AC 2012-3981: IMPROVING STUDENT LEARNING USING FINITE ELEMENT LEARNING MODULES: AN UPDATE IN RESEARCH FINDINGS

Dr. Ashland O. Brown P.E., University of the Pacific

Ashland O. Brown, Ph.D., P.E. is currently a professor of mechanical engineering at the University of the Pacific School of Engineering and Computer Science. He served as a Program Director in the Mechanical/Civil Engineering Section of the National Science Foundation from 1998 to 1999. He served as Dean of Engineering at the University of the Pacific from 1991 to 1998 and Dean of Engineering Technology at South Carolina State University from 1989 to 1991. He served as an Engineering Group Manager for the Body Structures Design Group at General Motor Corporation in the Warren Technical Center from 1984 to 1989, and served as a Engineering Principal Engineer for a number of engine and structural design groups at Ford Motor Company from 1977 to 1984. He served as a Research Engineer at Eastman Kodak Corporation from 1974 to1977. He received his M.S. (1970) and Ph.D. (1974) in mechanical engineering from the University of Connecticut in Storrs, Conn. and his B.S. (1966) in mechanical engineering from Purdue University in West Lafayette, Ind. He is currently the PI at the University of the Pacific for the four-year collaborative National Science Foundation TUES DUE grant entitled "Improving Learning for Undergraduate Engineering Programs using Finite Element Learning Modules," a joint collaboration award with the University of Texas, in Austin. He has authored approximately 50 papers with more than 20 on using finite element learning modules in undergraduate engineering. He was the PI for the initial four-year NSF CCLI grant entitled "The Finite Element Method Exercises for use in Undergraduate Engineering Programs."

Dr. Daniel D. Jensen, U.S. Air Force Academy

Dan Jensen is a professor of engineering mechanics at the U.S. Air Force Academy where he has been since 1997. He received his B.S. (mechanical engineering), M.S. (applied mechanics) and Ph.D. (aerospace engineering science) from the University of Colorado, Boulder. He has worked for Texas Instruments, Lockheed Martin, NASA, University of the Pacific, Lawrence Berkeley National Lab, and MSC Software Corp. His research includes design of Micro Air Vehicles, development of innovative design methodologies, and enhancement of engineering education. Jensen has authored approximately 100 papers and has been awarded more than $2.5 million in research grants.

Dr. Joseph J. Rencis P.E., Tennessee Technological University

Joseph J. Rencis is Dean of Engineering, Clay N. Hixson Chair for Engineering Leadership, and professor of mechanical engineering at Tennessee Technological University. From 2004 to 2011, he was in the Department of Mechanical Engineering at the University of Arkansas, Fayetteville and was Department Head, inaugural 21st Century Leadership Chair in Mechanical Engineering, and professor. From 1985 to 2004, he was professor and Director of engineering mechanics in the Mechanical Engineering Department at Worcester Polytechnic Institute. His research focuses on boundary element methods, finite element methods, atomistic modeling, and engineering education. He currently serves on the editorial board of Engineering Analysis with Boundary Elements and the Journal of Online Engineering Education. He is an Associate Editor of the International Series on Advances in Boundary Elements. Currently, he serves as Chair of ASEE Professional Interest Council (PIC) III, an ABET program evaluator, and a member of the ASME National Nominating Committee. He received the 2002 ASEE New England Section Teacher of Year Award, 2004 ASEE New England Section Outstanding Leader Award, 2006 ASEE Mechanics Division James L. Meriam Service Award, and 2010 ASEE Midwest Section Outstanding Service Award. Rencis is a fellow of ASEE and ASME. He received a B.S. from Milwaukee School of Engineering in 1980, a M.S. from Northwestern University in 1982, and a Ph.D. from Case Western Reserve University in 1985. V-mail: 931-372-3832; Email: jjrencis@tntech.edu.

Prof. Kristin L. Wood, Singapore University of Technology and Design

Kristin L. Wood is currently a Professor, Head of Pillar, and co-Director of the International Design Center (IDC) at Singapore University of Technology and Design (SUTD). Wood completed his M.S. and Ph.D. degrees in mechanical engineering (Division of Engineering and Applied Science) at the California Institute of Technology, where he was an AT&T Bell Laboratories Ph.D. Scholar. Wood joined the faculty at the University of Texas in Sept. 1989 and established a computational and experimental laboratory for research in engineering design and manufacturing. He was a National Science Foundation Young Investigator, the Cullen Trust for Higher Education Endowed Professor in Engineering, and University Distinguished Teaching Professor at the University of Texas, Austin.

Prof. Kyle A. Watson, University of the Pacific

Kyle Watson earned his B.S. in mechanical engineering from Villanova University and his M.S. and Ph.D. in mechanical engineering from North Carolina State University. He has been a faculty member at the University of the Pacific since 2003 and has taught undergraduate courses in thermodynamics, heat transfer, combustion, air-conditioning, dynamics, and senior capstone design.

Dr. Chuan-Chiang Chen, California State Polytechnic University, Pomona

Chuan-Chiang Chen is an Associate Professor in the Mechanical Engineering Department at California State Polytechnic University, Pomona since 2009. He earned his B.S. degree from National ChiaoTung University, Taiwan, and his M.S. and Ph.D. degrees from the Ohio State University, all in the field of mechanical engineering. Prior to joining Cal Poly Pomona, he was an Assistant Professor in the Mechanical Engineering Department at Tuskegee University. His teaching and research interests include solid mechanics, system dynamics, measurements, noise, and vibrations.

Dr. Vladimir A. Labay, Gonzaga University

Currently, Vladimir Labay is a professor and Chair of the Department of Electrical and Computer Engineering at Gonzaga University in Spokane, Wash., USA. Labay was born in Winnipeg, Manitoba, Canada and earned a B.Sc.(E.E.) and M.Sc.(E.E.) from the University of Manitoba. After graduating with a Ph.D. from the University of Victoria in 1995, he remained in Victoria, British Columbia, Canada as a lecturer and research engineer until he accepted an Assistant Professor position in 1999 at Eastern Washington University located in Cheney, Wash., USA. In 2007, Labay was a visiting scholar at SRM University in Chennai, India. His research interests include modeling of and the development of microwave/millimeter-wave integrated circuit devices used in wireless and satellite communications.

Dr. Ismail I. Orabi, University of New Haven

Ismail Orabi is professor of mechanical engineering, University of New Haven. Orabi has been performing research and teaching in the areas of machine design, mechanical vibrations, and dynamic systems and control. His research efforts have received support and awards from NASA, NSF, the state of Connecticut, and United Technologies. He received the ASEE Instrumentation Division Best Paper Award. He has published more than 30 refereed journal articles and conference publications.

Dr. Firas Akasheh, Tuskegee University

Firas Akasheh is an Assistant Professor at the Mechanical Engineering Department at Tuskegee University. He obtained a Ph.D in mechanical engineering from Washington State University in 2007. Besides his research interest in computational material science, he has interest in engineering education.

Dr. John J. Wood, U.S. Air Force Academy

John J. Wood is currently an Associate Professor of engineering mechanics at the United States Air Force Academy. Wood completed his Ph.D. in mechanical engineering at Colorado State University in the design and empirical analysis of compliant systems. He received his M.S. in mechanical engineering at Wright State University and his B.S. in aeronautical engineering from Embry-Riddle Aeronautical University in 1984. Wood joined the faculty at the United States Air Force Academy in 1994 while serving on active duty in the U.S. Air Force. After completing his Ph.D. in 2002, he returned to the Air Force Academy, where he has been on the faculty ever since. The current focus of Wood's research is the continued development of empirical testing methods using similitude-based approaches. This approach provides significant potential for increasing the efficiency of the design process through a reduction in required full-scale testing and an expansion of the projected performance profiles using empirically-based prediction techniques. Wood's research also includes the development of robotic ground and air vehicle systems using innovative conceptual design techniques for current technology implementations, as well as futuristic projections, applied in the framework of a senior capstone design course.

Prof. Rachelle Kisst Hackett, University of the Pacific

Rachelle Kisst Hackett, Ph.D, is an Associate Professor in the Benerd School of Education within the Educational and School Psychology Department, where she teaches graduate-level research methodology and applied statistics courses. She received her Ph.D. from Stanford University. In addition to serving as a consultant to faculty and students within her unit, Hackett serves as an independent evaluator on several state and federally-funded projects related to education.

Dr. Kathy Schmidt Jackson, Pennsylvania State University

Kathy Jackson is a Senior Research Associate at Pennsylvania State University's Schreyer Institute for Teaching Excellence. In this position, she promotes Penn State's commitment to enriching teaching and learning. Jackson works in all aspects of education, including faculty development, instructional design, engineering education, learner support, and evaluation.

Prof. Jiancheng Liu, University of the Pacific

Jiancheng Liu serves as an Associate Professor of the Department of Mechanical Engineering at the University of the Pacific. Prior to joining the University of the Pacific, he has worked in industry for many years. His research focuses on CNC machine design and analysis, computer aided manufacturing, and manufacturing system automation. He has published more than 80 peer-reviewed technical journal and conference papers. Liu was also awarded five patents. He has invented many new technologies, which have been practically applied in industries. He received the Industrial LEAD Award from SME in 2001. Liu received his B.S. and M.S. degrees in mechanical engineering in China. After receiving his Ph.D. degree in Japan, he moved to the States in 1997 and did his postdoctoral work at the University of California, Davis. V-mail: 209-946-3079; Email: jliu@pacific.edu.

Prof. Paul Henry Schimpf
Miss Alexis Pham, University of the Pacific

Alexis Pham is currently a Ph.D. student in educational psychology. She examines how students learn and develop in educational settings. She holds a M.A. in educational and counseling psychology from the University of the Pacific.

Krystian Zimowski, University of Texas, Austin

Krystian Zimowski is currently a Graduate Student at the University of Texas, Austin, studying wind energy harvesting. He plans to graduate in May with a master's degree in mechanical engineering with a focus in design and manufacturing. He holds a bachelor's degree in mechanical engineering from Northwestern University.

Kristin Taylor, University of the Pacific

Kristin Taylor is currently in the process of completing her master's of engineering science in mechanical engineering at University of the Pacific, where she is also working as a Graduate Assistant. She has also completed her bachelor's of science in bioengineering at the University of the Pacific.

Improving Student Learning using Finite Element Learning Modules: An Update in Research Findings

Abstract

The landscape of contemporary engineering education is ever changing, adapting and evolving. We are indeed living in interesting and exciting times. At the focal point of these times is the concept of active learning methods. This poster session and paper describes a novel approach to improving student learning using active learning finite element learning modules. This poster session summarizes the improved student learning over the past six years at nine engineering schools and colleges. These active learning finite element modules were originally developed using MSC Nastran, followed by development efforts in SolidWorks® Simulation, ANSOFT, ANSYS©, and other commercial FEA software packages. Researchers, with National Science Foundation support, have created over twenty-eight active finite element learning modules which continue to improve student understanding of difficult engineering concepts across engineering disciplines.

Finite element theory and application has often been the focus of graduate-level courses in engineering programs; however, industry needs B.S. engineering graduates to have skills in applying this essential analysis and design technique. We have used the Kolb Learning Cycle as a foundation element to improve student learning of difficult engineering concepts, along with gaining essential knowledge of finite element analysis and design content knowledge.

We discuss the implementation, improved student knowledge, impact, and assessment across demographics, learning styles and personality preference types. These learning modules are incorporated into undergraduate machine design, mechanical vibrations, heat transfer, bioelectrical engineering, electromagnetic field analysis, structural fatigue analysis, computational fluid dynamics, rocket design, chip formation during manufacturing, and large scale deformation in machining. Key assessment results show improvements in student knowledge of difficult engineering concepts measured with performance on pre- and post-learning module quizzes.

Introduction

As educators move forward in advancing engineering education, active learning tools are a viable choice for addressing how students struggle with complex topics in engineering, especially as a function of their backgrounds, demographics, and personality type. In order to move beyond the typical road bumps encountered when teaching difficult application methods, contemporary methods are being developed that seek to engage students actively, both inside and outside the classroom, as well as kinesthetically through the varied human senses. Such approaches have the potential to improve student comprehension and knowledge retention, and most importantly, to increase students' interest in material.[1]

Assisting students in the learning of imperative analysis tools is especially important with current advanced techniques used in industry. One such technique is finite element analysis. The finite element (FE) method is widely used to analyze engineering problems in many commercial engineering firms. It is an essential and powerful analytical tool used to design products with even shorter development cycles.[2-4] Today this tool is primarily taught at the graduate engineering level due to the fact that FE theory is very mathematics-intensive which in the past has made it more suitable for graduate engineering students who have a more rigorous mathematical education. This has changed most recently with the advent of high speed inexpensive computers and workstations and fast algorithms which simplify the FE software. Introducing new material into the already packed four year engineering programs poses challenges to most instructors. The need for integrating FE theory and application across engineering curriculum has been established and methods have been suggested by other engineering authors.[5-10] This paper discusses the technique of designing active FE learning modules across many areas of engineering and the success of these modules in improving the student's understanding of the engineering concepts and their understanding of the FE analysis technique. Previous authors over the past six years have reported their success in using their FE learning modules.[11-19] The primary focus of this paper is to report the incremental student improvement in learning from using many of the twenty-eight FE learning modules in nine specific areas of engineering at nine engineering colleges and universities over the past six years. This paper is an update of the research reported in an earlier paper No. AC 2009-2076 presented at the 2009 American Society for Engineering Education Annual Conference in Austin, TX.

An important goal for this work is to educate a diverse undergraduate group of engineering students with the basic knowledge of FE theory, along with practical experience in applying commercial FE software to engineering problems. The lack of experience in using numerical computational methods in designing solutions to structural, vibrational, electromagnetic, biomedical electromagnetics, computational fluid dynamics, and heat transfer is a noted problem for some engineering graduates.[6,20] The 2012-2013 Accreditation Board for Engineering and Technology, Inc. (ABET, Inc.) Criteria for Engineering Programs specify that engineering programs must demonstrate that their engineering students attain in Criterion 3, (k): "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."[21] Hence, engineering schools have, or are planning to add FE analysis to their curriculum[7-9,22-24], but these plans are not occurring fast enough to meet the demand of firms competing in the global economy. The National Science Foundation realized the need and has supported this work with a "Proof of Concept-Phase I" DUE CCLI Grant Award number 0536197 and most recently a TUES "Type 2 Collaborative Research at Several Institutions" DUE Award numbers 1023034 and 1023064, respectively. All learning modules developed in six years of work are available free to US engineering educational institutions on http://sites.google.com/site/finiteelementlearning/home.

Initially, we developed FE learning modules in six engineering areas: (1) structural analysis, (2) mechanical vibrations, (3) computational fluid dynamics, (4) heat transfer, (5) electromagnetics, and (6) biometrics. To evaluate these "Proof of Concept" modules, they were integrated into existing courses in the corresponding subject areas at the University of Pacific, Gonzaga University, and Tuskegee University. Faculty and students initially assessed their effectiveness at these three educational institutions. We included student demographic data, learning style preference data and MBTI data in the surveys' conducted on these initial twelve modules, but found that the sample size was in most instances too small to develop any statistically meaningful analysis.

In the second Phase 2 work we expanded our FE learning modules to an additional three engineering areas: (7) fatigue analysis, (8) manufacturing process analysis, and (9) manufacturing forming analysis. We continued to integrate these learning modules into existing courses in the corresponding areas. Faculty and students were asked to evaluate the effectiveness of these additional sixteen new learning modules with web-based personality learning assessment surveys in addition to the demographic, and student profile surveys. We are still dealing with small sample sizes in the learning personality style analysis, but have combined the earlier work for a specific learning module for example "Curved Bean Learning Module" administered with minor changes for over four years to obtain statistical sample sizes of significance. We are hopeful that as larger more diverse engineering colleges and universities join us in this work, their larger student populations will support statistical significant analysis of diverse student learning styles and MBTI personality analysis for these twenty-eight FE learning modules.

Overview of the Assessment Methodology

To analyze the effectiveness of the FE learning modules, a level of improved understanding is calculated by relating quiz scores to the learning styles and personality types, followed by the application of basic statistical analysis. The end goal is to accurately and comprehensively assess the quality of the learning modules and whether they are serving students across different demographics and other factors. These assessment goals were accomplished through three project assessment objectives;

1. *Assessment Methodology.* Develop and implement an iterative assessment system.
2. *Statistical Measures.* Determine improvement in student learning across distributions.
3. *Equitability Study.* Gain insight into the effectiveness of the FE learning modules across various personality types and learning styles.

This paper presents the updated results of our pre- and post quiz analysis results of twenty of our twenty-eight FE learning modules. The assessment of the spread of educational gain across personality types, and learning styles for our FE learning modules over the past six years will be published in a subsequent paper. The following section discusses the pedagogical foundations of this research project, including the aforementioned Kolb Learning Cycle.

Background

Kolb Learning Cycle

The pedagogical foundations for this project are based upon the *Kolb Learning Cycle.*[11,26,27,28] The Kolb model shown in Figure 1 describes a cycle around which learning experiences progress. The Kolb Learning Cycle improves student retention of the complex numerical procedure involved in FE analysis. During courses integrating FE learning modules, students are introduced to FE theory within their traditional lectures. Professors cover background of the FE method, fundamental mathematics of FE, the topology of the various finite elements, error analysis of FE results, and how to model engineering problems using this technique. Portions of Kolb's cycle are interlaced with hands-on activities that begin stating the proposed problem in a real-world manner. FE learning modules provide specific instructions on how to build the FE model of the engineering problem to increase student performance in the analysis for "*Concrete Experience"* on Kolb's cycle.

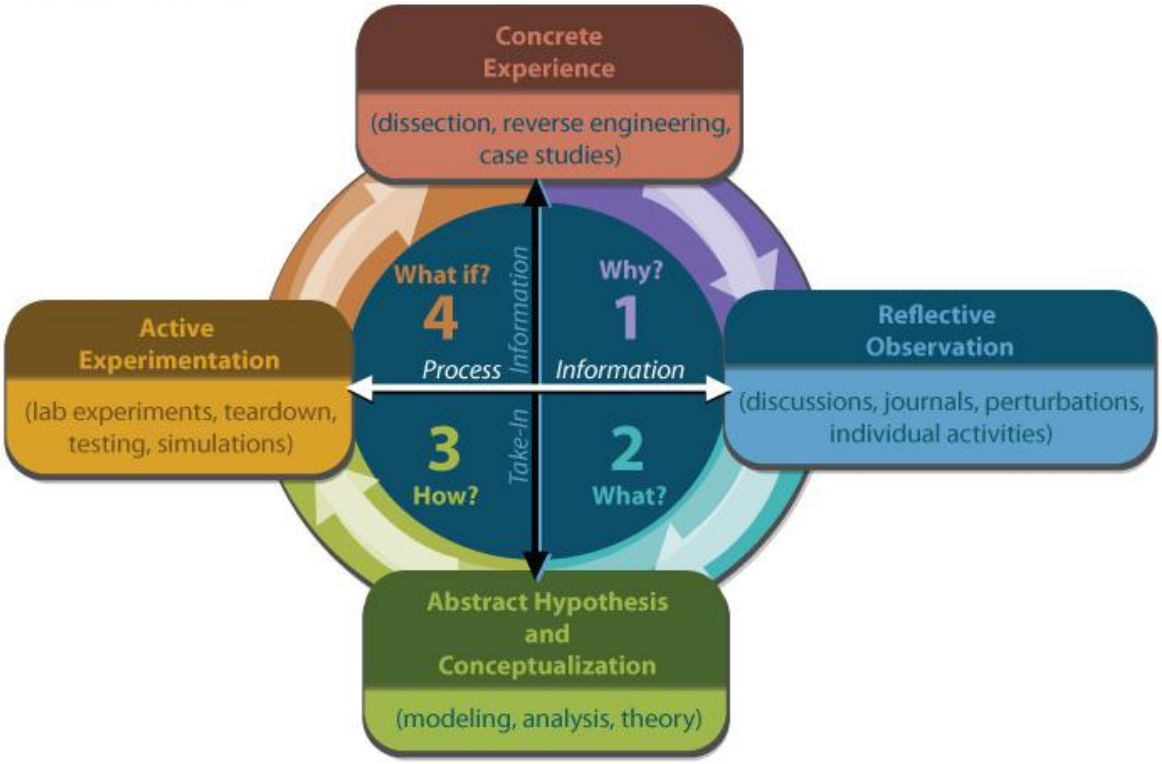

Figure 1. Kolb learning cycle.

Learning Styles

Each FE learning module developed in this work is designed to span a spectrum of different characteristics in which students learn. Felder-Soloman Index of Learning Styles[25] as shown in Table 1 is composed of four dimensions: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. Active learning tools are designed to meet the needs of students with a range of learning styles. Particular approaches to teaching often favor a certain learning preference. Therefore, it is important to incorporate a variety of teaching approaches. This index can assist instructors in creating active learning modules that impact all student learning styles effectively.

Table 1. Learning styles categories.

Felder-Soloman	
ACTIVE	REFLECTIVE
Doing something active with it. Discussing, applying, or explaining it to others.	Thinking about it quietly first.
SENSING	INTUITIVE
Learning facts.	Discovering possibilities and relationships.
VISUAL	VERBAL
See-- pictures, diagrams, flow charts, time lines, films, and demonstrations.	Words-- written and spoken explanations.
SEQUENTIAL	GLOBAL
Gain understanding in linear steps.	Learn in large jumps, suddenly "getting it."

Myers Briggs Type Indicator (MBTI) Personality Type

The Myers Briggs Type Indicator (MBTI) is similar to Felder-Silverman Learning Style, but is linked to personality preferences as shown in Table 2. MBTI includes four categories of how an individual processes and evaluates information.[29] The first category describes how a person interacts with his or her environment. People who take initiative and gain energy from interactions are known as *Extroverts (E). Introverts (I),* on the other hand prefer more of a relatively passive role and gain energy internally. The second category describes how a person processes information. People who process data with their senses are referred to as *Sensors (S)*, and a person who sees where data is going in the future is called an *iNtuitor (N)*. The *Sensor* versus *iNtuitor* category is an interesting area of study when it comes to engineering education, because professors are historically intuitors while most engineering student's are sensors.[25] The third category for MBTI preference describes the manner in which a person evaluates information. Those who tend to use a logical cause and effect strategy, *Thinkers (T)*, differ from those who use a hierarchy based on values or the manner in which an idea is communicated, *Feelers (F)*. The final category indicates how a person makes decisions or comes to conclusions. *Perceivers (P)* prefer to be sure all the data is thoroughly considered, and *Judgers (J)* summarize the situation as it presently stands and make decisions more quickly.

A number of researchers have used knowledge of MBTI types to enhance engineering education.[26,28,30,31] In this prior educational research, it has been shown that different MBTI types respond in unique ways to distinctive pedagogical approaches. The goal of using the MBTI data in concurrence with learning modules is to ensure the FE learning modules are effective across different personality types, bringing any of these nuances to light. The innovative step to our analysis here is to take the assessment one step beyond effectiveness. We are looking into how equally this effectiveness reaches across demographic groups, learning styles, and personality types.

Table 2. Myers Briggs Indicator (MBTI) personality type.

Overview of MBTI			
	Manner in Which a Person Interacts With Others		
E	Focuses outwardly. Gains energy from others. EXTROVERSION	Focuses inwardly. Gains energy from cognition. INTROVERSION	I
	Manner in Which a Person Processes Information		
S	Focus is on the five senses and experience. SENSING	Focus is on possibilities, use, big picture. INTUITION	N
	Manner in Which a Person Evaluates Information		
T	Focuses on objective facts and cause & effect. THINKING	Focuses on subjective meaning and values. FEELING	F
	Manner in Which a Person Comes to Conclusions		
J	Focus is on timely, planned decisions. JUDGEMENT	Focus on process oriented decision-making. PERCEPTION	P

Assessment Methodology

FE Learning Modules

A starting point for our educational objectives is the development of the FE learning module. Each learning module is pedagogically rooted in an active learning based on Kolb's learning cycle. By completing the cycle fully, the student will have a stronger grasp of the difficult engineering and FE material. As an accompaniment to traditional lectures, the learning module helps guide students through active experimentation, concrete experiences, and reflective observation.

The FE learning modules are designed for those students who have little to no experience using the FE analysis. Therefore, the basic nature of the problems makes it more possible that the students will grasp the correlations between the physical solution and the computational model. Each module was developed in PowerPoint and is available in ppt and pdf file format. Each FE learning module was developed with a common template presented as follows:

- References.
- Table of contents.
- Project educational objectives based upon ABET Criteria 3 for Engineering Programs.
- Problem description.
- Problem analysis objectives.
- General steps and specific step-by-step analysis.
- Viewing the results of the FE analysis.
- Comparison of FE analysis to another technique.
- Summary and discussion.
- Background information on finite element theory.

The FE learning modules are currently linked to one of six commercial FE codes (SolidWorks® Simulation, SolidWorks® Flow Simulation, MSC.Nastran, Comsol, ANSYS® ANSOFT, or AdvantEdge™) all commonly used in industry.

Assessment Foundations

Helpful steps to assessments for the FE learning modules are: (a) gathering student demographics (i.e., academic major, educational level, grade point average, expected grade earned in current course, reason for taking course, plans after graduation, age, ethnicity, and gender); (b) gathering Felder-Soloman learning styles and MBTI personality type (this analysis, along with learning objectives, can be reviewed and fed back into improving the modules); and (c) collecting all data and linking these data to a common student identification number for future evaluations and survey responses.

The next step is developing a measurement instrument for evaluating student learning directly associated with the active learning module. In this work, a multiple-choice quiz is used as the foundation for our baseline study. The content-based quiz is administered after the FE material is presented in class, but prior to the student being introduced to an FE learning module. This ideally isolates enhanced student learning due to the learning module alone. The learning modules supplement student learning of the difficult FE theories and methods, and associated engineering topic content. The same quiz is administered following the completion of the learning module. The pre- and post-quiz scores are again linked to the common student ID. In parallel, as soon as the student completes the FE learning module, an in-depth survey is administered to the students, providing the opportunity for much more open feedback to the assessment system.

Summary of the Assessment Program Results to Date

The assessment program can be divided into two distinct goals:

- Demonstrate learning improvement using the FE learning modules.
- Develop an iterative assessment process that shows no bias towards learning styles and personality types using the FE learning modules.

We will first show that the learning improvement goal has been met for each of the Phase 1 FE learning modules using quizzes administered prior to students completing the learning modules and post to their completing the learning module. We have summarized the improved student learning for the Phase 1 FE learning modules in Table 3 for ten of the twelve original learning modules used at the three engineering colleges of Tuskegee University, Gonzaga University, and the University of the Pacific. These FE Learning Modules reported here are:

- Curved Beam Structural Learning Module
- Bolt and Plate Stiffness Learning Module
- Vibration Analysis of a Cantilever Beam
- Long Bar Steady State Heat Transfer
- L-Bracket Transient Heat Transfer
- Biomedical Electromagnetics
- Electromagnetics Specific Absorption Rates

- Electromagnetics Transmission Parameters of Infinitely Long Co-Axial Cable
- Electromagnetics Probe Feed of a Patch Antenna
- Computational Flow over a Cylinder
- Computational Flow with Friction in a Pipe

Table 3. Summary table of Phase 1 TUES grant for FE learning modules showing student improvement in learning.

FE Learning Module	Semester	Institution	Number of Students	Pre-Quiz Average Score (100 Maximum)	Post-Quiz Average Score (100 Maximum)	% Student Improvement
Structural Analysis of a Curved Beam	Fall 2006	University of the Pacific	9	71.1	82.2	15.6%
	Fall 2007	University of the Pacific	16	52.75	66.31	25.7%
	Fall 2008	University of the Pacific	13	61.1	74.6	22.1%
	Fall 2009	University of the Pacific	45.2	82.1	81.6	45.2%
Averages			**13.2**	**58.7**	**76.1**	**32.9%**
Bolt and Plate Stiffness	Fall 2007	University of the Pacific	12	55.8	65.0	16.5%
	Spring 2010	University of the Pacific	8	66.5	74.13	11.5%
Averages			**10**	**61.2**	**69.6**	**14.0%**
Vibration Analysis of a Cantilever Beam	Fall 2007	Tuskegee University	7	63.1	79.6	26.1%
	Fall 2008	Tuskegee University	43.4	63.6	46.54%	43.4%
	Fall 2007	University of the Pacific	16	52.8	65.3	23.7%
	Fall 2008	University of the Pacific	15	66	74	12.1%
Averages			**10.8**	**56.3**	**70.6**	**27.1%**
Long Bar Steady-State Heat Transfer	Spring 2007	University of the Pacific	19	62.9	72.9	15.9%
	Spring 2009	University of the Pacific	14	69.86	78	11.7%
Averages			**16.5**	**66.4**	**75.5**	**13.8%**
Biomedical Electromagnetics	Fall 2006	University of the Pacific	20	31.9	65.6	105.6%
	Fall 2007	University of the Pacific	8	57.1	80	40.1%
	Fall 2009	University of the Pacific	7	31.9	59.16	61.1%
	Fall 2010	University of the Pacific	13	38.46	67.03	74.3%
Averages			**12.0**	**39.8**	**67.9**	**70.3%**
Electromagnetics Specific Absorption Rates	Fall 2006	Gonzaga University	20	63.8	81.5	27.7%
Electromagnetics Transmission Parameters of Infinitely Long Co-Axial Cable	Fall 2007	Gonzaga University	10	42.5	67.5	58.8%
Electromagnetics Probe Feed Patch Antenna	Fall 2008	Gonzaga University	10	60	81.3	35.5%
Averages			**13.3**	**55.4**	**76.8**	**40.7%**

We next will show that the learning improvement goals have been met for nine out of ten new Phase 2 FE learning modules using quizzes administered prior to students completing the learning modules and posting to their completing the module. We have summarized the improved student learning for our Phase 2 FE learning modules in Table 4 for ten of the sixteen new FE learning modules used at the nine engineering colleges of Tuskegee University, Gonzaga University, Washington State University, California State University at Pomona, University of New Haven, University of the Pacific, and United States Air Force Academy.

Table 4. Summary table of Phase 2 TUES grant for FE learning modules showing student improvement in learning.

FE Learning Module	Semester	Institution	Number of Students	Pre-Quiz Average Score (100 Maximum)	Post-Quiz Average Score (100 Maximum)	% Student Improvement
Structural Analysis of Large Deformation of a Cantilever Beam	Fall 2011	Tuskegee University	16	33.00	35.20	6.7%
Fatigue Analysis of Rotating Shaft	Spring 2010	University of the Pacific	8	63.25	75.75	19.8%
Vibration of Critical Speeds in Rotating Shafts	Fall 2011	California State Polytechnic University Pomona	25	47.20	59.20	25.4%
Vibration Modes of Circular Membranes	Fall 2011	California State Polytechnic University Pomona				
Computational Fluid Drag of Bobsled Model	Fall 2011	University of the Pacific	17	50.00	65.29	30.6%
Machining Analysis During Chip Formation	Spring 2011	University of the Pacific	13	68.53	90.21	31.6%
Thermal FEA: Semi Infinite Medium	Spring 2011	University of the Pacific	11	58.33	76.50	31.2%
Thermal FEA: Steady-State Heat Conduction	Spring 2011	University of the Pacific	11	58.33	76.50	31.2%
Axisymmetric Rocket Nozzle	Fall 2011	U.S. Air Force Academy	10	42.5	53.8	26.6%
Small Engine Cooling Fin	Fall 2011	U.S. Air Force Academy	10	57.5	62.5	8.7%

Results for Ten New FE Learning Modules from Phase 2 NSF TUES Grant

The following ten FE learning modules have been developed in Phase 2 of this NSF TUES grant as follows:

- Structural Analysis of Large Deformation of Cantilever Beam
- Fatigue Analysis of a Rotating Shaft with a Load
- Vibration of Critical Speeds of Rotating Shafts
- Vibration Modes of Circular Membranes
- Computational Fluid Drag of a Bobsled Model
- Machining Analysis During Chip Formation
- Thermal Finite Element Analysis: Semi-Infinite Medium
- Thermal Finite Element Analysis: Steady Heat Conduction
- Axisymmetric Rocket Nozzle
- Small Engine Cooling Fin

To illustrate the knowledge gained to improve each FE learning module we will use the Computational Fluid Drag of a Bobsled Model as an example to show student responses to these active learning tools. The cover slide to this module is shown in Figure 2.

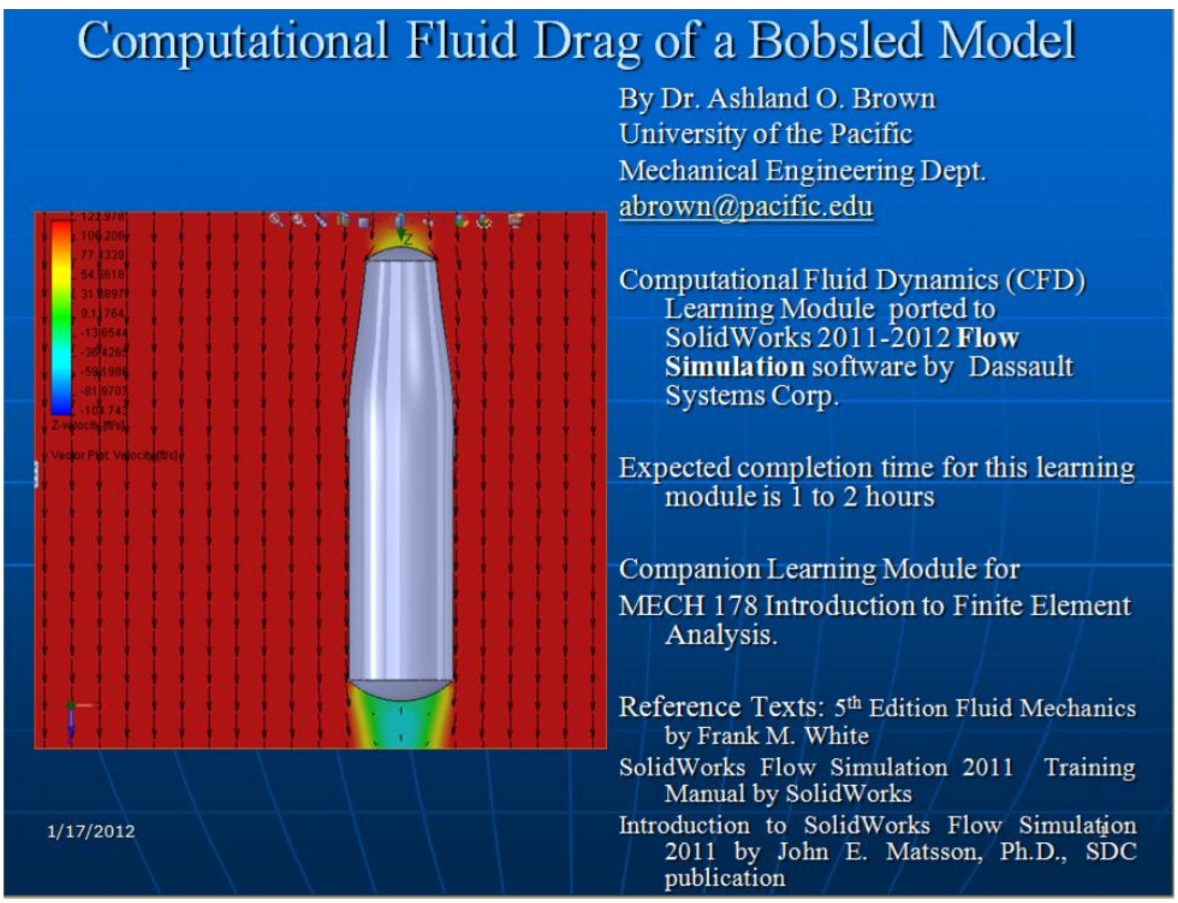

Figure 2. Computational fluid drag of a bobsled model.

The long term goal of this research to show no bias towards learning styles and personality types is a bit more difficult to achieve at the nine engineering colleges being the FE learning modules are administered to upper level junior and senior level classes with small enrollments. We have been successful in combining the small student populations for the original FE learning modules administered in the early years of this research without modifications. These combined results are providing a scan of which student learning styles and personality types are improving their learning more then their colleagues.

Assessment Results for the Computational Fluid Drag of a Bobsled Model

The primary method for assessing success of the twenty-nine learning modules is using the pre- and post-quizzes. These quizzes were designed primarily to assess the success of the learning modules in meeting the primary educational goal of providing different insight into the eight engineering disciplines of engineering and thereby reinforcing the concepts by providing a more visual and "hands-on" exercise. Table 5 shows the results of these pre- and post-quizzes used in the Computational Fluid Drag of a Bobsled Module. The quiz used in this assessment consisted of ten multiple choice questions (see Appendix A) and the same quiz is administered pre- and post-learning module. The results are tracked for each individual student through their Animal ID's. The results are shown above and although the sample size is relatively small, the results indicated there is a 30% improvement (on average) for pre-quiz to post-quiz for the seventeen students who completed this learning module.

Table 5. Paired t-test statistical analysis of the pre- and post-quiz results for bobsled module at University of the Pacific in Fall 2011.

Quiz	Sample Size	Mean Value	Standard Deviation	Standard Error of the Mean
Pre-quiz	17	0.50	0.15	0.04
Post-quiz	17	0.65	0.15	0.03
Difference	17	0.15	0.14	0.03
95% Lower Bound for Mean Difference = (0.080, 0.226)		t-value = 4.443	p-value < 0.001	

Due to the small sample size, the data gathered from the MBTI and learning styles surveys did not produce significant evidence that this learning module benefited a particular learning style or personality type, although the data will continue to be assessed in this research as more students participate in this assessment process.

To better understand students responses to the FE learning module as an education tool inside the classroom, specific student surveys are used by each researcher to measure students response to using these FE learning modules in the engineering class. The student surveys were administered to the students after they completed the above learning module in an Introduction to Finite Elements Course at the University of the Pacific in fall 2011.

There were two surveys administered to the students, a very specific survey (short survey in Table 6) used to measure the student knowledge gained from the Bobsled Module and a more general second survey (long survey in Table 7) which gathered specific areas for improvements in the Bobsled Module that the researcher will use in an iterative way to revise and improve the education experiences for future students taking this course. Table 7 was used to measure broader student response and will be used in all future FE learning modules. These results are summarized in Tables 6 and 7. The tables include feedback received from the Bobsled FE learning module conducted in fall 2011. Two different surveys were given for the Bobsled FE learning module students. Student responses are recorded on the left side of the table under "number of students respondents (n)" column. The valid percentages of these responses (out of 100 percent) are recorded on the right side of the table under the "percentage of valid responses (%)" column. Each question provides students with five options for response (disagree, partly agree, neither disagree or agree, partly agree, and agree) which are coded 1, 2, 3, 4, and 5, respectively. The average of the responses was calculated for each question and recorded under "M". The last column "SD" (standard deviation) indicates the amount of variation in student responses. Therefore, when examining the average of the responses for each question, a number more than 3 indicates that the students generally disagree with the statement. On the other hand, an average number of than 3 suggests that students generally agree with the statement, which is a positive reflection on the learning module in regard to aspect the item addresses.

Overall, the short survey in Table 6 shows that students agree with the questions, indicating that they hold a favorable view of this learning module. 19 out of 20 items were significantly higher than 3 (students agree with statements). The one question 6 in this survey was not found to be statistically significant. However, this question is neutral and does not reflect a positive or negative view of this module. The long general survey in Table 7 administered via the web indicated that the students generally favored the Bobsled learning module. This survey includes question 40 which is negatively worded, and the students generally disagree with this question, giving a more favorable rating to the module. Students rated 39 out of 40 questions more than 3, meaning that they agree with the positively stated questions of this survey.

In addition, one sample t-tests were conducted to test whether our sample means differ from the test value of 3. We want to see if the student responses are statistically different form a neutral response, in either direction. An asterisk placed by a mean within the "M" column in Tables 6 and 7 indicates that the item was one which students did not tend to feel neutral about.

Table 6. Short post-survey results for the bobsled FE learning module administered at the University of the Pacific in Spring 2011.

Survey Item	Number of Student Respondents (n)					*Percentage of Valid Responses (%)*					Statistics	
	Disagree	Partly Disagree	Neither A or D	Partly Agree	Agree	*Disagree*	*Partly Disagree*	*Neither A or D*	*Partly Agree*	*Agree*	M	SD
1. This activity helped me understand "aerodynamic design using a commercial CFD software" in a conceptual manner?	0	0	3	10	4	*0*	*0*	*17.6*	*58.8*	*23.5*	4.06*	.66
2. This activity helped me to understand the assumptions of "aerodynamic design using finite element commercial software"?	0	3	3	7	4	*0*	*17.6*	*17.6*	*41.2*	*23.5*	3.71*	1.05
3. This activity helped me understand the limitations of "using CFD software to design objects"?	0	1	5	9	2	*0*	*5.9*	*29.4*	*52.9*	*11.8*	3.71*	.77
4. This activity helped me understand the topic of "aerodynamic design" so that I have the ability to carry out aerodynamic design projects on my own.	0	0	3	8	6	*0*	*0*	*17.6*	*47.1*	*35.3*	4.18*	.73
5. This activity showed me that the finite element method provides an approximate solution for the aerodynamic drag of a design problem?	0	1	0	6	10	*0*	*5.9*	*0*	*35.5*	*58.8*	4.47*	.80
6. Activities like this one, and similar ones done by commercial finite element software vendors, are only required to understand finite element theory?	1	4	6	3	3	*5.9*	*23.5*	*35.3*	*17.6*	*17.6*	3.18	1.19
7. This activity showed me that an understanding of "fluid flow theory" can be reinforced with a project using commercial CFD analysis.	0	0	0	8	9	*0*	*0*	*0*	*47.1*	*52.9*	4.53*	.51
8. This activity helped me create the correct flow goals to model the "drag coefficient" for the bobsled model?	0	1	2	4	9	*0*	*6.3*	*12.5*	*25*	*56.3*	4.31*	.95
9. This activity helped me to gain experience using a commercial CFD software code to perform a flow analysis	0	0	1	6	10	*0*	*0*	*5.9*	*35.3*	*58.8*	4.53*	.62
10. This activity helped me to select the proper accuracy levels, numbers of fluid/solid elements and proper computational flow goals for this computational fluid analysis of the bobsled at three downhill velocities	0	1	3	4	9	*0*	*5.9*	*17.6*	*23.5*	*52.9*	4.24*	.97
11. This activity helped me understand that accuracy (not the correctness) of the solution is dependent on the quality of the flow mesh?	0	0	3	6	8	*0*	*0*	*17.6*	*35.3*	*47.1*	4.29*	.77

Table 6. 'Continued' Short post-survey results for the bobsled FE learning module administered at the University of the Pacific in Spring 2011.

Survey Item	Number of Student Respondents (n)					*Percentage of Valid Responses (%)*					Statistics	
	Disagree	Partly Disagree	Neither A or D	Partly Agree	Agree	*Disagree*	*Partly Disagree*	*Neither A or D*	*Partly Agree*	*Agree*	M	SD
12. This activity helped me to select the correct boundary conditions (initial flow conditions, wall conditions, and fluid properties) to model the "bobsled model at three flow velocities."	0	0	0	10	7	*0*	*0*	*0*	*58.8*	*41.2*	4.41*	.51
13. After completing this activity, I was able to implement a suitable CFD analysis of a model using the SolidWorks Flow Simulation software?	0	1	2	6	8	*0*	*5.9*	*11.8*	*35.3*	*47.1*	4.23*	.90
14. This activity helped me understand why it is important to check if the "boundary conditions, constraints and initial flow conditions" are specified correctly?	1	0	3	5	8	*5.9*	*0*	*17.6*	*29.4*	*47.1*	4.12*	1.11
15. This activity helped me to understand why it is important to check if the "computational goals and computer set-up for convergence" were specified correctly?	0	1	5	7	4	*0*	*5.9*	*29.4*	*41.2*	*23.5*	3.82*	.88
16. This activity helped me to understand why it is important to verify finite element solution quantities "drag coefficient" through an independent method, e.g., such as a wind-tunnel experiment?	0	0	3	7	7	*0*	*0*	*17.6*	*41.2*	*41.2*	4.24*	.75
17. Personally seeing and developing the finite element model on my own was better than a classroom demonstration?	1	1	0	2	13	*5.9*	*5.9*	*0*	*11.8*	*76.5*	4.47*	1.18
18. This activity was very clear?	1	1	2	6	0	*5.9*	*5.9*	*11.8*	*35.3*	*0*	4.00*	1.17
19. This activity was more effective than using class time for lectures or board-work?	0	0	3	6	8	*0*	*0*	*17.6*	*35.3*	*47.1*	4.29*	.77
20. I would like to learn more on using the finite element method to solve other mechanical engineering problems?	0	0	1	2	14	*0*	*0*	*5.9*	*11.8*	*82.4*	4.76*	.56

Table 7. Long post-survey results for the bobsled FE learning module administered at the University of the Pacific in Spring 2011.

Survey Item	Number of Student Respondents (n)					*Percentage of Valid Responses (%)*					Statistics	
	Disagree	Partly Disagree	Neither A or D	Partly Agree	Agree	*Disagree*	*Partly Disagree*	*Neither A or D*	*Partly Agree*	*Agree*	**M**	**SD**
1. I think that the learning module FEA activity was fun.	2	1	2	7	1	*15.4*	*7.7*	*15.4*	*53.8*	*7.7*	3.31	1.25
2. I think the learning module activity was motivating.	1	2	1	6	3	*7.7*	*15.4*	*7.7*	*46.2*	*23.1*	3.62	1.26
3. I think that the learning module activity was intellectually stimulating.	0	0	3	8	2	*0*	*0*	*23.1*	*61.5*	*15.4*	3.92*	.64
4. I think that the learning module activity was challenging.	0	2	3	7	1	*0*	*15.4*	*23.1*	*53.8*	*7.7*	3.54*	.88
5. I think that the example problem was interesting.	0	0	2	9	2	*0*	*0*	*15.3*	*69.2*	*15.4*	4.00*	.58
6. I think that the example problem was easy.	2	0	2	7	2	*15.4*	*0*	*15.4*	*53.8*	*15.4*	3.54	1.27
7. I think that the example problem was inspiring.	2	2	1	7	1	*15.4*	*15.4*	*7.7*	*53.8*	*7.7*	3.23	1.30
8. I would describe my experience with this activity as filled with effort.	0	0	2	6	5	*0*	*0*	*15.4*	*46.2*	*38.5*	4.23*	.73
9. I would describe my experience with this activity as disciplined.	0	1	4	5	3	*0*	*7.7*	*30.8*	*38.5*	*23.1*	3.77*	.93
10. I would describe my experience with this activity as focused.	0	1	2	6	4	*0*	*7.7*	*15.4*	*46.2*	*30.8*	4.00*	.91
11. I would describe my experience with this activity as successful.	0	1	2	8	2	*0*	*7.7*	*15.4*	*61.5*	*15.4*	3.85*	.80
12. I enjoy working with software.	0	1	3	6	3	*0*	*7.7*	*23.1*	*46.2*	*23.1*	3.85*	.90
13. I enjoy the FEA learning module.	2	0	1	6	4	*15.4*	*0*	*7.7*	*46.2*	*30.8*	3.77	1.36
14. I enjoyed working on the example problem as part of the activity.	2	0	2	7	2	*15.4*	*0*	*15.4*	*53.8*	*15.4*	3.54	1.27
15. The learning module made me interested to participate in similar activities as part of this course.	0	1	3	7	2	*0*	*7.7*	*23.1*	*53.8*	*15.4*	3.77*	1.36

Table 7. 'Continued' Long post-survey results for the bobsled FE learning module administered at the University of the Pacific in Spring 2011.

Survey Item	Number of Student Respondents (n)					*Percentage of Valid Responses (%)*					Statistics	
	Disagree	Partly Disagree	Neither A or D	Partly Agree	Agree	*Disagree*	*Partly Disagree*	*Neither A or D*	*Partly Agree*	*Agree*	M	SD
16. The learning module made me interested to participate in similar activities in other courses	0	1	4	6	2	*0*	*7.7*	*30.8*	*46.2*	*15.4*	3.69*	.85
17. I completed the learning module with time to spare	2	2	4	5	0	*15.4*	*15.4*	*30.8*	*38.5*	*0*	2.92	1.12
18. The learning module activity assisted me in understanding the course content.	0	0	2	10	1	*0*	*0*	*15.4*	*76.9*	*7.7*	3.92*	.49
19. The learning module activity was effective in assisting my learning.	0	0	2	9	2	*0*	*0*	*15.4*	*69.2*	*15.4*	4.00*	.58
20. The format of the learning module does NOT need improvement.	1	2	2	6	2	*7.7*	*15.4*	*15.4*	*46.2*	*15.4*	3.46	1.20
21. The organization of the learning module does NOT need improvement.	1	3	2	6	2	*7.7*	*23.1*	*7.7*	*46.2*	*15.4*	3.38	1.26
22. I understand the course topic covered in this learning module activity.	0	0	3	7	3	*0*	*0*	*23.1*	*53.8*	*23.1*	4.00*	.71
23. I like the approach used in this learning module activity.	0	0	4	6	3	*0*	*0*	*30.8*	*46.2*	*23.1*	3.92*	.76
24. This approach was NOT difficult to understand.	0	1	2	9	1	*0*	*7.7*	*15.4*	*69.2*	*7.7*	3.77*	.73
25. This approach is NOT difficult to use.	0	0	3	7	3	*0*	*0*	*23.1*	*53.8*	*23.1*	4.00*	.71
26. I would consider using FEA in the future.	0	0	2	6	5	*0*	*0*	*15.4*	*46.2*	*38.5*	4.23*	.73
27. I feel certain that I understand the course topic covered by the learning module activity.	1	0	2	9	1	*7.7*	*0*	*15.4*	*69.2*	*7.7*	3.69*	.95
28. The learning module activity assisted me in uncovering important information in engineering.	0	0	5	6	2	*0*	*0*	*38.5*	*46.2*	*15.4*	3.77*	.73
29. I feel confident in my understanding of the course topic covered by the learning module activity.	0	1	3	7	2	*0*	*7.7*	*23.1*	*53.8*	*15.4*	3.77*	.83

Table 7. 'Continued' Long post-survey results for the bobsled FE learning module administered at the University of the Pacific in Spring 2011.

Survey Item	Number of Student Respondents (n)					*Percentage of Valid Responses (%)*					Statistics	
	Disagree	Partly Disagree	Neither A or D	Partly Agree	Agree	*Disagree*	*Partly Disagree*	*Neither A or D*	*Partly Agree*	*Agree*	**M**	**SD**
30. The learning module helped me understand the material for the course.	0	0	3	6	4	*0*	*0*	*23.1*	*46.2*	*30.8*	4.08*	.76
31. I found the activity to be well organized.	1	1	2	8	1	*7.7*	*7.7*	*15.4*	*61.5*	*7.7*	3.54	1.05
32. I found the interface to be easy to use.	0	1	1	7	4	*0*	*7.7*	*7.7*	*53.8*	*30.8*	4.08*	.86
33. I identify very few, if any, mistakes in the learning module.	0	3	3	5	2	*0*	*23.1*	*23.1*	*38.5*	*15.4*	3.46	1.05
34. I found the problem statement (s) to be clearly worded.	0	1	1	8	3	*0*	*7.7*	*7.7*	*61.5*	*23.1*	4.00*	.82
35. I understood the learning objectives for the activity.	0	0	0	10	3	*0*	*0*	*0*	*76.9*	*23.1*	4.23*	.44
36. The learning module activity steps proceeded in a logical manner.	0	0	0	9	4	*0*	*0*	*0*	*69.2*	*30.8*	4.31*	.48
37. The learning module was easily understandable.	0	1	0	9	3	*0*	*7.7*	*0*	*69.2*	*23.1*	4.08*	.76
38. I found the learning module to be polished.	1	1	2	7	2	*7.7*	*7.7*	*15.4*	*53.8*	*15.4*	3.62	1.12
39. I found the learning module activity to be state-of-the-art.	1	0	6	4	2	*7.7*	*0*	*46.2*	*30.8*	*15.4*	3.46	1.05
40. Steps in the learning module seemed to be out of sequence for me.	2	5	2	2	2	*15.4*	*38.5*	*15.4*	*15.4*	*15.4*	2.77	1.36

Note: Question 40 is negatively worded.

Conclusion

This paper summarizes the work of two groups of researchers in gathering pre-post quiz data over the past six years using twenty eight learning modules in eight engineering areas. The Phase 1 NSF work with the original twelve learning modules has provided evidence that student knowledge improvements have gained from15 to 57% using pre- and post quizzes of student knowledge. Looking at Table 1 it is seen that this measured improvement in student knowledge has been repeated over the past six years at three engineering institutions. This work has continued with the current Phase 2 NSF work with sixteen new learning modules and looking at Table 2 we see sustained student improvement in knowledge ten new learning modules with student improvement gained from 20 to 31% using the same pre-post quiz methods. Our survey data is key to improving the performance of these learning modules and has shown positive student support for the work in the current learning modules and the past twelve learning modules.

Future Efforts

Our current twelve researchers analyzed the MBTI and LSI data gathered from over 1,000 students participating in this work at nine engineering institutions. Students taking these sixteen learning modules at nine engineering schools to define which personalities are benefiting the most from these active learning modules and discerning how we can improve the learning process across all learning personalities and styles in the future.

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Appendix A Pre- and Post-Learning Module Quiz for the Computational Fluid Drag of a Bobsled Module

Computational Fluid Flow Basic Knowledge
(Prior/Post to completing the Computational Fluid Drag of Bobsled Model Learning Module)

Your student ID **animal name** will be used only to match up your computational fluid flow basic knowledge prior to completing the Computational Fluid Drag of a Bobsled Model Learning Module and after completion of this Learning Module. Your best quiz will count for approximately 5% of your Mini-Project II Bobsled Design project grade in Mech 178. Thank you in advance for your cooperation in our research efforts to improve learning under our NSF Grant. Prof. Ashland O.Brown.

Student ID **Animal Name**:________________________

Note:
D is the cylinder diameter
L is the cylinder length
ρ is the fluid density
ν is the fluid kinematic viscosity
U is the uniform flow velocity in the x-direction
Re is the Reynolds number
F_D is drag force
A_c is the area of the cylinder perpendicular to the flow direction

Circle the best answer

1. The aerodynamic drag coefficient over a cylinder in uniform flow is, $C_D =$
   (A) $\frac{2 \cdot F_D}{UDL}$
   (B) $\frac{2 \cdot F_D}{\rho U^2 DL}$
   (C) $\frac{2 \cdot F_D}{\rho^2 U A_C}$
   (D) $\frac{2 \cdot F_D}{\rho U^2 A_C}$
   (E) $\frac{2 \cdot F_D}{\rho U^2 D}$

2. SolidWorks® Flow Simulation is a commercial computational fluid dynamics (CFD) software which solves the following differential equations at the flow mesh centers in the flow domain.
   (A) Bernoulli's Equations
   (B) Coquette Flow Equations
   (C) Navier-Stokes Equations
   (D) Euler's Equations
   (E) all of these sets of equations

3. SolidWorks® Flow Simulation has ________________ meshing which allows it to create finer meshes as required to obtain computational solutions to difficult flow problems automatically.
   (A) interactive
   (B) expandable
   (C) mesh-less
   (D) logical
   (E) adaptive

4. SolidWorks® Flow Simulation uses _____________ elements to mesh the flow domain.
   (A) parallelepiped
   (B) tetrahedral
   (C) plate
   (D) triangular plate
   (E) beam

5. Increasing the cylinder wall roughness on the bobsled causes the aerodynamic drag coefficient to.
   (A) none of these options
   (B) decrease
   (C) remain the same
   (D) increase

6. Setting the SolidWorks® Flow Simulation Results Resolution to _________ maximizes the number of finite elements in the computational flow domain thereby increasing the accuracy.
   (A) 3
   (B) 5
   (C) 8
   (D) 1
   (E) 10

7. SolidWorks® Flow Simulation uses _______________types of finite volume elements to mesh both the solid surfaces and the fluids in the computational flow domain.
   (A) 2
   (B) 4
   (C) 6
   (D) 3
   (E) 10

8. In SolidWorks® Flow Simulation _____________ are used to stop the iterative solution process in the computational flow domain.
   (A) boundary inserts
   (B) goals
   (C) stop orders
   (D) pause commands

9. In SolidWorks® Flow Simulation a typical flow analysis of an object study requires an average of ______________ finite volume elements in the computational flow domain to perform the analysis.
   (A) 1,000
   (B) 10,000
   (C) 100,000
   (D) 500,000
   (E) 300,000

10. In SolidWorks® Flow Simulation under, **calculation control,** the number of times a perturbation (pressure wave, velocity wave, etc.) moves through the computational flow domain is referred to as ______________.
   (A) iterations
   (B) calculation time
   (C) travels