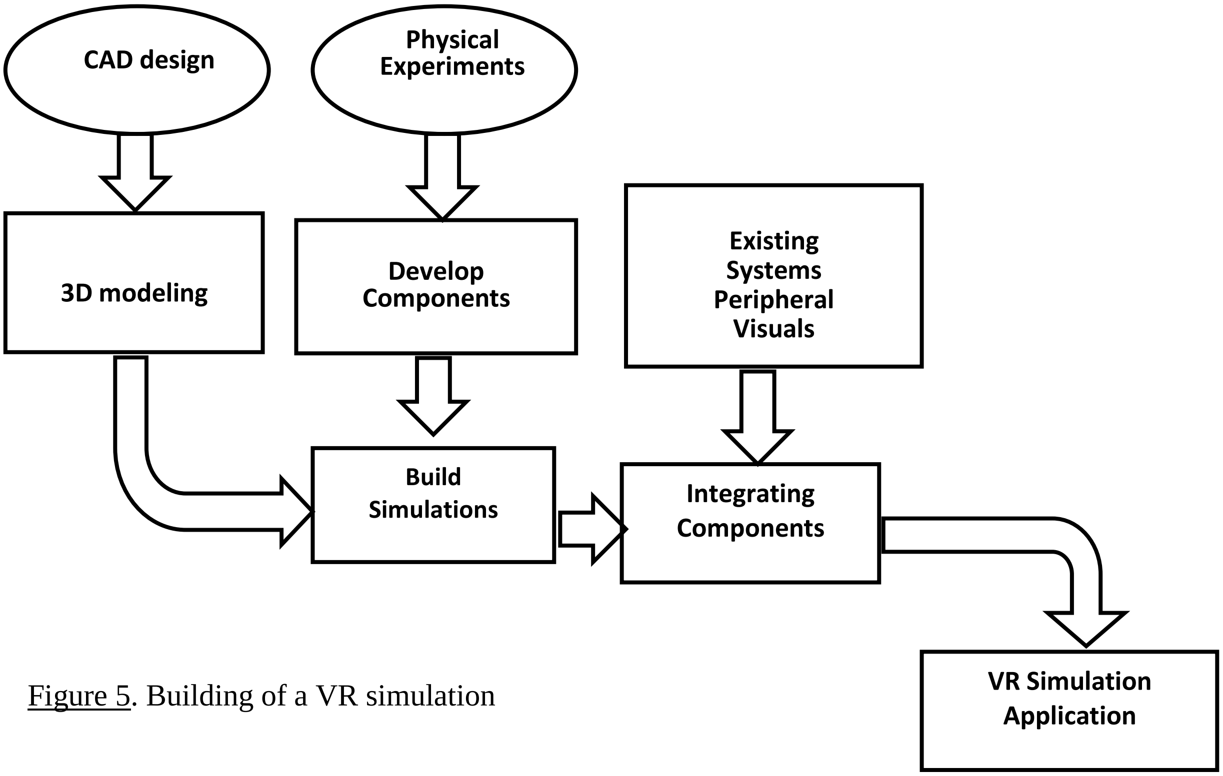


Figure 5. Building of a VR simulation

Assessment

Impact on sophomore students

So far most of the project time was devoted to the development of the virtual laboratory modules. A comprehensive assessment plan is in place. Only limited assessment data could be collected on modules that were not fully developed. The impact of the virtual laboratory modules was then assessed through a post survey of those students who participated in the learning modules. A group of students served as an intervention group, while another group of comparable students served as the control group for grades only. The control group was not asked to respond to the survey. The only difference in the learning experience between the groups was the participation in the virtual laboratory sessions.

A survey of attitudes toward the VL sessions and perceived learning impacts indicated those students in the VL had a positive experience that reinforced concepts from the course and provided application opportunities.

The survey data support the positive impact of using the VL modules on raising awareness of course content, understanding of subject matter knowledge, and gains in procedural knowledge.

It should be noted that the survey was self-report, and included open response items for student comment. The comments were used as part of the feedback used to improve the modules.

Impact on pre-college students

The VL modules were introduced to students in middle grade level during a campus visit (~age 12-13). The students saw a demonstration of the modules and were able to manipulate the labs as well. At the end of the visit, the students responded to a survey of attitudes toward the use of VL and career goals. The results indicate positive impacts of the experience. Specifically, students:

- gained knowledge about engineering from the VL lessons
- were able to understand and perform the VL lessons
- expressed interest in doing more VL lessons
- expressed interest in studying engineering in the future

Summary

The introduction of virtual experiments has proven to be beneficial to student learning. At the pre-college level, the laboratory is a tool that supports recruitment. Much more work is still needed and planned both in developing and perfecting the modules, and in assessing their impact on retention, recruiting, and overall success.

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