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Engineering Laboratory Instruction in Virtual Environment - “eLIVE”

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ABSTRACT

A novel application of web-based virtual laboratories to prepare students for physical experiments is explored in some detail. The pedagogy of supplementing physical laboratory with web-based virtual laboratories is implemented by developing a web-based tool, designated in this work as “eLIVE”, an acronym for Engineering Laboratory Instruction in Virtual Environment. Two physical experiments, one each from the thermo-fluids laboratory and the solid mechanics laboratory in the undergraduate mechanical engineering curriculum, are transformed into web-based virtual experiments for application as pre-lab practice sessions. The key question answered here is as follows: Do the web-based virtual experiments developed for supplementation of physical laboratory instruction enhance students’ knowledge of experimental procedure and data acquisition? This question is answered by assessing the performance of a “control” group of students that did not use “eLIVE” and comparing it with the performance of an “experimental” group that availed “eLIVE” prior to the physical experiment sessions. Students’ performance in tests and quizzes administered to both the groups prior to the physical experiments was analyzed, using a non-parametric statistical method, to establish the statistical significance of assessed results with respect to “eLIVE” intervention, and demographic parameters such as gender, ethnicity, academic achievement, age, course load etc. Statistical results as well as students’ response to surveys presented in this work point to “eLIVE” as being a very useful technology- enhanced interactive learning tool. The present study clearly establishes the pedagogy of physical laboratory



supplementation with web-based virtual laboratories on a firm ground for possible extension to other engineering laboratory courses at ODU as well as at other institutions.

Key Words: Web-based, virtual experiments, visualization.

INTRODUCTION

The ODU-DLR Project

This paper presents results from an engineering education project at Old Dominion University (ODU), funded through the Department Level Reform (DLR) program of the National Science Foundation. The ODU-DLR project is directed towards achieving pedagogical improvements in engineering education through creation of new pathways employing technology-based tools to help students learn better. A multidisciplinary team of 12 faculty members from three engineering departments, namely civil, electrical and mechanical, have participated in this project which is transforming the way faculty teach and students learn. The project is helping faculty align themselves with the ongoing transformation of engineering education from traditional teacher-centric to student-centric, a modality in which students are the focal point of the learning process. Using unfettered access to the newly developed web-resources in this project, students are increasingly learning in the anytime-anywhere mode. Although the modules have been used primarily to supplement conventional in-class learning, another broader impact of these web-based modules is that they can potentially be used as building blocks to create highly interactive web-based courses and virtual labs for distance education programs.

The web-based modules, using simulation software and visualization techniques, have been developed, implemented and assessed to gauge their impact on student learning. The ODU-DLR project has addressed both lecture and laboratory courses. For lecture courses, the web-based simulation and visualization modules provide virtual interactive exercise sessions to reinforce students' learning of basic concepts and principles in engineering science courses. For the laboratory courses, modules have been developed in the form of virtual experiments that replicate important features of the corresponding physical experiments. A web-based tool "eLIVE" using virtual labs, has been developed, implemented and assessed for application involving pre-lab practice sessions to enhance students' understanding of experimental procedure and data acquisition before scheduled physical laboratory sessions. In the present paper, only a part of the project findings in the form of assessment results and lessons learned from implementation of "eLIVE" are presented for two laboratories namely, solid mechanics laboratory and thermo-fluids laboratory. The project results



pertaining to implementation of web-based virtual modules in lecture classes will be summarized in a forth coming paper.

Motivation and Relevance

The motivation to pursue this project has come from recent advances in computer, Internet communication and video technologies, hailed by many as the digital revolution, that have opened new pathways to information and knowledge. One area, namely computer-based interactive visualization, holds considerable promise for becoming a powerful teaching and learning tool in engineering education. This is because current engineering students are more attuned to visual learning due to extensive exposure to computers, videogames and the Internet. This fact is corroborated by Felder who in his classical paper "Learning and Teaching styles in Engineering Education" describes most college age students as visual learners [1]. Using computer-based visualization, engineering educators have developed a variety of educational tools such as web-based multimedia modules, virtual laboratories, software for simulation and visualization etc. for engineering courses [2-6]. Many visualization-based modules for engineering courses, developed by partners in the NSF-sponsored SUCCEED Coalition are also available to engineering educators in the SUCCEED engineering visual data base [7]. Application of web-based virtual experiments for providing hands-on experience has lagged because most engineering professors view physical laboratories as the primary means of providing students hands-on experience and practical know-how for engineering practice. As a result, many of them remain skeptical about using simulated virtual experiments for this purpose. However, it should be pointed out that the definition of "hands-on experience" itself is changing as industry increasingly relies on computer simulations and virtual reality [8]. Consequently the term does not necessarily imply dealing only with physical hardware. Instead, hands-on experience can also be realized in the virtual domain, using computer, the Internet and virtual reality tools. Some industrial leaders, as well as educational leaders, have suggested that computer modeling and visualization be used in an interactive mode to provide students hands-on skills now being demanded by industry [9-10].

There are two types of web-based laboratories that have been reported in the literature. In the first approach, known as remote laboratories, a learner can perform a physical experiment remotely on the Internet without having to visit a university campus [11-14]. Although this approach leverages web technology quite well, its principal drawback is that the bench type physical experiments used in engineering education must be modified extensively at great cost. The second type, known as virtual laboratories, is designed to mimic physical laboratories closely so that they can be used as an alternative method for providing hands-on experience in the virtual domain [15-21]. Although web-based virtual laboratories are more cost effective compared to remote laboratories, they too



have a major drawback. It is very challenging if not impossible, to give a web learner true feel of a physical phenomenon through a virtual experiment. This limitation arises from inherent difficulty in simulating a physical experiment and mapping it on a one-to-one basis to the virtual domain, regardless of the level of sophistication in modeling and simulation. This fact represents a major barrier to incorporation of web-based virtual laboratories in engineering curricula as reflected in engineering professors' reluctance to use them in lieu of physical laboratories.

Since web-based virtual experiments have been developed in a variety of ways, we have classified the previous work into three broad categories, namely interactive, collaborative, and immersive. Interactive web-based virtual experiments are those in which a single user interacts with the module by setting operating parameters and records data on a computer screen. The user is prompted to follow certain steps that emulate the procedure for conducting the corresponding physical experiment. A majority of virtual experiments reported in the literature belong to this category [15–23]. Web-based collaborative experiments use online collaboration of computers to allow users to perform experiments as a team whose members are at different locations, as would be the case for learners in distance education programs. Collaboration, in addition to interactivity requirement raises the level of challenge in both development and operation of this type of virtual experiments. Virtual laboratories reported in Refs. 24–25 belong to this category. Immersive virtual laboratories are an improvement over interactive virtual laboratories since they provide both interactivity as well as immersion to give users a sense of presence in laboratory environment similar to what they would encounter in physical laboratories. Examples of immersive virtual laboratories can be found in many areas of education such as physics education [26–27], medical education [28] and engineering education [29–30].

GOALS OF PRESENT STUDY

Although a literature review of virtual laboratories indicates that the state of the art has advanced considerably in recent years, past research is yet to be translated into educational strategies that would make virtual laboratories an integral part of engineering laboratory instruction. In the present study we have attempted to bridge this gap between research and practice by exploring a novel application in which virtual laboratories are used for pre-lab practice sessions to prepare students for physical experiments. Traditionally, students at ODU have prepared for physical laboratory sessions by reviewing a laboratory manual that describes the details of experiments. However, this approach has not worked in recent years and many students have come to the laboratory classes unprepared to perform the scheduled experiments. This has degraded their academic performance and has lowered the quality of learning. The alternative of laboratory instructor lecturing students



about various aspects of experiments is not a feasible option because it would take away valuable class contact time in a one-credit hour laboratory course. To address this issue, the authors have introduced "eLIVE" in laboratory courses and have required students to perform pre-lab practice sessions with virtual experiments to enhance their understanding of the experimental procedure and data acquisition. This combination of virtual and physical labs, representing an exciting application of virtual laboratories to engineering education, has significant potential for enrichment of students' laboratory experience, and this aspect is explored here in some detail. Simulated virtual practice sessions, embedded in "eLIVE", are designed to provide knowledge of experimental procedure as well as comprehension of expected relationships between physical variables that are to be measured. This prior knowledge, described in the literature as declarative knowledge [31], plays an important role as students acquire procedural knowledge from the physical experiment. Procedural knowledge is largely action-oriented knowledge that eventually leads to engineering skills [31].

The main hypothesis of this work can be stated as follows: "Since current students are more attuned to visualization due to their extensive exposure to computers, Internet and video gaming they are more likely to learn better, regardless of demographic factors, through their engagement with highly interactive web-based virtual pre-lab practice sessions designed to supplement physical laboratory experiments". To test this hypothesis, two web-based virtual experiments have been created, one each for solid mechanics laboratory (ME 225) and the thermo-fluids laboratory (ME 305) courses in the mechanical engineering curriculum at Old Dominion University. Assessment instruments have been developed and statistical methods have been applied to objectively determine whether "eLIVE" used in the "supplementation" mode enhances learning of an "experimental" group compared to learning of a "control" group of students that did not use the web-based virtual experiment.

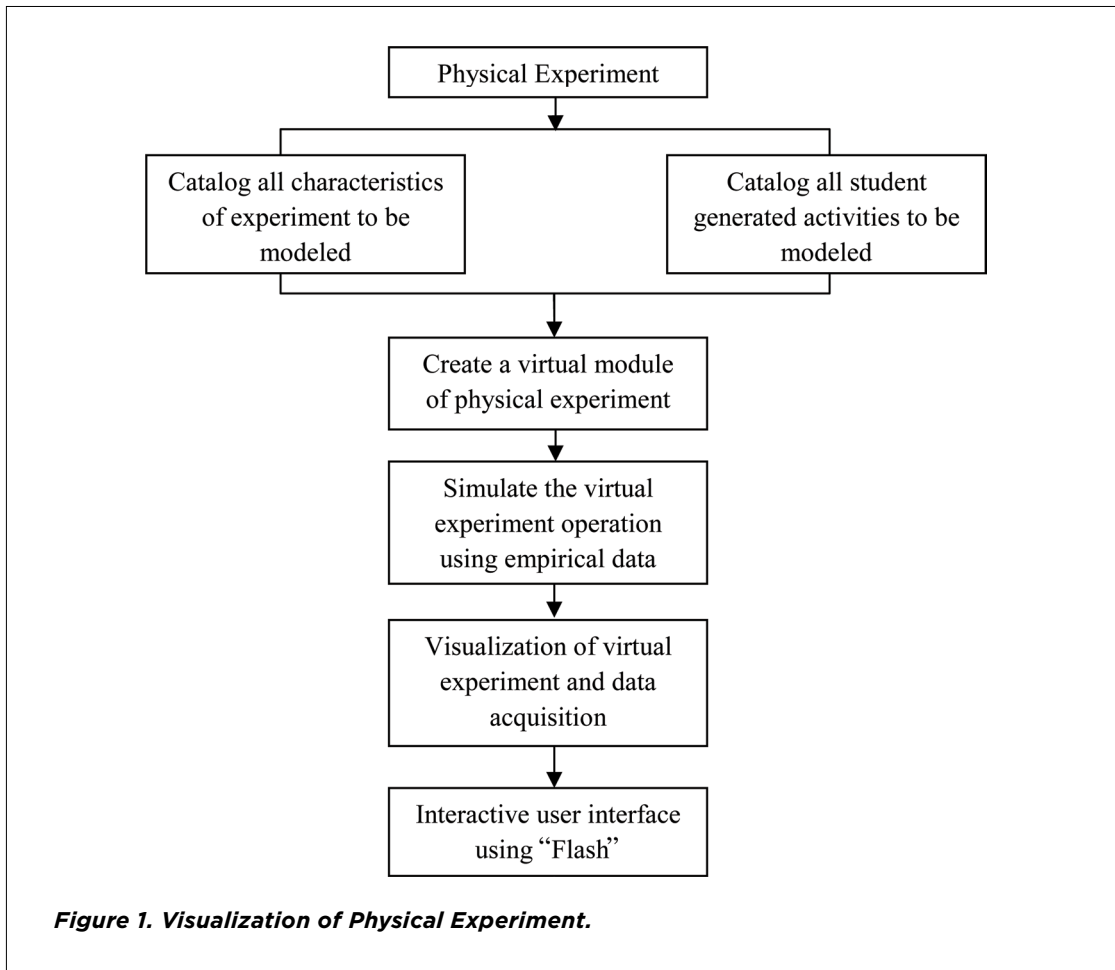
VIRTUALIZATION OF PHYSICAL EXPERIMENTS AND THE PEDAGOGY

Virtualization refers to a process of creating a virtual analog (software) of activities in a physical experiment, using modeling, simulation and visualization. This term has been used in computer science literature to describe the process of abstraction of computer hardware resources to build virtual machines. In the present context, this process creates virtual experiments that can be operated by a set of instructions coded into a computer program. The virtualized experiments are designed to include many hands-on activities that students are also expected to perform in the physical experiments. This process of "learning by doing" is considered by many educators as the best way to teach engineering students [32]. For example in the physical domain, 'learning by doing' can be achieved in a number of ways such as through class projects, laboratories and problem



solving. In the virtual domain, web-based learning modules of the type considered in this study provide students a platform to perform different tasks related to experiments. This is designated as "learning by doing in the virtual environments" (LDVE) pedagogy. This pedagogy has been discussed by Dede [33] in the context of distance education where learning by doing is accomplished in distributed domain due to geographical separation of learners. The "LDVE" pedagogy recognizes and incorporates an important tenet of engineering education that holds that students learn better by performing hands-on activities which in virtual domain would mean students interacting with a web-module through a computer keyboard or a mouse. In the present work we have used the "LDVE" pedagogy in conjunction with "eLIVE" to help students learn better in laboratory courses in conventional (on-campus) engineering programs. Although the primary mode of learning is still through physical laboratories, it is shown here that virtual practice sessions embedded in "eLIVE" can play a valuable role in preparing students for physical experiments.

For the visualization process to be effective, one needs to construct a good virtual model of a physical experiment that incorporates all the experimental characteristics and student-generated activities that are slated to be preserved in the physical-to-virtual transformation. Since virtual experiments are used primarily for pre-lab practice sessions to teach students about physical experiments, it is important that all the embedded activities in the virtual experiments follow a sequence similar to that in the corresponding physical experiment. This mapping process, shown in Fig. 1, is carried out in three steps. In the first step, a physical experiment is reviewed and important experimental characteristics and student-generated activities are cataloged for preservation in the physical to virtual domain transformation. Minimally, selected experimental characteristics and student-generated activities should be able to demonstrate the physics of the selected experiment. The second step is concerned with the type of data needed for recreation of the underlying physical phenomenon on a computer screen. There are two methods by which this data can be generated, numerically through modeling and simulation of the system or using the physical experiment to generate empirical data. In the numerical approach, a simplified model of the physical experiment is developed so that it can be analyzed using conservation equations governing the system. Once the system is modeled, its performance can be simulated by varying the operating parameters to develop a better understanding of the cause and effect relationship between parameters that are controlled or manipulated and parameters that are observed. The numerical data thus generated, can be used to visualize the system response on a computer screen. Since in many physical experiments, modeling and simulation of various processes may prove to be too complex and cumbersome, one can alternatively use empirical data obtained from the physical experiment to determine and visualize the virtual system's response. Although the empirical data approach may lack the elegance of a procedure involving numerical solutions of governing equations from the first principles, it is



often preferred as a time saving and practical way of designing and operating a virtual experiment. In the present study we have used the empirical data for creating back-end functionalities of the virtual experiment module. The third and the last step involves using a software that creates a user friendly visual interactive environment. In the present work, the Macromedia "Flash" software has been used to create the front-end functionalities of the virtual experiment module. This software possesses the ability to create highly interactive user interface (the front-end) which can receive inputs from the user and execute instructions based on input parameters.

The physical-to-virtual transformation presented here has one limitation. The experiments presented here are based on results for pre-selected operating conditions. In other words they are not based on real time modeling and simulation where operating conditions can be changed beyond the pre-selected operating conditions. In these real-time virtual experiments, the real-time transfer of data from the simulation program (the back-end of the module) to the front-end of the module



(the user interface) would be necessary. Thus far the authors have converted nearly six physical experiments into the virtual domain, with several more selected for transformation in the near future. Typically, the conversion of a physical experiment to virtual experiment requires about half man year of effort, provided the person involved, a graduate research assistant in this project, has some experience in programming in the "Flash" scripting language.

SOLID MECHANICS LABORATORY EXPERIMENT

The experiment, "Elastic Test of a Beam in Pure Bending", has been chosen for simulation and as a supplement to the Laboratory Manual for students' pre-lab preparation. This experiment is one of a dozen experiments in ME 225, Solid Mechanics Laboratory Sophomore course. The physical experimental set-up and its virtual analog are shown in Figure 2. The purpose of the experiment is to verify the basic assumption underlying the simple beam theory, namely that plane sections, transverse to the beam axis, remain plane after bending also; this leads to a linear variation of stress and strain across the beam depth. An aluminum beam with a rectangular cross-section (4 in. x 1.5 in.) is supported and loaded in four-point bending. Fourteen electrical resistance strain gages are bonded on the aluminum beam at various depths. The gages are connected to digital strain indicators through switching and balancing units.

In the physical laboratory experiment, the students measure the strains indicated by the various gages. The strains are also calculated from the bending stress, which is given by

$$\sigma = My/I \quad (1)$$

where σ is the bending stress, M is the bending moment at the strain gage location (the mid-section where the moment is maximum), I is the moment of inertia of the cross-section and y is the distance between the strain gage location and the neutral axis. The above equation is based on the assumption that plane sections remain plane. As Hooke's law is valid, the strains at any location (depth) can be computed from the equation

$$\epsilon = \sigma/E \quad (2)$$

where ϵ is the bending strain and E is the Young's modulus of the beam material. The computed strains are compared with the measured strains.

In the physical laboratory, the support bar, the beam specimen and the loading bar are positioned in the testing machine for compressive loading of the loading bar, leading to the bending of the beam. The strain gages are pre-installed on the beam specimen. The students adjust the gage factor

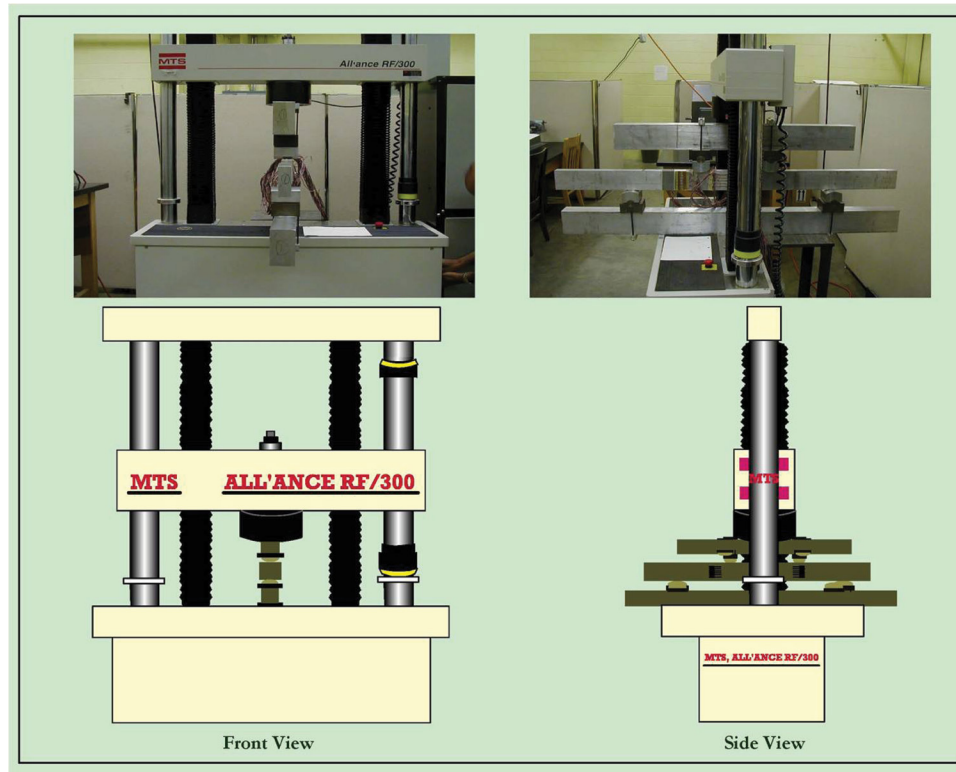


Figure 2. Physical Experiment and Virtual Model for Solid Mechanics Laboratory.

for each strain gage and 'balance' each gage under a preload of 500 lbs. The load on the beam is increased in increments of 1000 lbs. up to 5000lbs; at each load, the gage readings are noted/recorded. The measured and computed strains across the beam depth are plotted for various loads. The degree of agreement between the computed and measured strains indicates the validity of the assumption that 'plane sections remain plane'. The details of the virtual experimental procedure are given on the website <http://www.mem.edu.edu/bendingtest>

In the virtual experiment, the students are enabled to perform many of the steps that are part of the physical experiment. For instance, adjustment of the gage factor, balancing the gages, applying the beam loads, etc. Some of the steps that are not performed by the student in the physical laboratory, such as positioning the support bar, beam and the loading bar, as well as bonding the strain gages on the beam specimen, are simulated by the students in the virtual experiment. However, due to the limitations of the software, the rotary knobs on the physical strain-measuring instrument are simulated by up-and-down arrows.



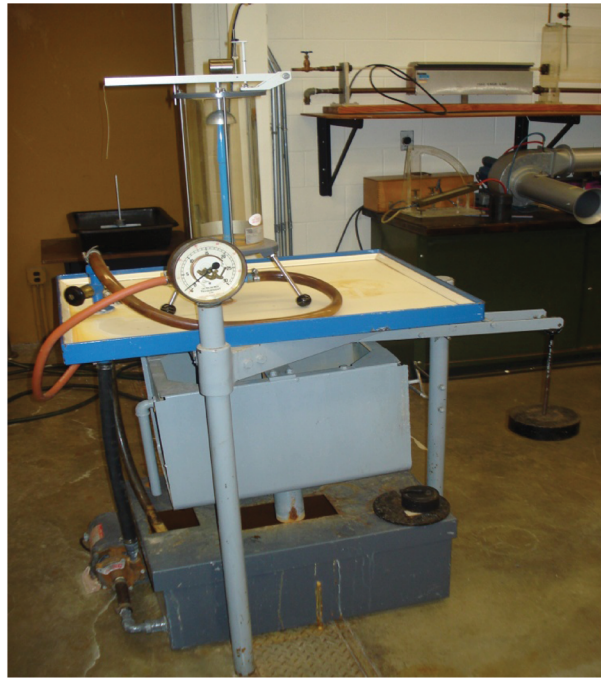
THERMO-FLUIDS LABORATORY EXPERIMENT

In this junior level laboratory, the experiment titled "Jet Impact Force on Vanes" has been chosen for the physical-to-virtual transformation. Both the physical experiment and its virtual analog are shown in Fig. 3. Students using this experiment determine the impact force arising from the reversal of a water jet after hitting a vane. The underlying principle of this experiment is the Newton's second law applied to a control volume enclosing the vane. The resultant jet impact force (F) is governed by two factors namely the jet mass flow rate (\dot{m}) and the shape of the vane. The equation relating F and (\dot{m}) can be expressed

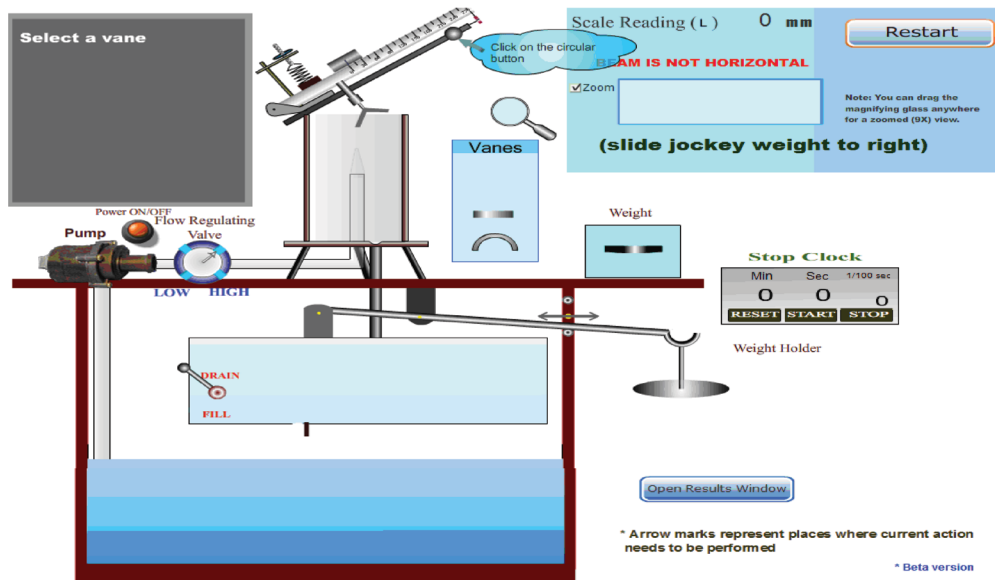
$$F = c\dot{m}^n \quad (3)$$

c is a constant that depends on the degree of reversal, characterized by the vane shape. The experiment involves vanes that produce a degree of reversal of 180° , 150° , and 90° . In the experiment, students measure force (F) and the jet mass flow rate (\dot{m}), and determine constants c and n from acquired data. The jet force is measured by 'moment of force' method. Water from a storage tank is pumped through a nozzle to create a jet directed towards a vane mounted on a pivoted arm on which a known jockey weight can slide. The deflected beam is returned to its balanced (horizontal) position by sliding the jockey weight on the spring loaded pivoted arm. The balanced position is achieved when the moments of the jockey weight, the spring force and the vane weight about the pivot point equal the opposing moment of the jet impact force. The displaced position of the jockey weight (L) is recorded. Through the moment balance equation, one can determine the jet impact force. The mass flow rate is determined by water collection method. In this method a known amount of water is collected in a storage tank over a recorded period of time (t). Details of both physical and virtual experiment are given on the website <http://www.mem.odu.edu/jetforce>

Since the primary goal of the virtual experiment is to teach the experimental procedure and data acquisition activities, it is important that features and activities related to these objectives are carefully cataloged and replicated. Students after conducting the virtual experiment should not only recognize all the distinctive features and parts of the physical experiment, but they should also be able to conduct the experiment smoothly without missteps. Twelve student-generated activities and eleven physical attributes are mapped into the virtual experiment. However, there are two major differences between the physical experiment and its virtual counterpart that should be noted. First, the virtual experiment is modeled in 2-D while the physical experiment is in 3-D. This is justified by the argument that since students see the physical apparatus in the laboratory, a 2-D virtual model is sufficient to teach them about lab procedure. A 3-D modeling will increase programming effort many fold and it has not been pursued further for the application discussed in this paper. However,



Physical set-up



The 2-D virtual experiment

Figure 3. Physical set-up and the 2-D virtual experiment.



it is important to note that a 3-D virtual model is highly recommended for those applications where the virtual experiment is to be used in lieu of the corresponding physical experiment. A 3-D virtual reality experiment with some level of immersion will be more appropriate for those applications. Secondly, the mechanism for changing the spring tension in the experiment involves a rotational movement of a screw. This movement is accomplished in 2-D virtual analog by a linear motion mechanism that creates a rotational effect.

Students in both the laboratory courses have been required to prepare for the physical laboratory sessions by reviewing the web-based virtual experiments. Since the objective of the pre-lab sessions is to provide an environment for self-learning on the web, no faculty assistance is provided during the pre-lab practice sessions.

ASSESSMENT DATA CHARACTERISTIC

To objectively determine whether the implemented virtual experiment modules had contributed to enhance students' learning effectiveness compared to the pre-implementation condition, i.e., was there any difference in the mean scores of quizzes and tests under "Without Module" (=control group) and "With Module" (=experimental group) virtual experiment module settings, course outcomes were collected and statistically analyzed for two courses in the mechanical engineering curriculum at Old Dominion University. Detailed information on these two courses is tabulated in Table 1.

Instead of simply comparing the arithmetic means of outcomes and subsequent visual display of graphs, which is limited to the descriptive statistics on per-event sample data and seldom provides

Course		Category Analyzed / Outcome Composition
ME 225	ME Lab II-	Fall Semester 2006
	Solid Mechanics (N = 29)	Control Group (10681/Without the module, n = 15) vs. Experimental Group (10682/With the module, n = 14)
ME 305	ME LAB III-	Fall Semester, 2006
	Thermo-Fluids (N = 32)	Control Group (10683/Without the module, n = 15) vs. Experimental Group (10684/With the module, n = 17)

Table 1. Courses Analyzed for Assessing Students' Learning Effectiveness Contributed by Implemented Virtual Experiment Module.



any population-level intrinsicity (=true module effectiveness), standard statistical analysis methodology (in form of experimental designs) was applied to make an objective and correct inference about the population-level intrinsicity or module effectiveness.

Standard gradebook data containing "Without Module" (=control) and "With Module" (=experimental) virtual experiment module outcomes in the form of numeric scores of quizzes and final total with student University Identification Number (UIN) were first collected from instructors. Subsequently, gradebook data were sent to the office of Institutional Research and Assessment (IRA) to further match and join the outcome data with student demographic data using student UIN as a common key attribute. Once joined, student UIN was then removed for the dataset to ensure the compliance to the Family Educational Rights and Privacy Act (FERPA)[34]. Selection of student demographic data categories were based on their potential influence/contribution to student's performance such as Degree/Major, Gender/Age, Attempt Hours, Passed Hours, Earned Hours/Transfer credit hours, Associate degree, Cumulative GPA, Current class load, Verbal and Math SAT scores and High school GPA. Detailed information on the joined outcome dataset used in the assessment is summarized in Table 2.

Joined student datasets were then used for statistical analysis to determine whether implemented virtual experiment modules had contributed to enhance students' learning effectiveness based on mean differences in course outcomes. Student demographic factors were also statistically analyzed to assess whether such demographic factors also contributed to student's performance under "Without Module" (=control) and "With Module" (=experimental) virtual experiment module settings, i.e., did some of demographic factors by themselves contribute to course outcomes regardless of module implementation?

STATISTICAL EXPERIMENTAL DESIGN FOR ASSESSMENT

Student outcome dataset joined with demographic data were tested first for normality using a standard Shapiro-Wilk W-statistics [35] at 95% level of confidence ($\alpha = 0.05$). Shapiro-Wilk W-statistic is the ratio of the best estimator of the variance (based on the square of a linear combination of the order statistics) to the usual corrected sum of squares estimator of variance. W-statistic ranges between zero and one, with small values of W leading to rejection of the null hypothesis of normality. Verification of sample normality is a critical step to ensure the validity of subsequent data analysis, both univariate and multivariate. For both laboratory courses, Shapiro-Wilk W-statistics for outcomes were significant ($\text{Pr} < W \lll 0.05$) indicating that the sample distribution of outcomes (Quiz #1, #2, Quiz total and Total score) are not normally distributed at $\alpha = 0.05$ level. Distributions



Category Attribute	Description
Callno	ODU Course CALL Number (CRN)
Sem	Semester for the ODU Course CALL Number (CRN)
UIN	ODU University ID (Removed/FERPA)
PIDM	ODU Banner ID (Removed/FERPA)
[Final Grade][Final Score]	Course final letter grade and total score. Depending on the extent of course topics implemented in the module, final total score may or may not reflect the effectiveness of implemented module. Typically, it is not directly proportional to module effectiveness.
[Quiz/Outcome], , ,	Assessment scores with and without the Module. Typically in form of Quizzes, ranging from two quizzes to 6 quizzes.
STUD_GENDER_DESC	Gender
STUD_ETHN_DESC	Ethnicity; White (Non-Hispanic), Black (Non-Hispanic), Asian Pacific Islander, Hispanic, Other, Missing Not Provided (=N/A)
STUD_MAJOR1	Abbreviation for Major (such as "ME" for Mechanical Engineering). Student's current major can be "undecided" (=N/A).
STUD_MAJOR1_DESC	Full description of Student's Major (such as "Mechanical Engineering").
CUML_HRS_EARN_TRANS	Transfer hours. Note that some students may have stayed in several institutions and therefore have many transfer hours, but some hours may be redundant and some may not be recognized by ODU.
STUDLVL	Student level (such as ""Junior" and "Senior," etc.). This variable is determined by student's credit hours.
Byr	Year of Birth
GPAHR	Cumulative GPA hours during current semester.
EARNHR	Earned hours during current semester. The cumulative hours are their institutional hours only (credits taken at ODU).
ATTEMPTHR	Attempted hours during current semester.
PASSHR	Passed hours during current semester.
earnhr_cum	Earned hours up to current semester.
attempthr_cum	Attempted hours up to current semester.
gpa_cum	Cumulative GPA up to current semester.
Ind_fresh	Transfer or First year. If a student comes to ODU as a non-degree student and then later enters a program, s/he would have a blank in this variable.
DEGREE_CODE	Whether a student holds an Associate degree in Science (AS). AS (means yes) or blank (means no).
SAT_V	SAT Verbal score.
SAT_M	SAT Math score.
hsgpa	High school GPA. Many transfer students do not have these values.

Table 2. Joined Student Outcome Datasets with Demographic Data Category.

of these non-normally distributed course outcomes were also significantly leptokurtic due to some of very high outcome scores.

To obviate such non-normality problem, a median-based one-way, pairwise nonparametric statistics, Wilcoxon Rank Sum statistics [36–38] was used to test the hypotheses on central tendency and



dispersion in place of typical studentized t-test to compare paired median as well as variance of all course outcomes (Quiz #1, #2, Quiz total and Total score) at 95% level of confidence ($\alpha = 0.05$).

$$H_0: \bar{\mu} [\text{Course Outcomes}\{\text{Without Module}\}] = \bar{\mu} [\text{Course Outcomes}\{\text{With Module}\}]$$

$$H_a: \bar{\mu} [\text{Course Outcomes}\{\text{Without Module}\}] < \text{ or } > \bar{\mu} [\text{Course Outcomes}\{\text{With Module}\}]$$

At 95% confidence level, if Wilcoxon Rank Sum p -value is less than 0.05, then a conclusion can be made that there is a significant difference between the mean scores of the course outcome being compared at their population levels, or mean scores of the student performance under “Without Module” (=control) and “With Module” (=experimental) virtual experiment modules are different. After “Without Module” and “With Module” comparisons were done, hypotheses on the course outcomes were subsequently tested again in conjunction with students’ demographic data to identify any potential influence of demographic factors toward the course outcomes.

$$H_0: \bar{\mu} [\text{Course Outcomes}\{\text{Without Module}||\text{DemoVar}\}]$$

$$= \bar{\mu} [\text{Course Outcomes}\{\text{With Module}||\text{DemoVar}\}]$$

$$H_a: \bar{\mu} [\text{Course Outcomes}\{\text{Without Module}||\text{DemoVar}\}]$$

$$< \text{ or } > \bar{\mu} [\text{Course Outcomes}\{\text{With Module}||\text{DemoVar}\}]$$

In the same manner, at 95% confidence level, if Wilcoxon Rank Sum p -value is less than 0.05, then a conclusion can be made that mean scores of the course outcome from “Without Module” (=control) and “With Module” (=experimental) virtual experiment modules are significantly different due to contribution from the particular demographic variable. There were a maximum of 106 [2 {Without/With} x {53 pair combinations of demographic factors}] pairwise Wilcoxon Rank Sum comparisons possible for each course outcome dataset when the demographic factors were juxtaposed. However, typical number of pairwise comparisons ranged between 50 to 70 since some of pairwise combinations fell into ‘no matching’ category in assessed outcome datasets. As a result, 53 pair combinations of sub-blocked demographic factors were used in this assessment as summarized in Table 3.

To compare contribution of “Without Module” (=control) and “With Module” (=experimental) virtual experiment modules settings toward enhancing students’ learning effectiveness, standard RCB (Randomized Complete Block) design [39] was used to construct control Treatment levels (“Without Module” and “With Module) with Blocks (demographic factors). Since the majority of demographic factors have multiple sub-levels, Blocks are further nested to replicate and randomize such sub-block elements. All analyses were conducted by using SAS/STAT Statistical Analysis System [40] available on the ODU LIONS SunGRID HPC computing cluster.



Demographic Variable	No. of Sub-Blocks	Level	No. of Pairs Combination (nC2)
Gender	2	Male, Female	1
Ethnicity	6	White (Non-Hispanic), Black (Non-Hispanic), Asian Pacific Islander, Hispanic, Other, Missing Not Provided (=N/A)	15
Student level	4	Freshman, Sophomore, Junior, Senior	6
Age Group	3	<25 yrs., 25-<35 yrs. old, 35 or older	3
Class load for Current Semester	3	0-6 cr. hrs, 7-12 cr. hrs, more than 12 cr. hrs.	3
Cum. GPA upto Current Semester	4	2.5 or less, >2.5-3.0, >3.0-3.5, >3.5-4.0	6
Transfer or First year	2	Transfer, First year	1
SAT Score / Verbal	5	N/A, less than 400, >400-500, >500-600 >600-700, >700-800	10
SAT Score / Math	4	N/A, less than 500, >500-600, >600-700, >700-800	6
High school GPA	3	N/A, less than 3.3, >3.3-3.8, above 3.8	2
Total (=Without/With * Pair Combinations)			106

Table 3. Pairwise Combinations of Students’ Demographic Category Variable with Sub-Blocks used in Wilcoxon Rank Sum Test.

Structure of the Randomized Complete Block design used to construct Treatment levels (“Without Module” and “With Module”) with Blocks (demographic factors) correlations for this assessment study is shown below.

$$y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \quad (i = 1, \dots, \text{Treatments}; j = 1, \dots, \text{Blocks})$$

where

y_{ij} = Response on (i, j) th Obs. (Course outcomes – Quiz #1, #2, Quiz total and Total score)

μ = Overall mean

τ_i = i th Treatment effect (“Without Module” and “With Module”)

β_j = j th Block effect (demographic factors, nested with sub-blocks)

ϵ_{ij} = Random error due to (i, j) th observation. $\epsilon \sim \text{NID}(0, \sigma^2)$

a) T.H. for Treatment effects (“Without Module” and “With Module”)

at 95% level of confidence

$$H_0: \tau_1 = \tau_2 = 0$$

$$H_a: \text{At least one } \tau_i \neq 0$$

b) T.H. for Block effects (demographic category variables) at 95% level of confidence

$$H_0: \beta_1 = \beta_2 = \dots = \beta_b = 0$$

$$H_a: \text{At least one } \beta_i \neq 0$$



RCB designs were then applied to and evaluated for Solid Mechanics Laboratory (ME 225) and Thermo-Fluids Laboratory (ME 305) course outcomes to assess the effectiveness of implemented virtual experiment module using Quiz #1, #2, Quiz total and Total scores.

$$H_0: \tilde{\mu} [\text{Course Outcomes}\{\text{Without Module}||\text{DemoVar}\}] = \tilde{\mu} [\text{Course Outcomes}\{\text{With Module}||\text{DemoVar}\}]$$

$$H_a: \tilde{\mu} [\text{Course Outcomes}\{\text{Without Module}||\text{DemoVar}\}] < \text{ or } > \tilde{\mu} [\text{Course Outcomes}\{\text{With Module}||\text{DemoVar}\}]$$

	i		I		I	
	j	j	J	J	j	j
Without Module	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)
With Module	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)	Ourtcome(k)

where

Treatment: Two levels (Without and With module)

“i” Block components : 10 demographic factors

“j” Nested sub-Block components : 54 comparative pairs of demographic factors

“k” Outcomes: Quiz #1, #2, Quiz total and Final Total scores

(i = 1, 2, 3, ..., 10; j = 1, 2, 3, ..., 15; k = 1, 2, 3, ..., 4)

ASSESSMENT RESULTS

Solid Mechanics Laboratory (ME 225)

Overall, no significant difference was observed in Final Total Score, Quiz #2 and Quiz Total scores between “Without Module” (n = 15) and “With Module” (n = 14) virtual experiment modules. However, “With Module” setting has a statistically significant higher mean of Quiz #1 score compared to “Without Module” setting indicating that students acutely responded the topical coverage implemented in the virtual experiment ($p = 0.0183$ at $\alpha = 0.05$). Majority of demographic factors (Gender, Ethnicity, Student Level, Age Group, Class Load for Current Semester, Cumulative GPA, Transfer, SAT Verbal Score, SAT Math Score, and High School GPA) were insignificantly contributing toward student learning effectiveness at 95% level of confidence for both “Without Module” and “With Module” settings. Thus it is highly likely that the module was the sole factor contributing to the difference in student learning effectiveness. Noticeably, there was a significant difference in the Final Total score under the demographic categories of Student Level and cumulative GPA indicating the upper-class and/or the higher GPA group students responded better to implemented virtual experiment module.



Thermo-Fluids Laboratory (ME 305)

"With Module" ($n = 17$) setting had significantly higher means of Quiz #1, #2, and Quiz Total scores than those from "Without Module" ($n = 15$) setting. However the difference in the means of Final Total scores remained insignificant between "Without Module" and "With Module." Thus, it again enforces the finding that students acutely responded the topical coverage implemented in the virtual experiment (Quiz #1: $p = 0.0278$; Quiz #2: $p = 0.0165$; Quiz Total: $p = 0.01$ at $\alpha = 0.05$), and implemented module significantly contributed to students' learning effectiveness in topics tested in Quiz #1, #2, and correspondingly improved the mean of Quiz Total scores.

Correspondingly, it is observed that the implemented virtual experiment module did enhance the level of student learning effectiveness in general since the most of contributing demographic factors were not statistically significant for mean scores of Quiz #1, #2, Quiz Total and Final Total Scores. With implemented module, the Senior student group responded better than the Junior student group in Final Total score, but not in Quiz #1, #2 and Quiz Total -- which suggests the Final Total Score difference was likely to be contributed by related knowledge that the Senior student group had gained in their ME major curriculum. Also observed was that the above-average GPA group responded significantly better to the implemented module than the low GPA group. All other demographic factors (Gender, Ethnicity, Age Group, Class Load for Current Semester, Transfer, SAT Verbal Score, SAT Math Score, and High School GPA) did not contribute to the outcomes of the module, indicating that implemented virtual experiment modules were the ones that improved the level of student learning effectiveness in their corresponding topical areas.

In conclusion, implemented virtual experiment modules had enhanced the level of student learning effectiveness in their corresponding topical areas with statistical significance at $\alpha = 0.05$ level for both in Solid Mechanics Laboratory (ME 225) and Thermo-Fluids Laboratory (ME 305) courses in the mechanical engineering curriculum at Old Dominion University, based on the **statistical outcome assessment** conducted on the course outcome data in conjunction with student demographic factors.

STUDENT SURVEY RESULTS

At the end of the semester, students belonging to the "experimental" group were given a survey form containing a series of questions framed to capture qualitative feedback from students concerning various aspects of the virtual pre-lab practice sessions in both solid mechanics and thermo-fluids laboratory courses. The survey form used the Likert scale of 1 to 5, with number one and five signifying students' strong disagreement and strong agreement respectively with a posed question. The purpose of this qualitative assessment is two-fold: (a) to gauge students' perception



Questions	Rating ODU	Rating ECU
1. The prelab practice module was helpful in understanding activities involved in experimental procedure.	4.8	4.4
2. The module improved my understanding of what parameters needed to be measured in the physical experiment.	4.8	4.15
3. After reviewing the module, I had a better understanding of potential errors involved in the experiment.	4.8	4.45
4. The module enhanced my understanding of theoretical basis for relationship between the jet impact force and the mass flowrate.	4	4.3
5. Overall, the module was effective in preparing me for the actual physical experiment session.	4.8	4.45
6. The module, through simulation and visual effects, replicated the actual physical experiment well.	4.8	4.25
7. More visualization modules of the type presented here should be developed for other physical experiments in the laboratory.	4.6	4
8. The prelab practice module was user friendly.	4.4	3.9
9. The time allocated for reviewing the module was adequate.	4.6	3.75
10. The dynamic visual images in the module helped me retain information for a longer time compared to the laboratory manual.	4.6	4.15
11. The module exposed me to information not readily available in the lab manual.	4.8	3.9

(RATINGS : 5-STRONGLY AGREE,4-AGREE,3-NEUTRAL,2-DISAGREE,1-STRONGLY DISAGREE)

TABLE 4. Students' Responses with Averaged Score for Each Question.

(positive or negative) concerning the pre-lab practice sessions, and its usefulness for preparing them for the physical experiments, (b) students' comments and suggestions for further improvement of virtual experiment module. The latter aspect was of particular interest to the authors since student comments in the initial phase of development were particularly useful in correcting the shortcomings or bugs in the beta-version of the modules. Table 4 shows the weighted averages for the ten questions in the student surveys conducted in the solid mechanics laboratory for the four semesters. Results indicate that students rated various aspects in range of 3.7 to 4.6, generally agreeing that the pre-lab virtual practice sessions were helpful in preparing them for the physical experiments.

In order to disseminate the results from this project, a partnership was established with the Department of Engineering at East Carolina University (ECU), with one of the co-authors taking the lead in making the "Jet Impact Force" virtual experiment module available to ECU students for pre-lab practice session. The physical experiment and lab instructions in the thermo-fluids lab at ECU are similar to the one at ODU. The student feedback at ECU was obtained for the same ten questions that were also used for the thermo-fluids laboratory at ODU. The weighted average results of student-response to survey questions is shown in Table 5 which also presents results from the



Questions	Fall 2006	Spring 2007	Fall 2007	Spring 2008
1. The prelab practice module was helpful in understanding the activities involved in the actual experiment.	3.8	4.5	4.3	4
2. The module helped me to visualize the hardware (specimen, loading fixture, testing machine, etc) used in experiment.	4	4.5	4.6	4.1
3. After seeing the module, I was better able to understand the objective of the experiment.	3.9	4.3	4.5	4.1
4. The module helped me to understand the strain gage: the gage, wire connections and the gage locations.	3.6	4.4	4.6	4
5. The module helped me to understand how the initial gage reading is zeroed.	3.5	4.3	4.3	3.8
6. The module helped me to understand what the 'gage factor' means and how it is adjusted on the strain indicator.	3.7	3.9	3.9	3.7
7. The virtual experiment on the computer prepared me better to conduct the actual experiment in the lab.	3.5	4.1	4.3	3.9
8. Because of the module, I was able to see what measurements needed to be taken in the experiment.	3.7	4.2	4.2	4.1
9. Because of the module, I was able to see how the readings had to be processed to get the desired results.	4	4.1	4.3	3.9
10. I recommend that similar modules be developed for other experiment.	4.1	4.2	4.3	4.3

TABLE 5. Student Survey of Bending Experiment Module (Solid Mechanics Laboratory).

survey of ODU students. As noted from Table 5, student groups at both ECU and ODU generally had a positive feedback about the usefulness of the virtual experiment for pre-lab practice session.

CONCLUSION

Two web-based virtual analogs of physical experiments from the undergraduate solid mechanics and the thermo-fluids laboratory were developed, implemented and assessed for pre-lab practice applications. The assessment was done using a statistical experimental design in which the student population was divided into a "control group" (without access to the virtual module) and an "experimental" group (with access to the virtual module). In the "control" group, learning about the experimental procedure was achieved conventionally through a lab manual while in the "experimental" group the students used web-based modules to supplement learning from the lab manual. Identical in-class quizzes were administered to both the groups prior to the scheduled physical experiment. Any positive difference in student performance quizzes for both the groups, as indicated by class averages, was taken as an indication of student learning gain. The average quiz scores for the "experimental"



groups were consistently higher compared to the "control" groups for both the laboratory courses. Assessment data, from each laboratory course, was analyzed further to determine which of the ten demographic factors namely gender, ethnicity, student level, age group, semester class load, cumulative GPA, transfer SAT verbal score, SAT math score and HS GPA are statistically significant or insignificant. A non-parametric analysis method known as Wilcoxon Rank-Sum Method, accounting for non-normality of the data, was used and the results for ME 225 (solid mechanics lab) indicated that all demographic factors considered were statistically insignificant for the web-based module embedded in the course. Since the learning gain of "experimental" group was statistically significant as compared to the "control" group, a direct conclusion one can draw is that this learning gain is singularly due to the web-based virtual experiment module since statistical analysis has ruled out the other ten factors. For the thermo-fluids laboratory experiment the learning gain of the "experimental" group was also statistically significant and eight of the ten demographic factors were indicated to be insignificant by a similar statistical analysis. The two factors, namely, student overall GPA (academic performance to date) and student academic level (Senior, Junior etc.) were statistically significant but due to relatively small sample size no definitive conclusion could be drawn.

Student surveys and comments obtained at both ODU and ECU indicated, in general, a positive disposition of the students towards the virtual pre-lab practice sessions as a means for learning about the physical experiments and experimental procedure. Based on statistical analysis of assessment data we conclude that the pedagogy of supplementing physical laboratory with web-based virtual laboratories contributes significantly to student learning gain for the two engineering laboratory courses considered in this study. Furthermore, "eLIVE" is shown to have no bias towards most of the student demographic factors considered in this study. Based on results of this study, the authors believe that the pedagogy of supplementing physical laboratory instruction with web-based tools such as "eLIVE" has great potential for applications to laboratory courses in other engineering disciplines. Even though the emphasis of the present study is primarily on assessment of "eLIVE" in the "supplementation" mode, it should be pointed out that it also has significant potential, although not explored in this work, for use in the "stand-alone" mode for distance learning applications.

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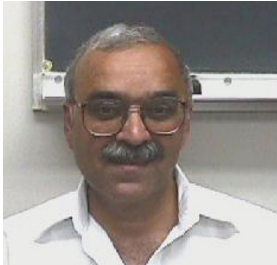


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