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Active Engineering Education Modules: A Summary of Recent Research Findings

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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 an Associate 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 90 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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Chuan-Chiang Chen is a 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, acoustics, and vibrations.

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Active Engineering Education Modules: A Summary of Recent Research Findings

Abstract

The landscape of contemporary engineering education is ever changing, adapting and evolving. As an example, finite element theory and application has often been included in *graduate-level* courses in engineering programs; however, current industry needs *bachelor's-level* engineering graduates with skills in applying this essential analysis and design technique. Engineering education is also changing to include more active learning. In response to the need to introduce undergrads to the finite element method as well as the need for engineering curricula to include more active learning, we have developed, implemented and assessed a suite of Active Learning Module (ALMs).The ALMs are designed to improve student learning of difficult engineering concepts while students gain essential knowledge of finite element analysis. We have used the Kolb Learning Cycle as a conceptual framework to guide our design of the ALMs.

Originally developed using MSC Nastran, followed by development efforts in SolidWorks Simulation, ANSOFT, ANSYS, and other commercial FEA software packages, a team of researchers, with National Science Foundation support, have created over twenty-eight active learning modules. We will discuss the implementation of these learning modules which have been incorporated into *undergraduate* courses that cover 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.

The findings in this paper includes statistical results for each module which compare performance on pre- and post-learning module quizzes to gauge change in student knowledge related to the difficult engineering concepts that each module addresses. Statistically significant student performance gains provide evidence of module effectiveness. In addition, we present statistical comparisons between different personality types (based on Myers-Briggs Type Indicator, MBTI, subgroups), different learning styles (based on Felder-Solomon ILS subgroups), and gender and ethnicity in regards to the average gains each group of students have made on quiz performance. Although exploratory, and generally based on small sample sizes at this point in our multi-year effort, the modules for which subgroup differences are found are being carefully reviewed in an attempt to determine whether modifications should be made to better ensure equitable impact of the modules across students from 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 student's 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 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 ASEE paper. 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, 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[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, 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 six 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 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. 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 twenty eight 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). The Mann-Whitney analyses were appropriate to utilize for the current study because the sample sizes being analyzed tended to be small.

Student Improvement and Learning Styles (Phase II Year 2)

We administered twelve of the Phase 2 FE ALMs during the second year of this research and focused on measuring both student learning content using the pre and post learning module quizzes and student learning bias toward a specific Myers Brigg Type Indicator (MBTI) or Index of Learning Style (ILS) as measured with the on-line MBTI survey and the on-line Felder-Solomon survey. Six of the learning modules suggested no bias toward a specific MBTI or Index of Learning Style and six of the learning modules suggested a bias toward a specific MBTI or Index of Learning Style.

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 1 is a Summary of Year 2 Student Improvement and Personality/Learning Style, and Results for Twelve (12) Phase 2 Learning Modules (2011-2012) during the second year of this National Science Foundation Grant.

Table 1. Summary of Year 2 Student Improvement and Personality Learning Style Results for Phase 2 Learning Modules (2011-2012)

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 ($0.05 \leq p < 0.10$)

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

The average improvement for the twelve learning modules administered was 32.33% where the number of students tested is shown as n and the quiz scores (both pre and post) are out of 100%. For reference, a sample twelve question pre/post quiz for the Thermal FEA Learning module is included in Appendix A; the same quiz is given both pre-and post-learning module activity. Three of the twelve FE learning modules showed **moderate evidence** of improved student performance ($.05 \leq p < .10$) as noted in Table 1 by *. Seven of the twelve FE learning modules **showed sufficient** evidence of improved student performance ($p<0.05$). Two of the twelve FE ALMs showed **insufficient evidence** of improved student performance (i.e. $p = 0.523$ and $p = 0.397$). The authors of these two FE learning modules will be working to improve their FE learning modules, assessment quizzes and other instruments to improve their students' performance.

As shown in Table 1, five of the FE learning modules **showed no evidence** of subgroup difference upon analysis of the MBTI and ILS surveys taken by the students, therefore these modules were considered ideal in their handling of the student subgroups taking the quizzes. Six of the remaining FE learning modules show statistically significant subgroup differences ($p <0.05$) for the MBTI and ILS student survey data.

Regarding the subgroups mentioned in the last column of Table 1, extroverts tend to take initiative and gain energy from interactions, whereas introverts prefer more of a relatively passive role and gain energy internally from cognition; sensors tend to process information with their focus on their five senses and the environment, whereas intuitors tend to focus on the possibilities of the information and see the big picture; perceivers prefer to be sure all data are thoroughly considered, whereas judgers summarize the situation as it presently stands and make decisions more quickly; and a sequential learner tends to gain understanding in linear steps, whereas a global learner tends to learn in large jumps, suddenly "getting it".

Student Improvement and Learning Styles (Phase II Year 3)

Table 2 presents similar results for the Phase 2, Year 3 Learning Modules (2012-2013). It can be seen that ten of the eleven learning modules **showed sufficient** evidence of improved student performance ($p<0.05$) as indicated by the ** in Table 2. The average improvement for the eleven learning modules administered was 27.71%.

Table 2. 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 ($0.05 \leq p < 0.10$)

Gender and Ethnicity Differences (Phase II Year 3)

Due to small sample sizes, it was not possible to compare gender and ethnicity differences in delta (i.e., change from pre-test to post-test scores) within every module implemented. During Phase II Year 2 of this project, ethnicity differences were not analyzed due to low representation by various ethnic groups. In addition, the students introduced to these modules were predominantly male and therefore only one module from Phase II Year 2 was analyzed for gender differences (Table 3).

Table 3. Gender Differences in Delta for Phase II Year 3 Learning Modules (2012-2013)

Module	Semester	Institution	Gender	Students (n)	Mean Delta	Significant Difference
Sheet metal forming using FE Analysis: Shallow Drawing of a Circular Sheet	Spring 2012	Tuskegee	Male	7	2.9	No (p=.218)
			Female	7	12.9	

Delta = post-quiz score minus pre-quiz score

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

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

There was insufficient evidence (p>.05) to support differences in change from pre- to post-test scores (i.e., delta) by gender in the module analyzed. Specifically, the change in score from pre-test to post-test was not significantly different for male and female students. An important limitation to note in the above analysis is the small sample sizes. With only 7 male and 7 female students represented, the statistical power to detect subgroup differences was too low to confidently rule out subgroup differences; however these preliminary results suggest that this module did not appear to favor students of one gender over the other.

Gender and Ethnicity Differences (Phase II Year 3)

Again, due to small sample sizes, it was not possible to compare gender and ethnicity differences in delta (i.e., change from pre-test to post-test scores) within every module implemented. During Phase II Year 3 of this project, gender differences were not analyzed due to low representation by female students.

Due to low representation of various ethnic groups, the six modules listed in Table 4 were the only modules analyzed from Phase II Year 3 looking at ethnicity. In addition, only the Asian/Pacific Islander and White/Caucasian students were compared due to their similar sample sizes.

Table 4. Ethnicity Differences in Delta for Phase II Year 3 Learning Modules (2012-2013)

Module	Semester	Institution	Ethnicity	Students (n)	Mean Delta	Significant Difference
Computational Fluid Drag of Bobsled Model	Fall 2012	UoP	Asian/Pacific Islander	4	27.5	No (p=.588)
			White/Caucasian	2	20.0	
Machining Analysis during Chip Formation	Spring 2013	UoP	Asian/Pacific Islander	7	16.9	No (p=1.000)
			White/Caucasian	7	16.9	
Curved Beam Stress	Fall 2012	UoP	Asian/Pacific Islander	12	16.7	No (p=.397)
			White/Caucasian	16	19.8	
Critical Speed of Rotating Shaft	Fall 2012	UoP	Asian/Pacific Islander	10	7.0	No (p=.924)
			White/Caucasian	15	6.7	
Thermal FEA: Semi-Infinite Medium & Steady State Heat Conduction	Spring 2013	UoP	Asian/Pacific Islander	10	3.3	No (p=.192)
			White/Caucasian	13	12.2	
Power Analysis of Rotating Transmission (Shaft Stress)	Spring 2013	UoP	Asian/Pacific Islander	10	2.4	No (p=.224)
			White/Caucasian	15	1.3	

Delta = post-quiz score minus pre-quiz score

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

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

There was insufficient evidence (p>.05) to support differences in change from pre- to post-test scores (i.e., delta) by ethnicity in the modules analyzed. Specifically, the change in score from pre-test to post-test was not significantly different for Asian/Pacific Islander and White/Caucasian students. Once again, it is important to highlight the small sample sizes in the above analyses. With these small sample sizes, the statistical power to detect subgroup differences was too low to confidently rule out subgroup differences; however, these preliminary results suggest that these modules did not appear to favor students of one ethnicity over the other.

Student Improvement and Learning Styles (Phase II Year 4)

We administered eight of the Phase 2 FE ALMs during the fourth year of this research and focused on measuring both student learning content using the pre and post learning modules quizzes and student learning bias toward a specific Myers Briggs Type Indicator (MBTI) or Index of learning Style and only one of these modules showed a bias toward a specific MBTI or Index of Learning Styles

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

We will continue to pursue differences in student improvements by gender and ethnicity differences as the data becomes available. It was not possible to compare gender and ethnic differences this third year due to small sample sizes. The results of the analysis for the eight learning modules are shown in **Table 5 below.**

Table 5 Summary of Year 4 Student Improvement and Personality Leaning Style Results for Phase 2 Learning Modules (2013-2014) during the fourth year of this National Science Foundation Grant

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 = 0.009, MWp=0.015)
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 = 0.02362, M Wp=0.03416) Visual(n=11)<Verbal(n=2)*^ (ILS; p = 0.03353, M Wp=0.04083)

Overall Student Improvement Average = 46.77%

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

Conclusions and Future Efforts

This paper summarizes the results from three years of a Phase 2 NSF grant (2011-2012, 2012-2013, and 2013-2014). Of particular significance is the student improvement in the pre- learning module versus post learning module -quiz scores. Specifically, these student improvements were 32.33% for academic year 2011-2012, 27.7% for academic year 2012-2013 and 49.26% for academic year 2013-2014. We will begin the process of analyzing the student improvement each of four years <u>for each module</u> and intend to summarize this in a future paper. Since these learning modules are designed to supplement traditional lecture material in order to reinforce concepts that are typically difficult for students to understand, the authors believe that these student improvement performances are significant.

We also reviewed the second goal of this research in analyzing differences in personality types based upon Myers-Briggs Type Indicator, MBTI differences in learning styles based upon Felder-Solomon ILS subgroups. Our preliminary results were from the academic year 2011-2012 resulted in five out of twelve modules exhibited differences in subgroup MBTI behavior and only one module exhibited differences in subgroup learning style ILS behavior. Our results were during the academic year 2012-2013 we found four out of eleven modules exhibited differences in MBTI behavior and only two out of eleven exhibited differences in learning style ILS behavior. Our results during the academic year 2013-2014 two out of the seven different learning modules exhibited differences in MBTI and learning styles ILS behavior. We continue to analyze these differences and attempt to quantify these results in our next paper.

While somewhat challenged in finding meaningful results regarding the effects of the learning modules on different learning styles, genders, and ethnicities, primarily due to small sample sizes, the authors are continuing to gather data in order to increase these sample sizes. The goal is to gather and analyze data from several institutions in order to assess the pre- and post-quiz scores to determine if any MBTI or ILS types, genders, or ethnicities perform significantly better than their counterparts. In cases where they do perform significantly better, we intend to offer the learning module author suggestions on how to refine the learning modules (either in content or implementation process) in order to attempt to minimize the differences in performance across these types, while maintaining a high level of increase in performance as indicated by improved quiz performance after completing the learning modules for a vast majority of students.

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Appendix A (Pre- and Post-Learning Module Quiz)

Pre/Post Quiz:

Thermal Analysis Finite Element Learning Module Activities

Animal ID: ____________________

1. Which of the following is true for a semi-infinite medium:

   a) Heat conduction does not change with time

   b) Heat conduction is one-dimensional

   c) Heat conduction is multi-dimensional

   d) There will always be heat generation

2. Which of the following is true for a semi-infinite medium:

   a) Heat conduction results from the thermal condition at one boundary

   b) Heat conduction results from the thermal conditions at two boundaries

   c) Heat conduction results from the thermal conditions at more than two boundaries

   d) Heat conduction does not occur

3. A semi-infinite medium that is exposed to a moving fluid with a very large heat transfer coefficient has a boundary condition that can be treated as:

   a) A specified heat flux boundary condition

   b) A specified temperature boundary condition

   c) An insulated boundary condition

   d) A line of symmetry

4. A large plane wall that is initially at a temperature T_i is suddenly exposed to a hot moving fluid on one side. When can this object be treated as a semi-infinite medium?

    a) Never

    b) Always

    c) For a finite period of time immediately after the object is subjected to the hot moving fluid

    d) For a finite period of time beginning some time after the object is subjected to the hot moving fluid

5. A large plane wall that is initially at a temperature T_i is suddenly exposed to a hot moving fluid on one side and a cold moving fluid on the other side. When can this object be treated as a semi-infinite medium?

    a) Never

    b) Always

    c) For a finite period of time immediately after the object is subjected to the hot moving fluid

    d) For a finite period of time beginning some time after the object is subjected to the hot moving fluid

6. A two dimensional steady-state heat conduction problem requires how many boundary conditions in order to determine the temperature distribution?

    a) 1

    b) 2

    c) 3

    d) 4

7. An initial condition is *not* required in order to solve for the temperature distribution for which type of heat transfer problem?

    a) A semi-infinite medium problem

    b) A transient, one-dimensional problem

    c) A multi-dimensional problem

    d) A steady-state problem

8. The finite element method of modeling conduction heat transfer approximates a partial differential equation with:

    a) An ordinary differential equation

    b) A finite number of algebraic equations

    c) A series of finite numbers

    d) A finite number of elements

9. The finite element method of modeling conduction heat transfer results in an approximate solution for: (fill in the blank)

    ____

10. Two different objects (*A* and *B*) are exposed to a hot fluid on their left side that results in one-dimensional, steady-state heat conduction. The thermal conductivity of object *A* is double the thermal conductivity of object *B*. The temperature at the right side of object *A* will be:

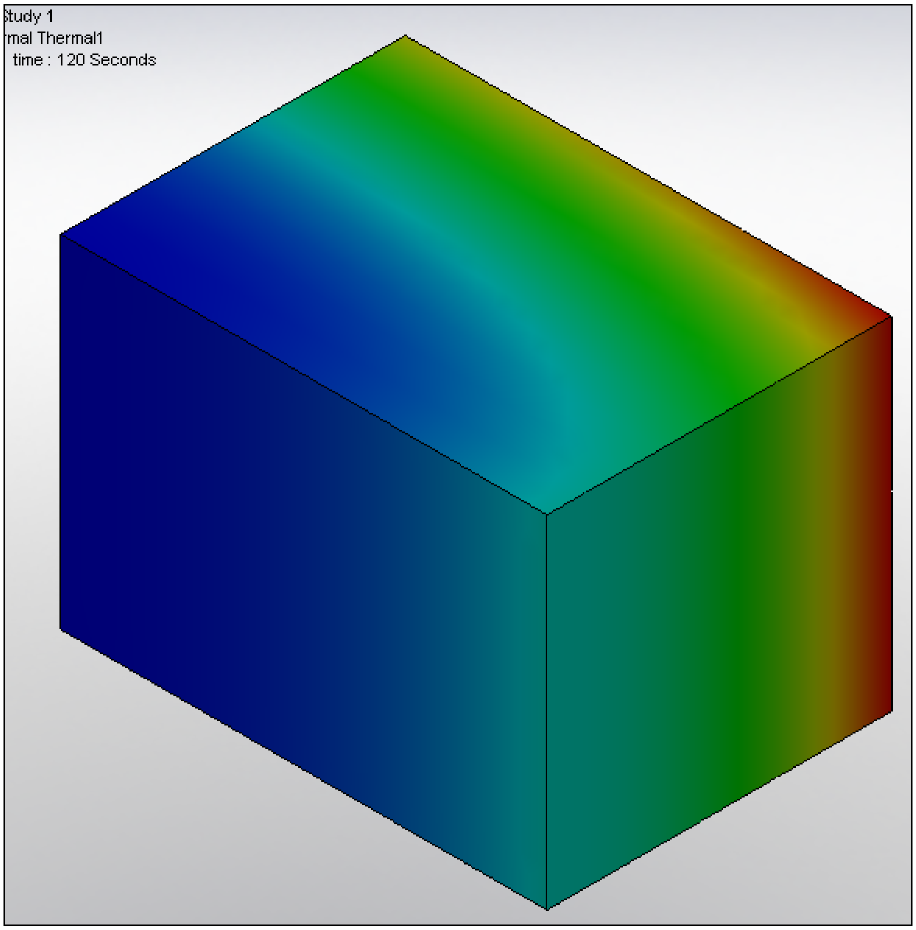
    a) Higher than the temperature at the right side of object *B*

    b) Lower than the temperature at the right side of object *B*

    c) The same as the temperature at the right side of object *B*

    d) Unknown (it cannot be determined from the given information)

11. The temperature distribution throughout a solid body is shown below. Which of the following statements is true?



a) This is a one-dimensional heat transfer problem

b) This is a two-dimensional heat transfer problem

c) This is a three-dimensional heat transfer problem

d) It cannot be determined whether this is a 1-D, 2-D or 3-D problem

12. A top view of the temperature distribution from the solid body shown in the previous problem (problem #11) is shown below. Which type of boundary condition occurs at the bottom surface labeled below?

a) A specified temperature boundary condition

b) A heat generation boundary condition

c) A convection boundary condition

d) An insulated (zero heat flux) boundary condition

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