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Finite Element Analysis Active Learning Modules Embedded Throughout A Curriculum: Implementation and Assessment of Results Based on Student GPA

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Abstract

Commercial finite element packages are widely used in industry thereby making exposure to this tool an essential component of undergraduate engineering education. This paper discusses the development, implementation, and results of integrating active learning modules (ALM's) throughout an engineering curriculum with the goal of providing an effective learning resource that reinforces fundamental, yet challenging, course concepts without requiring knowledge of the rigorous mathematical theory underlying the finite element method. Fifteen ALM's have been implemented into eight courses at six different universities; this paper focuses on four ALM's that have been implemented at the University of the Pacific for several years thereby providing a significant amount of data. Assessment has been done through the use of identical pre- and post-ALM quizzes and a survey that gathers student information such as GPA, gender and ethnicity. Results indicate that there is a significant increase in student performance after completing the ALM's and there is a more substantial positive impact on students with lower GPA's (< 3.0) than those with higher GPA's (≥ 3.0). These results provide strong evidence that the ALM's designed and implemented during this study result in improved student comprehension of challenging topics while exposing all undergraduate engineering students to the finite element method.

Introduction

Active learning tools are becoming increasingly popular in addressing student challenges in learning and retaining complex topics in engineering. The effectiveness of these active learning tools is often a function of student background, personality type, demographics, academic prowess, and other measures. In order to move beyond the typical challenges that are encountered while teaching difficult concepts to a diverse population of students, contemporary methods are being developed that seek to engage students actively, both inside and outside of the classroom. Such approaches have the potential to improve student comprehension and knowledge retention, and most importantly, to increase student interest in the material[1-9].

The finite element (FE) method is a widely used tool in industry for analyzing engineering problems. It is an essential and powerful analytical tool that is being used to design products with increasingly shorter development cycles[10-12]. The most basic FE theory and applications are offered primarily as a graduate-level course, or in some cases, as an upper-level elective for undergraduate students. Therefore, the majority of engineering programs do not require coverage of FE theory and application as a component of their undergraduate curriculum. Industry is placing an increased emphasis on the ability to apply this powerful computational tool; so it follows that students earning an undergraduate degree in engineering should learn this skill in order to meet the demands of entry-level engineering job descriptions. The persistence of the deficiency of FE coverage in undergraduate engineering programs is due to various reasons, such as the recent focus on reducing credit-hours in engineering programs; the need to remove other course material at the expense of adding this new material; and the fact that FE theory is very mathematics-intensive thereby making it more suitable for graduate students who have a more rigorous mathematical education. For example, a typical undergraduate heat transfer course within a mechanical engineering curriculum will cover the basic theory behind conduction (1-D, 2-D, and 3-D; steady-state and transient), convection (internal and external forced convection; natural convection), and radiation in one fifteen-week semester; this material comprises eleven of the fourteen chapters of Çengel and Ghajar's textbook *Heat and Mass Transfer: Fundamentals and Applications*[13], including a chapter on "Numerical Methods in Heat Conduction" that provides a basic introduction on how to use finite difference techniques to approximate the heat conduction equation. Thus, the amount of material that needs to be covered in a heat transfer course makes it a challenge to spend an extensive amount of time covering FE theory and application without sacrificing other important course material. Regardless, there is clearly a need for knowledge of FE theory and application and undergraduate engineering curriculums should attempt to integrate this important topic into the existing curriculum.

The need for integrating FE theory and application across the engineering curriculum has been established and methods have been suggested by other authors[14-15]. The primary focus of the current paper is to report the development and implementation of active learning modules (ALM's) that would educate a broader spectrum of undergraduate engineering students with the basic knowledge of FE theory as applied to thermal and structural analyses, in addition to reporting the results that have been acquired after implementing the ALM's into various engineering courses over a span of several years; in particular, the results will focus on the effectiveness of the ALM's as a function of student grade point average (GPA). More details of the NSF-funded project that these learning modules are a component of can be found elsewhere[16].

It should be noted that the pedagogical foundation for this project is based, in part, on the Kolb Learning Cycle[17], which presents a four-stage cyclical model of learning that stresses the importance of these four stages in the learning process; these stages are often simplified as events that involve "feeling", "observing", "thinking", and "doing." Kolb's Learning Cycle has been applied extensively in engineering education[18-19] and it has been reported that learning activities that involve students applying all four-stages of Kolb's model provide the maximum opportunity for complete comprehension of the material[20]. More details of the implementation of Kolb's Learning Cycle into this project are discussed elsewhere[16, 21-22].

Active Learning Module Summaries

As part of the NSF-funded grant, ALM's have been developed and implemented into eight courses at six different universities using five different software packages. All of the ALM's have been developed to meet various educational and instructional objectives. The **educational objectives** of the learning modules include the following:

a) to provide a different insight into traditionally challenging concepts that are covered in a required undergraduate mechanical engineering course,
b) to provide undergraduate engineering students with a basic understanding of FE theory as applied to thermal and structural analyses, and
c) to provide undergraduate engineering students with an ability to apply commercial FE

software in order to solve thermal and structural engineering problems by creating a valid model and understanding how to interpret and verify the results.

The **instructional objective** of the learning modules is the following:

a) to provide easily accessible thermal and structural FE learning modules that require minimal instructor effort in order to integrate them into a required mechanical engineering undergraduate course.

The NSF funding for the development and implementation of these learning modules has been 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 (2010-2014). 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 phase cannot be combined into a larger data set in order to increase the sample size and assemble more meaningful interpretations. Therefore, the results that are discussed in this paper focus on the ALM's that have been implemented during phase two when little, if any, changes were made to the ALM's or assessment procedure; furthermore, the focus will be on the ALM's that have been implemented at the University of the Pacific and have provided the most data that can be combined into larger data sets. Specifically, four ALM's will be the focus of this paper and those ALM's are summarized in Table 1. It should be noted that most of the ALM's have been implemented into classes that are relatively small (typically 10-20 students per class), so multiple years of data are required in order to find meaningful trends in the data from these sample sizes.

Table 1: Summary of the active learning modules that are the focus of this paper.

Title	*FEA Software*	*Course Name*
Bobsled Computational Fluid Drag	**Solidworks Flow Simulation**	**Finite Element Analysis**
Machining Analysis During Chip Formation	**AdvantEDGE**	**Machine Design I**
Semi-Infinite Medium	**SolidWorks Simulation**	**Heat Transfer**
Steady-State Heat Conduction	**SolidWorks Simulation**	**Heat Transfer**

In order to better understand the types of problems that are solved in each ALM, the two heat transfer modules that have been implemented into a heat transfer course at the University of the Pacific are discussed in the following sections. More details regarding these learning modules can be found elsewhere[23-24].

Two heat transfer ALM's were designed to meet the educational and instructional objectives described earlier. These modules include the following:

a) A steady-state, two-dimensional heat conduction problem ("Steady-State Heat Conduction") involving a long bar with fixed temperature, convection, and insulated boundary conditions.

b) A transient heat conduction problem involving a furnace wall which can be modeled as a semi-infinite medium ("Semi-Infinite Medium") as long as the heat from the inside of the furnace has not penetrated to the exterior surface.

These two problems were chosen for the following two reasons:

a) Both problems can be solved by performing hand calculations that involve theory that has been covered during the lecture portion of the course thereby allowing for a comparison between the FEA solution and the hand calculations that will allow for a verification of the FEA solution.

b) The theory related to the hand calculations for both of these problems (*i.e.*, the finite-difference method in two-dimensional heat conduction and transient heat conduction through semi-infinite mediums) have traditionally been challenging for students and an objective of the FE learning modules is to provide an alternative insight for students that will ideally make these topics easier to understand.

The problems for each learning module are summarized in Figs. 1 and 2. The steady-state problem (Fig. 1) was adopted from an exercise at the end of Chapter 4 (“Two-Dimensional, Steady-State Conduction”) of Incropera et al.’s textbook[25], while the transient, semi-infinite medium problem (Fig. 2) was adopted from an exercise at the end of Chapter 4 (“Transient Heat Conduction”) of Çengel and Ghajar’s textbook[13].

After the introduction of the problem statement and summaries of the educational objectives and relevant FE and course theory, each ALM includes the following solutions steps (these steps are applicable to thermal ALM’s using SolidWorks and SolidWorks Simulation, but similar steps are followed for ALM’s that use other software packages):

1. *Using SolidWorks to create a 3-D model.*
   The steps required to draw the model in SolidWorks are summarized, including creating a two-dimensional sketch and extruding the sketch to make a 3-D object and dimensioning the 3-D object. These elements of the learning module are presented such that a student with minimal background with SolidWorks will be able to model the problem.

A long bar of rectangular cross-section (0.4 m × 0.6 m) with a thermal conductivity of $k = 1.5$ W/m·°C, is subjected to the following boundary conditions: two sides are maintained at 200°C, one side is insulated, and the remaining side is subjected to convection with the surrounding fluid at $T_\infty = 30$°C and $h = 50$ W/m^2·°C. Determine the temperature distribution in the bar and the heat transfer rate between the bar and the fluid per unit length of the bar.

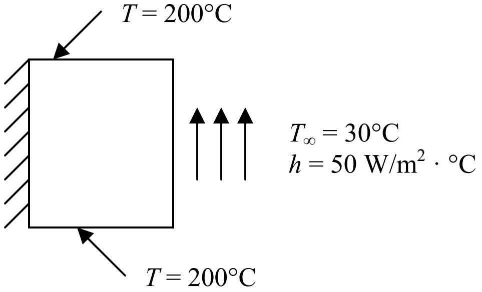

Figure 1: Steady-state heat conduction problem description (adopted from Incropera et al.’s textbook[25]).

A 40-cm-thick concrete wall of a furnace is initially in thermal equilibrium with the surrounding air at 20ºC. When the furnace is fired, the combustion event creates an environment where the temperature of the inside surface of the furnace is instantaneously increased to 980ºC (*i.e.*, the convection heat transfer coefficient in very large). Use SolidWorks Simulation to perform the following:

a) determine how long the wall can be treated as a semi-infinite medium.
b) determine the temperature distribution throughout the wall at a particular time.
c) determine the transient response (T vs. t) at a particular location inside the wall.
d) create an animation of the transient temperature distribution.

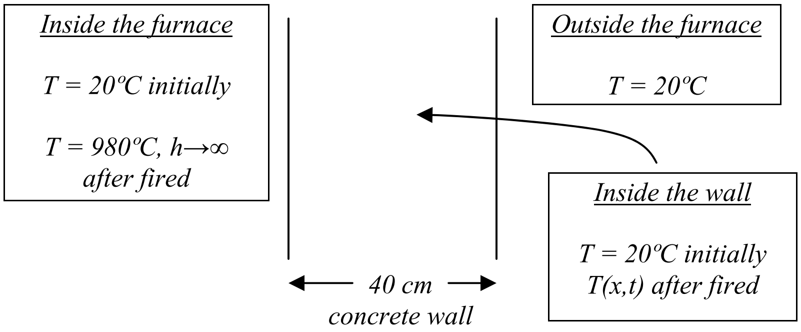

Figure 2: Transient, semi-infinite medium heat conduction problem description (adopted from Çengel and Ghajar's textbook[13]).

2. *Creating a "Thermal Study" using SolidWorks Simulation.*
The steps required to create a thermal study for the 3-D part are summarized, including how to create a steady-state or transient study. For a transient study, the requirements for defining the transient conditions are summarized including the total time of study and the time increment.

3. *Defining material properties.*
The steps required to assign the material properties which are necessary for a thermal analysis are summarized. Instructions for creating both custom-defined materials and common material types are included.

4. *Defining the thermal boundary conditions and initial condition.*
The steps required to define the thermal boundary conditions are summarized, including convection, specified temperature, heat flux, and adiabatic (zero heat flux) conditions. The transient learning module includes steps for defining the initial condition.

5. *Meshing the model and running the study.*
The steps required to create a three-dimensional mesh using second-order tetrahedral solid elements type are summarized in addition to the simple step of running the finite element analysis.

6. *Post-processing the FEA results.*
   Information on post-processing the FEA results is included, including using a temperature probe to determine the temperature at any location, creating 3-D color plots of the temperature distribution, finding the transient temperature response at any location, and creating animations of the transient temperature distribution. For reference, the temperature distribution that results from the steady-state heat conduction ALM is included in Fig. 3 and a transient temperature response at a particular location that results from the transient, semi-infinite medium ALM is included in Fig. 4.

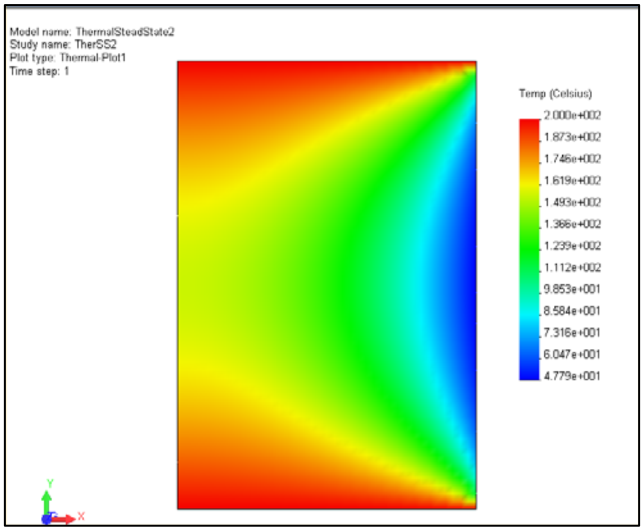

Figure 3: Temperature distribution for the steady-state heat conduction learning module.

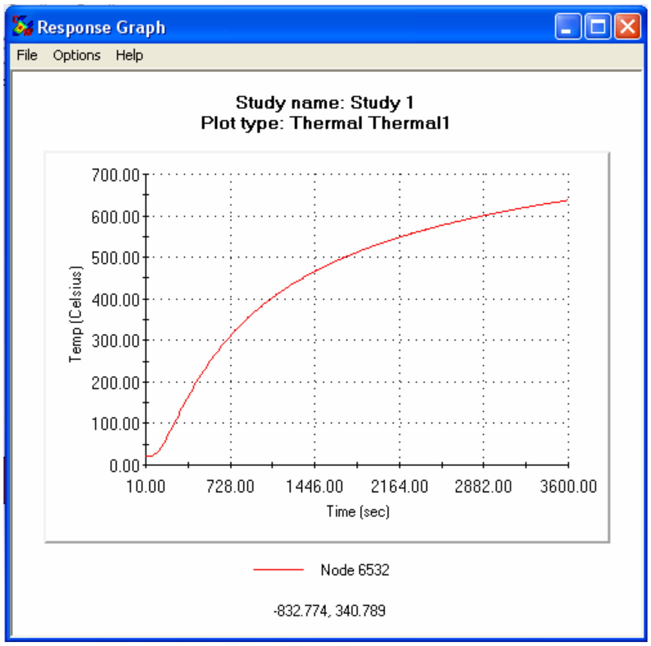

Figure 4: Temperature response for the transient, semi-infinite medium learning module (note the initial condition of 20ºC).

7. *Comparing the FEA results to hand calculations.*
   Information is given on how the problems can be solved by using hand calculations that involve either the finite-difference method (for the steady-state heat conduction learning module) or semi-infinite medium theory (for the transient, semi-infinite medium learning module); these topics have been covered during the lecture portion of the course and can be used as a comparison to the FEA solution thereby allowing for FEA verification.

8. *Additional exercises.*
   Additional exercises are suggested for further exploring the use of FEA in analyzing heat conduction problems. These exercises involve exploring the effects of mesh size and thermal conductivity on the temperature distribution and viewing isotherms.

Implementation

Both of the learning modules discussed above have been incorporated into an undergraduate heat transfer course at the University of the Pacific. All of the students in this class have taken a CAD course and the majority of students have taken a CAD course using SolidWorks, but this is not required since the learning modules are written such that no familiarity with SolidWorks is necessary. The topics of heat conduction through semi-infinite mediums and the finite-difference method as applied to heat conduction are covered before the learning modules are implemented. With this knowledge, students are able to solve the learning module problems by hand and eventually compare the FEA output with these hand calculations. For the purposes of correlating data gathered across different measures and so as to collect information confidentially, each student is assigned an identifier (specifically, animal names are used); these animal ID identifiers are used in gathering the following information from the students:

1. Demographic data (e.g., class standing, major, gender, ethnicity, and GPA) are collected through the use of a survey administered on-line.

2. Similarly, information on student learning styles (Felder-Soloman Index of Learning Styles) and personality types (Myers-Briggs Type Indicator) are collected by having the students take on-line surveys:

3. The pre-learning module quiz is administered in class (the heat transfer quiz is included in Appendix A).

4. The learning modules are assigned; this is accomplished by e-mailing the learning modules in the form of PowerPoint slides to the students and requiring them to complete each module outside of class.

5. The post-learning module quiz (which is identical to the pre-learning module quiz) is administered in class.

6. A 15-question student opinion survey is administered where the students respond to questions with answers on a 5-point scale (Disagree; Partly Disagree; Neither Agree nor Disagree; Partly Agree; Agree).

Once this procedure is completed, trends in the data can be explored, in particular how various groups of students' performances are affected by having performed the ALM's through comparison of their pre- and post-quiz scores.

Discussion of Results

The results that are discussed in this section focus on the change in student performance on the pre- and post-quiz, in general, and as a function of student GPA. Once again, four of the fifteen ALM's are the focus of this discussion for reasons discussed earlier. Furthermore, the two heat transfer ALM's are assessed using the same pre- and post-quiz, so three sets of data (instead of four) are discussed below. Table 2 includes the average pre- and post-quiz score for each of the three data sets, as well as the number of years implemented and the total number of students within each data set.

Table 2: Summary of results for the three data sets including all students

Active Learning Module Title	*# of Years Implemented*	*# of Students*	*Average Pre-Quiz Score (%)*	*Average Post-Quiz Score (%)*	*Percent Increase*
Bobsled Computational Fluid Drag	3	48	49.8	77.1	54.8
Machining Analysis During Chip Formation	4	68	63.9	86.6	35.6
Semi-Infinite Medium & Steady-State Heat Conduction	4	97	46.8	59.8	27.7

It can be seen from Table 2 that there is significant improvement for all three data sets when comparing pre- versus post-quiz performance; specifically, the percent improvement for the three data sets are 54.8%, 35.6%, and 27.7%. This alone is a significant result that indicates that the ALM's are successful in reinforcing basic concepts while exposing students to FE theory. In order to statistically validate the results, a paired sample *t*-test was performed on each of the three data sets and the significant results are summarized in Table 3.

Table 3: Summary of the statistical data for the three data sets including all students

Active Learning Module Title	*Pre-Quiz Std Dev (%)*	*Post-Quiz Std Dev (%)*	*Pre-Quiz Std Error Mean (%)*	*Post-Quiz Std Error Mean (%)*	*t-stat*	*p-value*
Bobsled Computational Fluid Drag	15.5	18.3	2.24	2.65	9.27	< 0.001
Machining Analysis During Chip Formation	15.9	14.1	1.93	1.71	12.2	< 0.001
Semi-Infinite Medium & Steady-State Heat Conduction	19.9	21.7	2.02	2.21	6.96	< 0.001

Most importantly, the *p*-values seen in Table 3 are all much less than 0.001, which indicates that there is statistically-significant evidence that there is a high probability (> 99.9%) that student performance will improve upon performing each of the ALM's as measured by student performance on the post-quiz and comparing the paired results to student performance on the pre-quiz. Furthermore, the relatively large *t*-stat values shown in Table 3 are another indication of the improvement in student performance on the post-quiz in comparison to the pre-quiz. These values quantify the number of standard errors that the average of the difference in paired pre- and post-quiz scores are from a difference of zero, which is the null condition that would signify that there is no improvement in student performance after completing the ALM's.

Within the data, some students did not show improvement on their post-quiz while others actually performed worse on the post-quiz. While this result is surprising, it can be explained by the fact that students were minimally incentivized (if at all) to maximize their performance on the pre- and post-quizzes. Undoubtedly, without implications on their course grade, some students will not take the quizzes seriously. With this in mind, it is worthwhile to analyze the larger subset of students that *did* show improvement on their post-quiz and the results from this subset are summarized in Table 4.

Table 4: Summary of results for the three data subsets including only those students that improved on their post- versus pre-quiz

Active Learning Module Title	*# of Students who Improved*	*Average Pre-Quiz Score (%)*	*Average Post-Quiz Score (%)*	*Percent Increase*
Bobsled Computational Fluid Drag	41	48.5	81.0	66.8
Machining Analysis During Chip Formation	60	62.6	88.9	42.1
Semi-Infinite Medium & Steady-State Heat Conduction	66	42.4	65.2	53.6

Similar trends can be seen in the data from Table 4 as in the data from Table 2. That is, there is still significant improvement for all three data sets when comparing pre- versus post-quiz performance. As expected, Table 4 shows an even larger percent improvement for the three data subsets since only those students that showed improvement are included. Specifically, the percent improvement for the three data subsets are 66.8%, 42.1%, and 53.6% (in comparison to 54.8%, 35.6%, and 27.7%, respectively, for the data sets that include all students).

In an effort to determine if different groups of students were benefitting from the ALM's in different ways, the results were examined as a function of student GPA. Figure 5 is a scatterplot of percent improvement (on the post- vs. pre-quiz) versus student GPA and the plot includes the data from all three data sets that are summarized in Table 4 (N = 167).

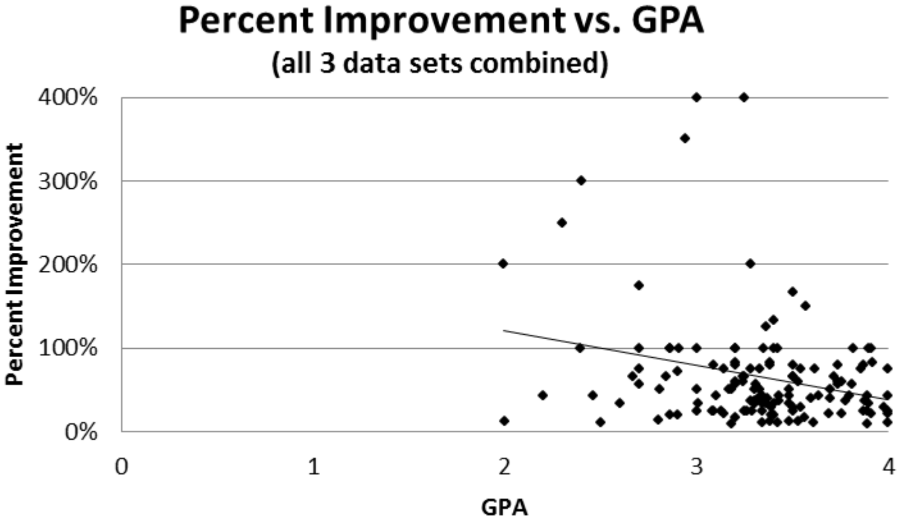

Figure 5: Percent improvement versus student GPA for all three data sets from Table 4.

While there is considerable spread in the data in Figure 5, it is clear that, on average, students with lower GPA's are demonstrating more improvement on the post-quiz than students with higher GPA's; this trend is particularly evident from the linear best-fit line through the data. This data implies that the ALM's are particularly effective in providing a tool that allows students that typically perform poorer to better understand the challenging material that is reinforced by the ALM. In other words, the ALM's seem to level the playing field for students across the entire range of GPA's. To further examine this point, Table 5 includes the average pre- and post-quiz performance for students with GPA's below 3.0 and students with GPA's at or above 3.0 for each of the three data sets.

Table 5: Summary of the results for the three data sets divided into two GPA ranges.

Active Learning Module Title	*GPA Range*	*Avg. Pre-Quiz Score (%)*	*Avg. Post-Quiz Score (%)*	*Percent Increase*
Bobsled Computational Fluid Drag	< 3.0	46.7	80.0	71.4
	≥ 3.0	49.6	81.5	64.3
Machining Analysis During Chip Formation	< 3.0	50.0	86.4	72.7
	≥ 3.0	61.8	89.0	44.2
Semi-Infinite Medium & Steady-State Heat Conduction	< 3.0	36.3	63.2	74.3
	≥ 3.0	42.1	62.8	49.2

It can be seen from Table 5 that the students with GPA's below 3.0 demonstrate a larger percent increase for all three data sets. Furthermore, each data set shows that the difference in performance on the pre-quiz between the two GPA ranges is much greater than the difference in performance on the post-quiz. In fact, the post-quiz data shows that the two GPA ranges perform similarly. Once again, this data indicates that the ALM's seem to level the playing field for students across the entire range of GPA's. This trend is also illustrated by the plot in Figure 6 which graphically displays the same information that is included in Table 5.

Figure 7 is a plot of the individual student performance on the pre- and post-quiz versus GPA for one of the three data sets – in particular, the "Machining Analysis During Chip Formation" ALM. This plot includes four best fit lines for the four subsets of data included in the plot legend.

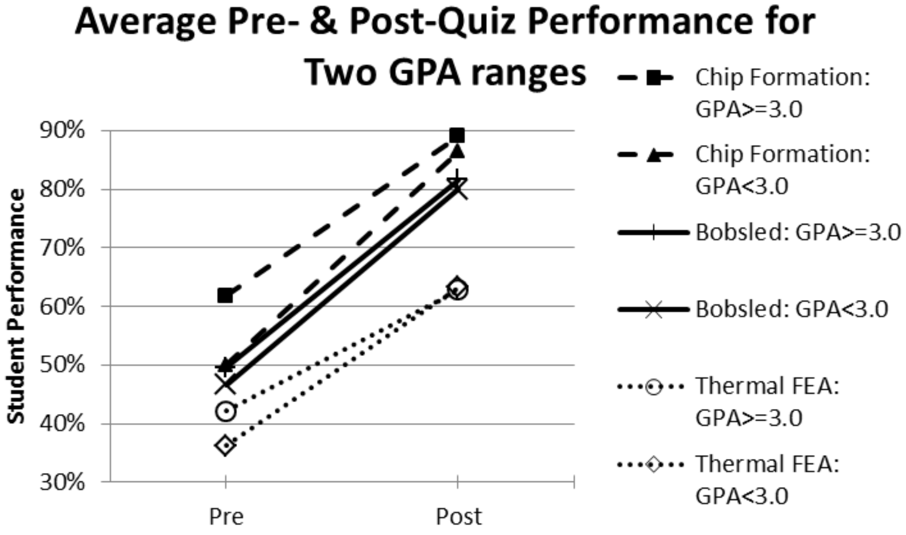

Figure 6: Average pre- and post-quiz performance for each GPA range (< 3.0 and ≥ 3.0) for all three data sets.

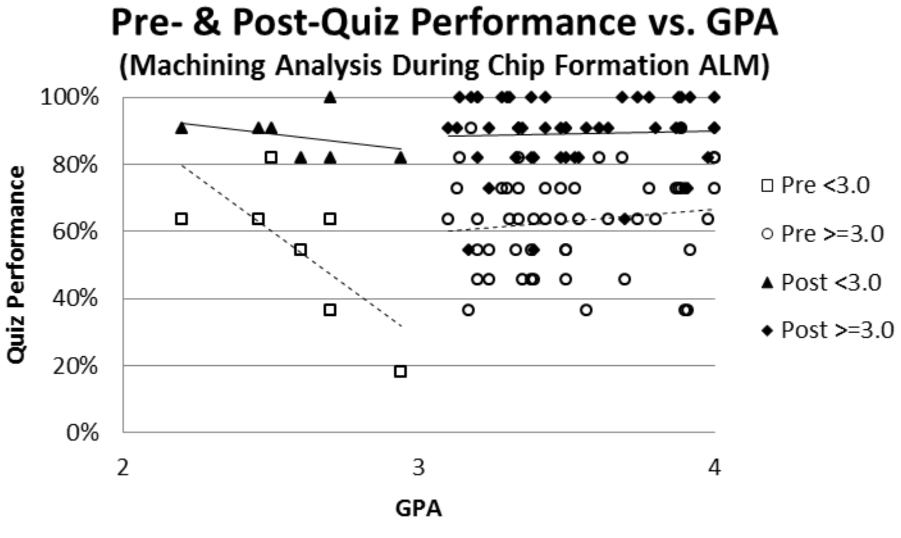

Figure 7: Pre- and post-quiz performance versus student GPA for one of the three data sets (Machining Analysis During Chip Formation ALM).

Figure 7 shows that, in general, the performance on the pre-quiz is poorer than on the post-quiz over the entire GPA range. Furthermore, students with a GPA below 3.0 have a larger spread in performance on the pre-quiz as evidenced by the dashed best-fit line with the steep negative slope. Also evident from Fig. 7 is the fact that the performance on the post-quiz is similar across the entire GPA range as highlighted by the similarities between the two solid best-fit lines through the two post-quiz data subsets; in particular, both of these lines have smaller slopes than their pre-quiz counterparts and both of these lines are near the 90% performance level. This is yet another indicator of the effectiveness on the ALM's in providing a significant benefit to students who typically perform poorer in classroom activities, as evidenced by their GPA.

Conclusions

This paper reports the use of active learning modules across a mechanical engineering curriculum in order to expose all graduates to finite element theory and practice as well as to provide an alternative insight into traditionally challenging topics. Increasing industry demand for graduates to have the ability to use and apply commercial FE packages has created a need for integrating FE instruction throughout an engineering curriculum. These ALM's provide a tool for easily implementing the FE method and application into the curriculum in order to provide a basic understanding of FE theory as applied to thermal and structural analyses. Furthermore, assessment of the results indicates that these learning modules are successful in reinforcing some of the more challenging concepts while exposing students to FE theory. The results indicate that student performance has improved through the implementation of these ALM's into three courses over a span of three or four years; specifically, student improvement from pre- to post-quiz was 54.8%, 35.6% and 27.7%, on average, in each of the three courses. Moreover, of the students that demonstrated improvement, these percentages increased to 66.8%, 42.1% and 53.6% for the same three courses, respectively. The results from paired sample *t*-tests that were performed on each data set provide statistically-significant evidence of the effectiveness of the ALM's in producing an improvement in student performance; the *p*-values for each of the three data sets are well below 0.001. Of particular significance is the observation that the learning modules have a more substantial positive impact on students with lower GPA's (< 3.0) than those with higher GPA's (≥ 3.0) as evidenced by a larger increase in performance on the post-quiz for those students with lower GPA's than those with higher GPA's (for example, one of the ALM's showed an average improvement of 72.7% for students with GPA's < 3.0 versus an improvement of 44.2% for students with GPA's ≥ 3.0). It is believed that the alternative insight provided by the active learning modules provides a valuable learning tool especially for those students with lower GPA's.

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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

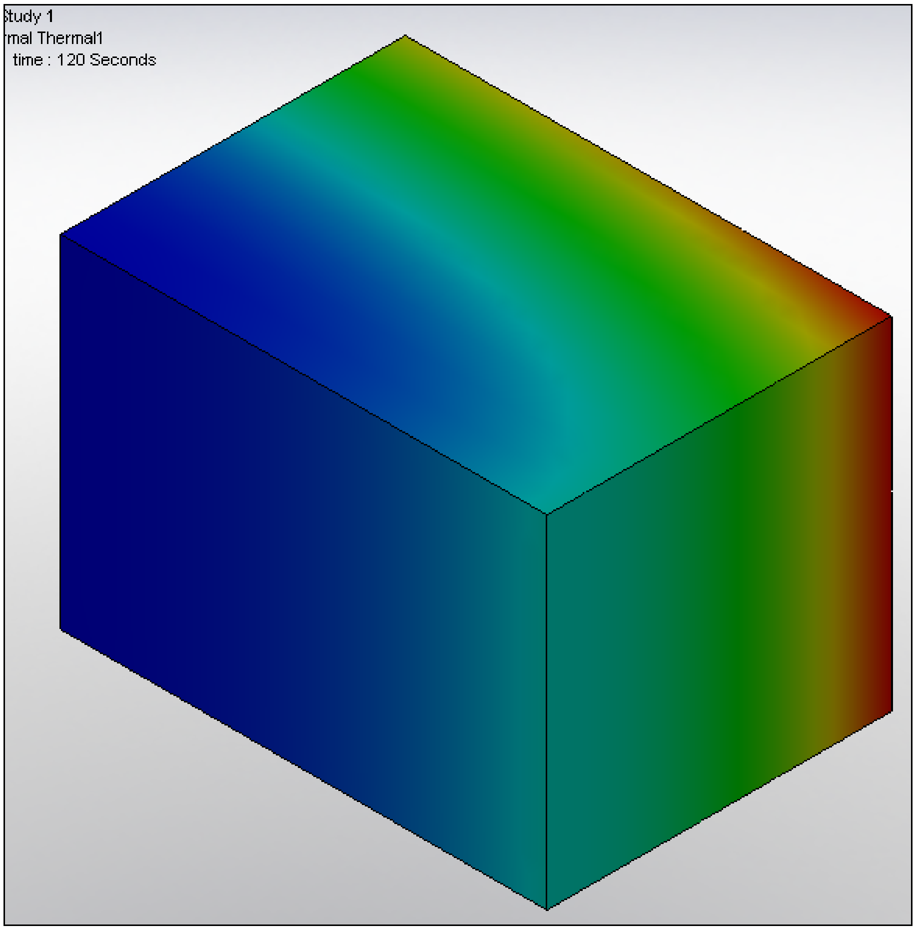
9. The finite element method of modeling conduction heat transfer results in an approximate solution for: (fill in the blank)

   ____

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