Active Engineering Education Modules: Summary Paper of Five Years of Incremental Improvements to the Modules

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Dr. Richard H. Crawford is a Professor of Mechanical Engineering at The University of Texas at Austin and is the Temple Foundation Endowed Faculty Fellow No. 3. He is also Director of the Design Projects program in Mechanical Engineering. He received his BSME from Louisiana State University in 1982, and his MSME in 1985 and Ph.D. in 1989, both from Purdue University. He teaches mechanical engineering design and geometry modeling for design. Dr. Crawford's research interests span topics in computer-aided mechanical design and design theory and methodology. Dr. Crawford is co-founder of the DTEACh program, a "Design Technology" program for K-12, and is active on the faculty of the UTeachEngineering program that seeks to educate teachers of high school engineering.

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Professor Orabi received his B.S. in Mechanical Engineering from Cairo Institute of Technology (now Helwan University), in 1975, his M.S. degree in Mechanical Engineering from the State University of New York at Buffalo, in 1982, and his Ph.D. degree from Clarkson University, in 1987. Dr. Orabi conducts theoretical and computational research in mechanical vibrations and dynamic systems and control. His more than 25 papers span a wide spectrum of problems in the dynamics of systems and structures. Dr. Orabi has also been involved in developing schemes for vibration control of space structures during the lift off and in orbit. Professor Orabi has taught courses in both undergraduate and graduate level Mechanical Vibrations and undergraduate level capstone design courses, thermodynamics, Measurement Systems, Engineering Mechanics and Introduction to Engineering. One of Professor Orabi's most recent projects involves the development of learning modules. These modules provide undergraduate engineering students with improved learning of basic, conceptually-difficult engineering concepts in the context of a basic knowledge of finite element analysis.

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.

Prof. Jiancheng Liu, University of the Pacific

Dr. Jiancheng Liu is a Professor of Mechanical Engineering at the University of the Pacific. Dr. Liu's research experience and teaching interest have been in the areas of machine design and manufacturing engineering, with specific focuses on CNC machine tool design, mechanical micro machining, cutting process, flexible manufacturing system automation, sensing and control technology, and intelligent CAM technology. With his many years' experience in industry and universities, Dr. Liu has published over 100 technical journals and conference papers. He was awarded four patents. Many of his research results have been successfully implemented as commercial products or practically applied. Among his many honors is the Industrial LEAD Award from SME.

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Kathy Jackson is a Researcher at Pennsylvania State University's Teaching and Learning with Technology Group. In this position, she works with faculty across Penn State to study and research how learning works in today's media enhanced learning environments. In addition, she is an Affiliate Faculty in the Higher Education Department where she is teaches a class on college teaching.

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Abstract

The landscape of contemporary engineering education is ever changing, adapting and evolving. Finite element theory and application has often been the focus of *graduate-level* courses in engineering programs; however, industry needs more *bachelor's-level* engineering graduates to have skills in applying this essential analysis and design technique. Today's globally competitive world requires fast redesigns of products/ processes that are well-suited to using finite element analysis to reduce the design cycle. We have used the Kolb Learning Cycle as a conceptual framework to improve student learning of difficult engineering concepts, and to gain essential knowledge of finite element analysis (FEA) and design content knowledge.

A team of researchers, with a National Science Foundation grant for the past five years, have created and made improvements to seventeen active learning FEA modules which were originally developed using MSC Nastran, following the development efforts in SolidWorks Simulation, ANSOFT, ANSYS, and other commercial FEA software packages. We summarize the incremental improvements of these learning modules during the past five years as we implemented them into *undergraduate* courses that covered topics such as machine design, mechanical vibrations, heat transfer, bioelectrical engineering, electromagnetic field analysis, structural fatigue analysis, computational fluid dynamics, rocket design, and chip formation during manufacturing, and large scale deformation in machining.

This paper summarizes five years of incremental improvements to the modules comparing the student performance on pre- and post-learning module quizzes to gauge change in student knowledge related to the difficult engineering concepts addressed in each module. The researchers made significant changes to their finite element learning modules annually to improve student understanding of these difficult engineering concepts in their classes. Statistically, significant student performance gains provide evidence of module effectiveness by gender and ethnic groups was found to be minimal. In addition, we present statistical comparisons between different personality types (based on Myers-Briggs Type Indicator, MBTI subgroups) and different learning styles (based on Felder-Solomon ILS subgroups) in regards to the average gains each subgroup of students has made on quiz performance. Although exploratory, and generally based on small sample sizes in our five-year formative evaluation process, the modules for which subgroup differences were carefully reviewed and some instances re-administered in a different settings in an attempt to improve student performance across specific personality and /or learning styles subgroups (e.g. MBTI Intuitive versus Sensing; ILS Sequential versus Global).

Introduction

As educators advance engineering education, active learning approaches are becoming preferred choices 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 concepts, contemporary methods are being developed that seek to engage students actively, inside and outside the classroom, as well as kinesthetically through the various human senses. Such approaches have the potential to improve student comprehension and knowledge retention, and most importantly, to increase students' interest in the 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 ever 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 limitation 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 4-four year engineering programs poses challenges to most instructors. The need for integrating FE theory and application across the engineering curriculum has been established and methods have been suggested by other engineering authors[4-6] . This paper discusses the technique of designing finite element active learning modules (ALM) across many areas of engineering and the success of these modules in improving the students' understanding of the engineering concepts and of the finite element analysis technique. Previous authors over the past six years have reported their success in using their finite element learning modules[7-15].

The primary focus of this paper is to report the incremental student improvement in engineering learning from using many of the seventeen finite element learning modules in nine specific areas of engineering at five engineering colleges and universities over the past five years. This paper is a summary of the research reported in four earlier ASEE papers. This paper also reports the initial findings on the effects of student personality types on improvement in specific engineering areas of these ALMs.

An important goal for this work is to educate a diverse undergraduate group of engineering students with the basic knowledge of FE theory, while providing 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[16-17]. The Accreditation Board for Engineering and Technology, Inc. (ABET, Inc.) expects engineering graduates to have "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice" such as FE analysis[18]. Hence, engineering schools have, added or are planning to add, FE analysis to their curricula, but these plans are not occurring fast enough to meet the demand of firms competing in the global economy[19-25].

All learning modules developed in these five years of work are available free to all USA 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. Faculty and students initially assessed their effectiveness at three higher educational institutions. We included student demographic data, learning style preference data and MBTI data in the surveys' conducted on these initial twelve learning modules, but found that the sample size was in most instances too small to develop any statistically meaningful analysis.

In the 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. Small sample sizes are still a concern in the learning personality style analysis, but we are working toward combining all data for a specific learning module (e.g. “Curved Beam Learning Module”) administered with minor changes over four years to obtain larger sample sizes to analyze. We are hopeful that as larger, and more diverse engineering colleges and universities join us in this work; their larger student populations will support statistically significant analysis of diverse student learning styles and MBTI personality analysis for these 28 ALMs.

Methodology

The following methodology was used in analyzing the data:

1. Dependent samples t-tests were conducted in order to analyze whether or not exposure to the module significantly improved student performance on the pre-post measure, given before and after module implementation.
2. Independent samples t-tests were conducted to compare improvement on the pre-post measure for each personality type, learning style, ethnicity, and gender subgroup. The purpose was to examine whether or not any subgroup might have benefitted more (i.e., improved more from pre-test to post-test) from exposure to a module than another.
3. Beginning in the third year of implementation, Mann-Whitney analyses were conducted in addition to the independent samples t-tests. These analyses are generally more stringent than t-tests and do not assume that the scores in the population are normally distributed. The assumption of normal distribution is generally made when samples sizes are larger (i.e., justified by the Central Limit Theorem). Since most these tests are based on small samples, the equivalent Mann -Whitney test is used to assure accuracy of results. Unlike t-

test, the Mann-Whitney test is a non-parametric test which does not require the assumption of normality. On top of this primary analysis, we also summarize student feedback for professors implementing these modules. The student survey results are shared with the researchers to give them feedback on student responses to their learning modules.

4. Note that there are some assumptions inherent in this assessment strategy. First the quizzes which are given before the active-learning -module (pre-ALM) and again after (post-ALM) the active-learning-module are effective measures of the students' understanding of the learning module technical content. We have worked with assessment experts and composed an ASEE *paper*[17] discussing the use of quizzes to assess student knowledge and proper design of these quizzes. We believe that enhancement that commonly accomplished the infusion of active learning into the classroom and the inherent benefit of exposure to the finite element method allows us to make the assumption that if the students' quiz scores increase (pre to post ALM) then the ALMs are effective.
5. Finally, we are assuming that if one student learning group (Personality Types: Myers-Briggs Type Indicator MBTI-8 student types, Felder-Solomon's Index of Learning Styles (ILS-8student types) benefits more than another group of students taking a specific learning module, then this represents an opportunity to improve the learning experience of all student groups by altering the ALMs or the classroom environment . Note our goal is not to "even-out" the benefit.(meaning that we alter the ALMs so that the group that showed an increased benefit has their benefit lowered while the student group with less benefit has theirs raised). Instead our goal is to alter the ALM so that the benefit for the lower group is increased while the benefit for the higher group remains the same or also rises.

Active Learning Module Summaries

Table 1 As part of this TUES Phase 2 NSF- grant, fifteen learning modules have been developed and implemented into eight courses at six different universities using five different software packages. The information for each learning module is summarized in this table.

Title	FEA Software	Course Name	University
Sheet Metal Forming	Comsol	Manufacturing	Tuskegee University
Large Deformation Analysis of a Cantilever Beam	Comsol	Theory of Machines	Tuskegee University
Fatigue Analysis of a Rotating Shaft	SolidWorks Simulation	Machine Design II	University of the Pacific
Bobsled Computational Fluid Drag	SolidWorks Flow Simulation	Finite Element Analysis	University of the Pacific
Critical Speeds of a Rotating Shaft	SolidWorks Simulation	Vibrations	University of the Pacific CSU Pomona
Vibration Modes of Circular Disc	SolidWorks Simulation	Vibrations	University of the Pacific CSU Pomona
Power Analysis of a Rotating Transmission	AdvantEdge	Machine Design II	University of the Pacific
Machining Analysis During Chip Formation	AdvantEdge	Machine Design I	University of the Pacific
Multiple Story Building Frame	SolidWorks Simulation	Vibrations	University of New Haven
Bioelectric Field	Matlab	Bioengineering Special	Washington St.

Modeling		Topics	University
Semi-Infinite Medium	SolidWorks Simulation	Heat Transfer	University of the Pacific
Steady-State Heat Conduction	SolidWorks Simulation	Heat Transfer	University of the Pacific
Axisymmetric Rocket Nozzle	MSC Patran/Nastran	Finite Element Analysis	USAF Academy
Engine Cooling Fin	MSC Patran/Nastran	Finite Element Analysis	USAF Academy
Curved Beam	SolidWorks Simulation	Machine Design I	University of the Pacific

6. The NSF funding for the development and implementation of this finite element learning modules has been completed in two phases. The first four-year phase of funding occurred from 2006 through 2010, while the second four-year phase occurred immediately after the first phase (2010-2015). The ALM's underwent many revisions during the first phase; these revisions consisted of changes that were made to the ALM's themselves, as well as revisions that were made to the assessment procedure that was used to evaluate the effectiveness of the ALM's in improving student learning. For this reason, the results obtained during the first NSF Prototype phase cannot be combined into a larger data set in order to compare with the data set of this TUES Phase 2 NSF data set.

The five FE Learning Modules analyzed during the First Year of this Phase 2 NSF Grant research were

- Biomedical Electromagnetic Field Modeling
- Curved Beam Structural Analysis
- Machining Analysis during Chip-Formation
- Thermal FEA : Semi-Infinite Medium
- Thermal FEA : Steady-State Heat Conduction

Table 1 is a Summary of Year 1 Student Improvement and Personality/Learning Style, and Results for Five (5) Phase 2 Learning Modules (2010-2011) during the first year of this National Science Foundation Grant.

Improving Learning for Undergraduate Engineering Programs using Finite Element Learning Modules- NSF TUES Phase II

FE Learning Module	Semester	Number of Students	Pre-quiz Average Score out of 100	Post-quiz Average Score out of 100	Student Improvement
Biomedical Electromagnetic Field Modeling	Fall 2010	13	38.46	67.03	74.28%
Curved Beam Structural Analysis	Fall 2010	15	63.33	75.50	19.22%
Machining Analysis during Chip-Formation	Spring 2011	13	68.53	90.21	31.64%
Thermal FEA: Semi-Infinite Medium	Spring 2011	11	58.33	76.50	31.15%
Thermal FEA: Steady-State Heat Conduction	Spring 2011	11	58.33	76.50	31.15%
		Overall Student Improvement Average			**37.49%**

The twelve FE Learning Modules analyzed during the Second Year of this research were

- Structural Analysis of Large Deformation of a Cantilever Beam
- Sheet Metal Forming using FE Analysis: Shallow Drawing of a Circular Sheet
- Vibration of Critical Speeds of Rotating Shafts
- Computational Fluid Drag of a Bobsled Model
- Power Transmission Shaft Stress Analysis
- 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
- Defibrillation Electrode Modeling
- Bioelectric Field Modeling

Table 2 Student Improvement and Personality Learning Style Results for Phase 2 Learning

FE Learning Module	Semester	Institution	Students (n)	Pre-Quiz Avg (%)	Post-Quiz Avg (%)	% Student Improvement[1]	Subgroup differences MBTI or ILS[2]
Structural Analysis of Large Deformation of a Cantilever Beam	Fall 2011	Tuskegee	16	33.0	35.2	6.90 ($p = 0.523$)	Introvert (N=7) > Extrovert (N=9)** (MBTI; $p = 0.034$)
Axisymmetric Rocket Nozzle	Fall 2011	USAFA	11	42.0	54.5	29.73* ($p = 0.093$)	Extrovert (N=5) > Introvert (N=5)** (MBTI; $p = 0.014$)
Small Engine Cooling Fin	Fall 2011	USAFA	11	63.6	59.1	-7.14 ($p = 0.397$)	No
Vibration of Critical Speeds in Rotating Shafts	Fall 2011	CSU Pomona	9	62.2	72.2	16.07* ($p = 0.067$)	Introvert (N=6) > Extrovert (N=3)** (MBTI; $p = 0.033$)
Computational Fluid Drag of Bobsled Model	Fall 2011	UoP	17	50.0	65.3	30.60** ($p < 0.001$)	No
Vibration of Critical Speeds in Rotating Shafts	Fall 2011	UoP	25	47.2	59.2	25.42** ($p = 0.003$)	Intuitive (N=12) > Sensing (N=13)** (MBTI; $p = 0.018$)
Machining Analysis During Chip Formation	Spring 2012	UoP	12	50.8	83.3	64.18** ($p < 0.001$)	Perception (N=2) > Judgment (N=10)** (MBTI; $p = 0.046$)
Thermal FEA: Semi Infinite Medium and Steady-State Heat Conduction	Spring 2012	UoP	26	62.5	74.7	19.52** ($p = 0.002$)	No
Power Transmission Shaft Stress Analysis	Spring 2012	UoP	17	59.3	81.4	37.19** ($p < 0.001$)	N/A
Defibrillation Electrode Modeling	Spring 2012	Washington	18	27.1	57.6	112.82** ($p < 0.001$)	No
Bioelectric Field Modeling	Spring 2012	Washington	19	45.9	63.9	39.34** ($p < 0.001$)	Sequential (N=12) > Global (N=7)** (ILS; $p = 0.041$)
Sheet metal forming using FE Analysis: Shallow Drawing of a Circular Sheet	Spring 2012	Tuskegee	18	50.0	56.7	13.33* ($p = 0.083$)	No
Overall Student Improvement Average						**32.33%**	

[1] Percent (%) Improvement = [(post-quiz score - pre-quiz score)/pre-quiz score] * 100

[2] Felder-Soloman Index of Learning Styles (ILS); Myers Brigg Type Indicator (MBTI)

** Sufficient evidence of statistically significant improvement or subgroup differences ($p < 0.05$)

* Moderate evidence of statistically significant improvement or subgroup differences ($0.05 \leq p < 0.10$)

Modules (2011-2012)

Student Improvement and Learning Styles (Phase II Year 3)

The twelve FE Learning Modules analyzed during the third Year (2012-2013) of this research were

- Curved Beam Stress
- Computational Fluid Drag of a Bobsled Module
- Axisymmetric Rocket Nozzle
- Small Engine Cooling Fin
- Vibration of Critical Speeds in Rotating Shafts (Fall 2011 CSU Pomona)
- Machine Analysis during Chip Formation
- Power Transmission Shaft Stress Analysis
- Thermal FEA Semi-Infinite Medium & Steady State Heat Conduction
- Fatigue Analysis of Rotating Shaft
- Dynamics 2D Frame
- Sheet Metal Forming using FE Analysis: Shallow Drawing

Table 3 Summary of Year 3 Student Improvement and Personality/Learning Style Results for Phase II Learning Modules (2012-2013)

FE Learning Module	Semester	Institution	Students (n)	Pre-Quiz Avg (%)	Post-Quiz Avg (%)	% Student Improvement[1]	Subgroup differences MBTI or ILS[2]
Curved Beam Stress	Fall 2012	UoP	36	72.2	89.4	23.72** ($p < 0.001$)	No
Computational Fluid Drag of Bobsled Model	Fall 2012	UoP	8	48.8	72.5	48.72** ($p = 0.001$)	No
Rocket Nozzle	Fall 2012	USAFA	16	42.2	67.2	59.26** ($p < 0.001$)	No
Cooling Fin	Fall 2012	USAFA	16	39.1	59.4	44.74** ($p < 0.001$)	No
Critical Speed of Rotating Shaft	Fall 2012	CSU Pomona	13	69.2	78.5	13.33** ($p = .040$)	No
Machining Analysis during Chip Formation	Spring 2013	UoP	20	65.9	87.3	32.41** ($p < 0.001$)	Feeling (N=4) > Thinking (N=14)** (MBTI; p = 0.114, MWp = .046) Extrovert (N=10) > Introvert (N=8)* (MBTI; p = 0.034, MWp = .055) Active (N=14) > Reflective (N=4)* (ILS; p = 0.024, MWp = .061)
Power Analysis of Rotating Transmission (Shaft Stress)	Spring 2013	UoP	31	62.1	77.7	25.11** ($p < 0.001$)	No
Thermal FEA: Semi-Infinite Medium & Steady State Heat Conduction	Spring 2013	UoP	29	42.0	54.0	28.77** ($p = 0.001$)	Extrovert (N=12) > Introvert (N=14)** (MBTI; p = 0.026, MWp = .041)
Fatigue Analysis of Rotating Shaft	Spring 2013	UoP	31	68.1	75.8	11.37** ($p < 0.001$)	Judgment (N=24) > Perception (N=7)* (MBTI; p = 0.045, MWp = .054) Reflective (N=9) > Active (N=22)* (ILS; p = 0.035, MWp = .064)
Dynamics 2D Frame	Spring 2013	New Haven	15	43.6	49.7	13.89** ($p = 0.007$)	No
Shallow Drawing	Spring 2013	Tuskegee	15	58.5	60.6	3.51 ($p = 0.308$)	No
Overall Student Improvement Average						**27.71%**	

P= t-test results; MWp=Mann-Whitney results

[1] Percent (%) Improvement = [(post-quiz score - pre-quiz score)/pre-quiz score] * 100

[2] Felder-Soloman Index of Learning Styles (ILS); Myers Brigg Type Indicator (MBTI)

** Sufficient evidence of statistically significant improvement or subgroup differences ($p < 0.05$)

* Moderate evidence of statistically significant improvement or subgroup differences ($0.05 \leq p < 0.10$)

Student Improvement and Learning Styles for Phase 2 Learning Modules (2013-2014) during the fourth year of this National Science

The eight FE learning modules analyzed during the fourth year of this research were:

- Vibration Modes of Circular Disks
- Two Dimensional Frame
- Machine Analysis of Chip Formation
- Thermal FEA
- Power Analysis (Shaft Stress)
- Large Deformation of Cantilever Beam (Fall 2014)
- Large Deformation of Cantilever Beam(Spring 2014)
- Computational Fluid Drag of Bobsled Model

Table 4 Summary of Year 4 Student Improvement and Personality/Learning Style Results for Phase II Learning Modules (2013-2014)

FE Learning Module

	Semester	Institution	Students (n)	Pre-Quiz Avg (%)	Post-Quiz Avg (%)	% Student Improvement[1]	Subgroup differences MBTI or ILS[2]
Vibration Modes of Circular Disks	Fall 2013	Pomona	12	40.833	70.833	73.47** (p <0.001)	No
Two Dimensional Frame	Spring 2014	New Haven	18	43.889	65.556	49.37** (p <0.001)	No
Machine Analysis of Chip Formation	Spring 2014	UoP	23	66.40	85.77	29.17** (p<0.001)	No
Thermal FEA	Spring 2014	UoP	34	33.82	46.35	37.05** (p = 0.001)	No
Power Analysis (Shaft Stress)	Spring 2014	UoP	20	54.0	83.0	53.70** (p < 0.001)	Intuitive (n=13) < Sensing (n=7)** (MBTI; p = 0.018, MWp=0.03)
Large Deformation of Cantilever Beam	Spring 2014	Tuskegee	6	34.848	54.545	56.52** (p = 0.027)	No
Large Deformation of Cantilever Beam	Fall 2014	Tuskegee	28	31.166	49.674	59.39** (p <0.001)	No
Computational Fluid Drag of Bobsled Model	Fall 2014	UoP	16	51.25	69.375	35.37** (p<0.001)	Active (n=8) < Reflective (n=5)* (ILS; p = 0.04723, M Wp=0.06831) Visual(n=11)<Verbal(n=2)*^ (ILS; p = 0.06705, M Wp=0.08166)

Overall Student Improvement Average = 49.26%

p: t-test results; M Wp: Mann-Whitney results

[1] Percent (%) Improvement = [(post-quiz score - pre-quiz score)/pre-quiz score] * 100

[2] Felder-Soloman Index of Learning Styles (ILS); Myers Brigg Type Indicator (MBTI)

** Sufficient evidence of statistically significant improvement or subgroup differences ($p < 0.05$)

* Moderate evidence of statistically significant improvement or subgroup differences ($0.05 \leq p < 0.10$)

^ The sample size for one group is extremely small, so the results should be viewed with caution

Table 5 Five Year Summary Chart of Active Learning Modules

Summary Chart of Active Learning Modules by Authors and Their Weighted Average for Years Administered								
Semester/ Year	**Active Learning Module (ALM)**	**School**	**ALM Author**	**# Students**	**Student % Improvement**	**Weighted Average of % Improvement**	**P-Value**	**Personality Differences**
Fall 2010	Bioelectric	UoP	Schimpf	13	74.29	74.29	0.003	None
Spring 2012	Biomedical Electromagnetic Field	WSU	Schimpf	19	39.34	39.34	< 0.001	Sequential vs. Global (p = 0.041)
Fall 2011	Bobsled	UoP	Brown	17	30.59	49.93	< 0.001	None
Fall 2012	Bobsled	UoP	Brown	8	48.72		0.001	None
Fall 2013	Bobsled	UoP	Brown	23	74.78		< 0.001	None
Fall 2014	Bobsled	UoP	Brown	16	35.38		< 0.001	None
Fall 2011	Cantilever Beam	Tuskegee	Akasheh	16	6.9	37.81	0.523	Introvert vs. Extrovert (p = 0.034)
Spring 2014	Cantilever Beam	Tuskegee	Akasheh	6	19.7		< 0.001	None
Fall 2014	Cantilever Beam	Tuskegee	Akasheh	28	59.35		< 0.001	None
Spring 2011	Chip Formation	UoP	Liu	13	31.63	35.34	< 0.001	None
Spring 2012	Chip Formation	UoP	Liu	12	64.18		< 0.001	Perception vs. Judgement (p = 0.061)
Spring 2013	Chip Formation	UoP	Liu	20	32.41		< 0.001	Introvert vs. Extrovert (p = 0.034) Active vs. Reflective (p = 0.024)
Spring 2014	Chip Formation	UoP	Liu	24	29.12		< 0.001	None
Spring 2015	Chip Formation	UoP	Liu	14	28.91		< 0.001	Thinking vs. Feeling (p < 0.05) Active vs. Reflective (p < 0.05)
Fall 2011	Cooling Fin	USAFA	Wood	11	-7.14	23.60	0.397	None
Fall 2012	Cooling Fin	USAFA	Wood	16	44.74		< 0.001	None
Fall 2012	Curved Beam	UoP	Liu	36	23.72	27.28	< 0.001	None
Fall 2013	Curved Beam	UoP	Liu	31	41.38		< 0.001	Sensing vs. Intuitive (p = 0.027)
Fall 2014	Curved Beam	UoP	Liu	12	1.54		< 0.001	Sensing vs. Intuitive (p = 0.035)
Spring 2012	Defibrillation Electrode	WSU	Schimpf	18	112.82	112.82	< 0.001	None
Spring 2013	Dynamic 2D Frame	New Haven	Orabi	15	13.89	39.41	0.007	None
Spring 2014	Dynamic 2D Frame	New Haven	Orabi	16	63.33		< 0.001	None
Spring 2013	Fatigue Analysis	UoP	Liu	31	11.37	11.37	< 0.001	Perception vs. Judgement (p = 0.045) Active vs. Reflective (p = 0.035)
Spring 2014	Power Transmission Shaft Stress Analysis	UoP	Liu	24	53.7	35.90	< 0.001	None
Spring 2012	Power Transmission Shaft Stress Analysis	UoP	Liu	17	37.19		< 0.001	None
Spring 2013	Power Transmission Shaft Stress Analysis	UoP	Liu	31	25.11		< 0.001	None
Spring 2015	Power Transmission Shaft Stress Analysis	UoP	Liu	22	30.67		< 0.001	Sequential vs. Global (p < 0.05)
Fall 2011	Rocket Nozzle	USAFA	Wood	11	29.73	47.23	0.093	Introvert vs. Extrovert (p = 0.014)
Fall 2012	Rocket Nozzle	USAFA	Wood	16	59.26		< 0.001	None
Spring 2012	Shallow Drawing	Tuskegee	Akasheh	18	13.33	8.87	0.083	None
Spring 2013	Shallow Drawing	Tuskegee	Akasheh	15	3.51		0.308	None
Spring 2011	Thermal FEA	UoP	Watson	11	31.17	29.60	0.013	None
Spring 2012	Thermal FEA	UoP	Watson	28	19.49		0.002	None
Spring 2013	Thermal FEA	UoP	Watson	29	28.77		0.001	Introvert vs. Extrovert (p = 0.026)
Spring 2014	Thermal FEA	UoP	Watson	39	37.05		0.001	None
Spring 2015	Thermal FEA	UoP	Watson	26	29.59		0.009	Thinking vs. Feeling (p < 0.05)
Fall 2011	Vibration of Critical Speeds in Rotating Shafts	Pomona	Chen	9	16.07	20.29	0.067	Introvert vs. Extrovert (p = 0.033)
Fall 2011	Vibration of Critical Speeds in Rotating Shafts	UoP	Chen	25	25.42		0.003	Sensing vs. Intuitive (p = 0.018) Thinking vs. Feeling (p = 0.077)
Fall 2012	Vibration of Critical Speeds in Rotating Shafts	Pomona	Chen	13	13.33		0.040	None
Fall 2013	Vibrational Modes of Circular Disk	Pomona	Chen	12	73.47	73.47	< 0.001	None

Researcher's Comprehensive Conclusions from this Research

Each researcher provides a comprehensive summary of their conclusions gained from their research in teaching finite element analysis using active learning modules (ALMs), or to improve the assessment process for teaching finite element analysis during the past five years in the narratives below:

Ashland O. Brown- PI and Author of the Fatigue Analysis of a Rotating Shaft Module the CFD Bobsled Module and Curved Beam Structural Module

Prof. Jiancheng Liu administered my Fatigue Analysis on a Rotating Shaft active learning module in his Machine Design Class in spring 2013 with student improvement of only **11.37%.** We analyzed and agreed that this module contained too many PowerPoint slides which provided overtaxing content for our students to comprehend and apply correctly. We would have to reduce the number of PowerPoint content slides significantly to improve student learning significantly for this active learning module. We discontinued using this active learning module during the last three years of this NSF grant due to my limited man-hours available in this project to simplify this ALM slides.

Prof. Jiancheng Liu administered my Curved Beam active learning module in his Machine Design class and made the appropriate changes to improve this module over the four years of this grant, his summary report discusses his changes and the corresponding student learning improvements he gained from this research.

A concentrated effort was made to improve the computational fluid dynamics Bobsled active learning module_with different adjustments to the active learning module and a few in-class environmental changes over the past four years. Student surveys from fall 2011 brought to my attention errors in the Bobsled learning module PowerPoint slides which were eliminated thereby student learning improved from 30.59% to 48.72 % in fall 2012. Reducing more PowerPoint errors and using fewer PowerPoint slides to illustrate software operations along with more class -time between pre and post quizzes yielded a student improvement of 74.78**%** for fall 2013. The improved error-free PowerPoint active learning module slides along with the longer class-time between pre and post quizzes were provided to my fall 2014 class with a student improvement of only 35**.** 38%. The larger student improvement obtained in fall 2013 was unsustainable for this module year to year and that the weighted average of 49.93% is sustainable for this active learning module. A 49.93% weighted average improvement for 64 students taking this active learning module over four years is great. Increasing the in-class time between the pre and post module quizzes along with error-free PowerPoint slides were key factors in improved student learning of a difficult finite element computational problem as we gained in this research.

The P values less than .001 for the student quiz results for all four years attests to the statistical soundness of this module when properly administered to small classes in undergraduate finite element method courses. The fact that there were no differences found in student learning styles (MBTI, ILS) for 64 students attests to the uniformity of student response to this module regardless of their learning styles and is testimony to properly administered active learning modules showing minimum preference of different student learning styles or MBTI's.

Kyle Watson-Author for a Semi-Infinite Medium Heat Transfer Module and a Steady-State Heat Conduction Module

The thermal FEA learning modules were implemented for five consecutive years during the spring semesters of 2011 through 2015. The learning modules were implemented by first covering the theory behind semi-infinite mediums and steady-state conduction in a conventional lecture delivery. The pre-quiz learning module was then administered, followed by the implementation of the two learning modules. The students were given approximately three weeks to perform the two learning modules and submit assignments that required them to apply what they learned from the two learning modules. The post-quiz was given shortly after the assignment was submitted. The results indicate an improvement of 29.6% for all five years combined, with a minimum improvement of 19.5% in 2012 and maximum improvement of 37.1% in 2014. The p-values for each year imply the statistical soundness of these modules when properly administered. The only significant changes that were made to the learning modules during those five years were changes that were necessary due to SolidWorks version changes, such as icon changes. Otherwise consistency was used in order to be able to consolidate the data that was acquired. Furthermore, based on the demographic data that was collected, it was determined that there is a more substantial positive impact on students with lower grade point averages GPA's (< 3.0) than those with higher GPA's(≥ 3.0). These results collectively provide strong evidence that the learning modules result in improved student comprehension of challenging topics while exposing all undergraduate engineering students to the finite element method. It is believed that the alternative insight provided by the learning modules provides a valuable learning tool especially for those students with lower GPA's.

Jiancheng Liu-Author Power Analysis of a Rotating Transmission Module and the Machine Analysis during Chip Formation Module, Administrator of the Curved Beam Structural Module

In the five years, I have developed three modules and administrated these modules for the courses of Machine Design and Analysis and Advanced Manufacturing Processes. The total number of modules that I administrated is thirteen for students majoring mechanical engineering management and bio engineering program in the School of Computer Science and Engineering of the University of the Pacific. Majority of students are undergraduate students; some are graduate students. These modules include Curved Beam Stress Analysis, Power Transmission Shaft Stress Analysis, Fatigue Analysis, and Chip Formation Process Simulation Process. During the years while I administrated these modules, I have continuously improved the modules and implementation method by taking the student and peer's feedback. These modules can be also used by other colleagues working in other institutions.

It is found that these active learning modules are effective in terms of improving student's learning. In the case of Power Analysis of a Rotating Transmission module, the overall improvement percentage is 35.9% for 94 students over the four year; for the module of Machining Analysis during Chip Formation, the overall improvement rate is 35.3% for 83 students; for curved beam stress analysis, the overall improvement is 27.3%. For these three modules, the average improvement rate is 32.82%, which is significant. Our students also naturally learned the skills on how to perform different kinds of FE analysis for various engineering problems. It is also worth mentioning that students have used the knowledge and skills absorbed through performing these active learning modules to do their course and senior design projects.

Dan D. Jensen, author and developer of the assessment techniques used in this research of these active learning modules. Not Available

Paul H. Schimpf, author of the Bioelectric Head Modeling, and Defibrillation Electrode active learning modules

Bioelectric Head Modeling

This module covers forward and inverse electric fields in a model of the human head created from medical imagery. The forward problem is solved by applying the finite element method to the Poisson equation, with neural sources simulated as dipolar current sources. A non-conforming, adaptive mesh of hexahedral elements is used, for which custom software for MS Windows, developed by Dr. Schimpf is provided. The inverse problem of locating a constrained number of sources from scalp potentials is also covered using a forward transfer matrix (or lead-field) extracted from forward simulations using reciprocity. This module originated in Phase 1 of the program, with refinements every year. During year one of Phase two this module was tested at WSU and demonstrated an average student performance gain of 74%, with no differences for student personality or learning styles. It was tested again in year 2, demonstrating a performance gain of 39%, with a statistically significant performance difference between sequential and global learners. The 95% confidence interval on the difference was 1% to 30%, indicating that the performance improvement for sequential learners was at least 1% (and at most 30%) higher than for global learners. In order to address this difference a two page "roadmap" document was produced to provide a global overview of the module. The learning module slides were also annotated to identify which portion of the roadmap each slide pertains to. In addition, the instructor was advised to allow students to take multiple passes through the learning module, as desired, between executions of the pre-and-post learning module quizzes. Unfortunately, we have not had a chance to test these changes as the targeted bioengineering course has not been offered. An alternative course that can serve the purpose has been identified at EWU (CSCD 409, Scientific Programming), which a likely venue for any future is testing.

Defibrillation Electrode Modeling
This module originated in Phase two, was developed during the summer of 2011 and refined during the spring of 2012. It covers the simulation and refinement of current density profiles below a defibrillation electrode using the finite difference method with spherical symmetry. The tutorial covers application of the Laplace equation to this problem along with development of the finite difference approximation, including Matlab code. Changes to the current density under the electrode are examined for an electrode directly over tissue, for an intervening layer of electrode gel, and for variations in the number of concentric rings in the electrode. This module was tested in spring 2012 with a student performance improvement of 113%, with no difference between learning styles.

Cody Rasmussen for John Wood (deceased) author of Rocket Nozzle and Cooling Fin active learning modules. Not Available

Ismail L. Orabi author of the Dynamic 2D Frame active learning module Not Available

Richard Crawford, Co-PI Technical and Assessment Manager.

My major role in the project was development and establishment of the online repository for pre/post quiz data, as well as personality type and learning style data. Initially the repository was implemented using the SurveyStation survey engine. During 2012-2013, we moved all the instruments to the Qualtrics survey engine at UT Austin due to the retirement of SurveySolution. During this migration, we also created the ability for self-scoring the pre/post quizzes and offered this option to the professors participating in the project.

The 2011-2012 cumulative results of all 12 FE ALMs were very positive. From the correlations areas of improvement for future iteration of particular ALMs were identified. On a whole, the average improvement to student learning directly related to these ALMs was significant. The ALMs provided students with the chance to go from below passing on content quizzes to above passing. Specifically, the assessment over the 12 ALMs indicated the average pre-to-post-quiz increased over 30%. The iterative assessment method (based on the equitability correlations) identified demographic groups that benefited less than other groups from the implementation of the ALMs, providing indication of areas to refine and improve each ALM to be more equitable across the student demographic groups.

During the 2012-2013 and 2013-2014 years we analyzed this data again and made suggestions to the modules. The learning modules were analyzed with respect to student learning styles and student learning personalities. During 2012-2013 , six of the ALMs showed no evidence of subgroup differences, while six of the ALMs did show statistically significant subgroup differences ($p<0.05$) for Myers-Briggs Type Indicator (MBTI) personality inventory and Index of Learning Styles (ILS) student survey data. During 2012-2014, six of the ALMs showed no evidence of significant subgroup differences ($p<.05$) for Myers-Briggs Type Indicators and Index of Learning Styles student survey data. Each year, as part of our iterative assessment and improvement process, after we identified groups (either MBTI or ILS) that did not perform as well as their counterparts, we recommended adjustments in the project administration that can be implemented before the presentation of the ALMs.

Firas Akasheh, author of the Cantilever Beam and Shallow Drawing active learning modules

Both the ALMs developed by Prof. Akasheh involved nonlinear phenomena. The nonlinearity in the Cantilever Beam module is a geometrical one while the origin of nonlinearity in the Shallow Drawing module is material plasticity nonlinearity. Nonlinear behavior is typically considered an advanced topic and is not covered in undergraduate curricula. Comparison of the two ALMs shows that the student students' learning gains ware much better in the case of the Cantilever Beam about 37% compared to the Shallow Drawing case about 9%. In my opinion, the reason for this discrepancy is that the Cantilever Beam is more tangible and more connected to students experiences. It also appears in several courses whereas the Shallow Drawing is covered as an isolated part of the course whose nature is descriptive. Furthermore, I was able to improve the Cantilever Beam ALM administration in several ways. After the first implementation errors and hard-to-follow directions were pointed out by students which were corrected. I provided more practical insight about the geometry nonlinearity of the Cantilever Beam using a physical demonstration in-class using composite rods. Finally, the pre/post quiz was improved by adding more questions and expanding the choices, which resulted in a better testing instrument. These refinements can explain the improvement in student learning after the first implementation of the Cantilever Beam ALM.

Joseph Rencis, Co-PI, author of paper on preparing quizzes for ALMs. Not Available

Chuan-Chiang Chen, author of the Vibration of Critical Speeds in Rotating Shafts and Vibration of Modes of Circular Disk active learning modules Not Available

Kathy Jackson, author of white paper on Teaching Students via Learning Modules. Not Available

Mouchumi Bhattacharyya, Independent Evaluator of the Learning Module Assessment Processes for Small Sample Sizes

Contributions to the project: Dr. Bhattacharyya joined this project in the spring of 2014.

Dr. Bhattacharyya's primary role was that of directing a graduate student in the statistical analysis of student responses to various learning modules administered to students at the University of the Pacific and elsewhere. Paired t-tests were used to investigate whether students' quiz scores improved after being exposed to the learning modules. Independent sample t-tests were used to investigate whether students' scores varied based on their personality types. Since most of these tests were based on small samples, the equivalent Mann-Whitney tests were used to assure accuracy of results. Unlike t-test, Mann-Whitney test is a non-parametric test which does not require the assumption of normality. On top of these primary analyses, students' feedback for professors implementing these modules was also summarized. The student survey results were shared with the researchers to give them feedback on student responses to their learning modules.

Intellectual Merit of this Research

This project provided an innovative method to teach undergraduate engineering students across diverse universities basic finite element analysis (FEA) and the ability to correctly use commercial FEA software to solve engineering problems. The assessment strategy allowed us to measure the student learning improvements using a quiz on the new FEA material before administering the FEA learning module and the same quiz after the students had taken the FEA learning module. We effectively measured student competency versus different student demographic variables during this research.

Broader Impacts of this Research

This project used 17 new FEA modules to teach engineering concepts and FEA theory to 751 undergraduate engineering students in a broad range of undergraduate engineering courses. These hands-on modules provided active learning through interactive analysis using perturbation studies and computer visualization of typical engineering problems. These 17 new FEA modules were added to existing 12 FEA modules from our initial CCL Phase 1 NSF Grant on our GOOGLE website to share these modules and their assessment tools with educators around the globe

Summary of Significant Results of this Research

Over 751 undergraduate engineering students were administered seventeen finite element active learning modules at eight engineering colleges and universities over five years. Quizzes on the basics of using FEA to analyze engineering problems were given to the students prior and after the FEA modules produced measured improvements in knowledge of 30% and above for these FEA modules. Furthermore, based on the demographic data that was collected, it was determined that there is a more substantial positive impact on students with lower grade point averages GPA's (< 3.0) than those with higher GPA's(≥ 3.0). These results collectively provide strong evidence that the learning modules result in improved student comprehension of challenging topics while exposing all undergraduate engineering students to the finite element method. It is believed that the alternative insight provided by the learning modules provides a valuable learning tool especially for those students with lower GPA's.

Key Outcomes or Other Achievements

The engineering students were able to use these new engineering FEA skills to design their senior projects for their capstone engineering courses in most instances. Many students included these new FEA skills in their senior vitae to assist them in obtaining engineering jobs in competitive fields upon graduation.

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