AC 2008-697: EFFECTIVE INTEGRATION OF MATHEMATICAL AND CAE TOOLS IN ENGINEERING

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EFFECTIVE INTEGRATION of MATHEMATICAL AND CAE TOOLS IN ENGINEERING

Abstract

Today, more than ever, engineers are challenged to use efficient computational tools in the simulation and design processes. Math software tools such as MATLAB®, MathCAD® and Excel® in recent years have achieved wide spread acceptance throughout the educational and industrial communities. Moreover, CAE tools such as Solid Edge, Unigraphics®, I-DEAS®, ANSYS®, etc., are used to perform parametric design and finite element analysis of individual components and simple mechanical assemblies. Integration of such tools into the engineering curriculum enhances students understanding of, and appreciation for the iterative and open-endedness nature of design problems. This paper describes the teaching and learning experiences of including such tools in few example courses in mechanical engineering. One of them is a Computational and Experimental course ("Course 1" taught at Saginaw Valley State University (SVSU) using MATLAB), the second one is a Computational course ("Course 2", taught at Baker College (BC)), and the third course is Machine Design ("Course 3", taught at Kettering University (KU) using Excel and other CAE/FEA tools). The first and the third courses are 4-credit and junior level subjects that include workshop sessions and laboratory assignments, while the second one is a 4-credit, senior level theoretical course. These example courses have both individual and collaborative assignments, which include conduction of experiments in order to generate data. Experience from all these courses taught at these universities shows that when students generate data on their own using good engineering judgment, they can easily process the data, develop and interpret any mathematical and statistical models for the experiment.

Introduction

MATLAB® (MATrix LABoratory)[1,2] is a tool for doing numerical computations with matrices and vectors. It has a programming feature similar to Basic and C and it can also display information graphically in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Because of its versatility, this software can be used in a wide variety of areas in engineering and science. In the context of this paper, both junior and upper level undergraduate courses can utilize the capabilities of this or other similar math software to provide excellent learning tools for a wide variety of subjects.

MathCAD is a mathematical computation tool allowing the user to solve a wide range of scientific problems, in symbolic or numeric form. Plots and reports can be easily generated.

CAE tools such as UG-NX, I-DEAS, ANSYS[3,4], are engineering tools for solid modeling and analysis in an interactive way. These are used routinely in many engineering applications by both practicing engineers and in academia. Such CAE tools provide opportunities for creative design and analysis of machine components and to understand the interaction between the components of an assembly before final design decisions are made[4].

Course 1: Computational and Experimental Methods in Engineering (Taught at SVSU)

Course Description:
Use of modern engineering software tools and techniques for acquiring, reducing, and analyzing data; Applications include basic algorithm development, graphing, regression and curve fitting, statistics and experimental uncertainty analysis, design of experiments, and computer-based data acquisition; Solution of equations using mathematical software (MATLAB®).

Prerequisites: Mathematics (Calculus II) and Physics

Course Learning Objectives (CLOs):
1. To provide the students fundamental notions of computer-oriented numerical methods
2. Acquaint the student with MATLAB® Programming
3. To enable the students to conduct experiments, collect data, and use computer to analyze data and develop mathematical models.

Course Topics:
Theory: Modeling, Computers, Statistical and Error Analysis of Data; Roots of Equations and Applications; Matrices and Systems of Linear Algebraic Equations; Regression Analysis and Curve Fitting; Numerical Differentiation and Integration and Applications of O.D.E.

Lab: Weekly Workshop Sessions (Programming using MATLAB®); Assignments based on Computational and Experimental data acquisition

Relationship of Course to ABET POs (see Appendix I at the end of the paper):
All students were expected to maintain a laboratory notebook that contains the original data and calculations, results, discussion of and conclusions based upon these results. A number grade was assigned at the end of the term based upon the completeness and quality of the contents. The students were also asked to include the original data sheets and scratch calculations. A formal technical report was also needed to convey the results of their experimentation to other interested readers.

Assessment Tools and Analysis of Results:
Tools used for the assessment of this course were the homework, midterm exams, final examination, MATLAB Programming and several Lab experiments to generate data. The students conduct several experiments prior to the MATLAB sessions. Typical Experiments are:

1. Measurements of Physical and Mechanical properties of steels for conducting the sample and population statistical analysis
2. Variation of mechanical properties of steels versus temperature and time for the purpose of single-variate and multi-variate regression analysis.
3. Flow of water in a tank (Filling, Draining, and simultaneous filling and draining of water from a cylindrical tank) to verify the thermodynamics and fluids concepts related to the "open systems". Curve fitting and numerical integration results are used.
4. Ice melting: correlation of experimental results with theory and numerical approximation.

A number rating of 0-69 (poor), 70-79 (satisfactory), 80-91 (good), 92-100 (excellent) has been used in the assessment of the student performance. Also, the group project is evaluated as follows:

- Team members must be present during the experiment.
- Team members must sign the cover page of the report indicating a fare share input (peer-review).
- Team members are encouraged to use the University Writing Center.
- Team members must submit the raw data and the compiled work to the instructor
- Team members must be available to meet with the instructor for questions regarding the results and Academic Integrity.

Due to space limitations in this paper, only a brief description of the results of the various assessment tools is provided as follows.

<u>Midterm Exam</u>**:**

Four (4) problems were given on the midterm examination. A 70% or more score is considered as satisfactory to meeting of the corresponding CLO. For example, the CLO descriptor on the first problem was "Computer representation of numbers, Identification of efficient methods for solving nonlinear equations, Statistical analysis of data". The average score of the students was 86% meaning that this CLO is satisfied to a great extent. Similarly, the CLO descriptor on the second problem was "Matrices and Systems of Linear Equations". The average student performance on this problem was 83.5% indicating that this CLO has been met satisfactorily. Likewise, the CLO descriptor and the average score on problem #3 respectively, were "Least Squares and Curve Fitting Methods" and 89.6%, meaning that this CLO is also satisfied to a great extent. The CLO descriptor for the last question and the average performance respectively, were "True/False Questions; Selection of best models for specified sets of data" and 64%. This means that the CLO is not met. Analysis of this midterm exam with action taken for continuous improvement reveals the following:

- Results for Problem #'s 1 and 3 were "Very Good" with the "Objectives met" to a great extent.
- Few students missed points on Problem #2 because they did not make the matrix diagonally dominant. As a result, it took more number of trials for the iterative process to converge. This was pointed out when the tests were returned to students.
- For Problem #4, the results were "Fair"; there were 29 questions and one-third of students did not manage the time properly. As a corrective action, the problem for such performance was explained by using an overhead projector and also explained about time management in the in-class exams. In addition to time management, difficulties with calculus remain to be an issue. During the lab session, after one hour of interactive programming, students have at least two hours to perform lab exercises assigned by the instructor. During this time instructor observes student work for accuracy. For the lab report in which students have ample time (one week) to prepare the report, they are required to discuss the rough draft of their report with the instructor. This helps students to correct possible mathematical errors in the formulation. However, no help is available during the exams and as a result, only those with strong calculus skills can receive good grades.

***Laboratory Assignments*:**
There were 11 labs conducted during the terms. These included: Roots of nonlinear equations; Matrices and systems of linear equations; Least squares and Curve fitting methods; A comprehensive experiment involving material properties and mathematical modeling; Statistical error analysis; Applications of numerical integration; Treatment of improper integrals; Two comprehensive experiments were conducted:

(a) Time-Temperature-Transformation Experiment of Plain Carbon Steels. Processing of the measured data and Development of Mathematical Models using Nonlinear Regression
(b) Open Systems: Fluid Flow in Tanks. Data collection, Mathematical Modeling, Construction of numerical solution of the governing differential equation. Comparison of Theoretical, Experimental and Numerical Results.

The average laboratory grade varied from 86% to 100% which indicated that the performance was "Very good." The main reason was the 11 Workshop sessions conducted by the instructor during the semester. Each Workshop session illustrated a particular topic of the course. During the Workshop students used MATLAB® programming and verified examples in pertinent Chapters of the Textbook and worked on additional lab exercises assigned by the instructor.

***Final Exam*:**

Table 1: Assessment of Final Examination

Problem #	CLO Descriptor	Ave. score %
1	Matrix Operations	91.7
2	Modeling and solving electrical circuit problems	78
3	Improper Integrals	64.5
4	Numerical differentiation	70

Analysis and action plan on Final Exam:
The student performance on Problem 1 was "Excellent". The success in understanding matrices and matrix operations was due to comprehensive workshop sessions using MATLAB®, which is an excellent environment for matrix operations and students benefited from the workshop sessions. The performance on Problem 2 was "Good" and the objectives were met. Few students forgot to use newly computed values in the current iteration. For Problem 3 the result was "Fair". Few students forgot the basic concept of improper integrals. Also, few did not realize that the given data had to be subdivided into two groups, each having a different mesh size. Finally, for Problem 4, the result was "Good". Few students forgot the extrapolation scheme using Richardson's method. Others did not finish the iteration process needed in the Euler method. These points will be kept in mind for future to spend more time on improper integrals and on numerical differentiation.

Further Studies and Analysis of Current Year Results:
The results from the current year show some changes. The students and the student population however, are obviously different. A class section composed of 12 students is considered and the results are compiled according to scores in five categories: H = Take Home Assignments, P =

Formal Reports for the MATLAB Programming and Experiments, Exams: T1 = Test 1, T2 = Test 2, and F = Final Exam.

Grading Scheme:
100 points for the items mentioned above have been assigned for a total of 500 points. The grade distribution is shown in Table 2. The corresponding statistical parameters are shown in Table 3. These are rounded figures to fit into the Table. We assume that the grades are normally distributed.

Table 2: Grade Distributions

No	H	P	T1	T2	F	Total	%
1	56	87	81	63	79	366	73
2	52	63	58	61	57	291	58
3	89	89	69	51	46	344	69
4	92	91	83	76	73	415	83
5	79	85	76	44	47	331	66
6	60	67	69	67	71	334	78
7	89	97	83	66	86	421	84
8	76	92	69	24	50	311	62
9	98	95	96	91	77	457	91
10	79	92	74	72	68	385	77
11	93	92	78	49	48	360	72
12	93	92	85	59	53	382	76

Discussion:
The grades for n = 12 students in m = 5 units were stored in a Matrix A (12x5) and the Covariance was computed from
C = [1(/n-1)]A′A

Table 3: Grade Statistics for the Course

Statistical Parameters	H	P	T1	T2	F
Min	52	63	58	24	46
Max.	98	97	96	91	86
Mean	80	87	77	60	63
St. Dev.	16	11	10	17	14
SE Mean	5	3	3	5	4
Median	84	92	77	62	63

The result indicates that:

- The largest diagonal element occurs in the second row
- All off-diagonal elements are positive indicating that there is a positive correlation between the results in all of the subjects, i.e., there is a tendency for students doing well/poorly in one topic to do well/poorly in the others.
- The largest off-diagonal element occurs in the C(2,1) position, showing that there was a strong correlation between H & P.

These results indicate that students' performance on Homework and Projects assignments is in general satisfactory. The *in-class* exams continue to be a problem because the time management is being ignored by the majority of students.

Course 2: Dynamic Systems and Control (Taught at Baker College)

Course Description:
Mathematical modeling of mechanical, fluid, and electrical systems; time and frequency response of linear systems and linear feedback control

Prerequisites: Differential Equations, Dynamics, Electric Circuit Analysis

Student Learning Outcomes (SLOs):

1. Distinguish between open-loop and closed-loop control systems, their designs and applications
2. Apply Laplace Transform and Inverse Laplace Transform to solve problems involving mathematical modeling of control systems
3. Use transfer functions and impulse-response functions to model control systems
4. Use block-diagrams to represent control systems
5. Use state-space representation to describe control systems
6. Apply mathematical modeling to solve problems involving control of mechanical, electrical, and fluid systems
7. Perform transient-response analysis to solve problems involving control of first and second order dynamic systems
8. Apply Routh's stability criterion to model and optimize control systems
9. Complete a course project involving topics of the course and transient and steady-state response analysis of the control system

(Note: The SLOs are being revised to a more condensed list by the College)

Course Topics:
Theory: Differential Equations, Laplace Transform, Open-Loop/Close-Loop Control Systems, Mathematical Modeling of Dynamic Systems (Mechanical, Fluid, Electrical), Transient and Steady-State Response Analysis

Computational lab: Weekly lab sessions using MathCAD; Assignments using computer software

Relationship of Course to ABET POs (see Appendix I at the end of the paper):
In addition to weekly assignments and exams, all students were required to complete a project including mathematical modeling, and design of a simple control system, and its analysis performed with MathCAD. Students also prepared a power point presentation of their design project, and presented it to the class during the final class session.

Assessment Tools and Analysis of Results:
Tools used for the assessment of this course were weekly homework assignments, weekly quizzes, midterm exam, final exam, and design project using MathCAD. Due to space limitations in this paper, only a brief description of the results of the various assessment tools is provided as follows.

When run in the academic year 2006-07 there were three senior students enrolled in the course. Even though they do not constitute a statistically significant population, the data collected and analyzed allows for a comparative analysis, and year-to-year trends analysis. For each Student Learning Outcome (SLO) assessed, a score of 70% or better is considered satisfactory achievement.

Quizzes:

Table 4: Assessment of Quizzes

Problem	SLO	Average Score
Q1.3	1	93.3
Q1.1, Q1.2	2	95.6
Q2.1, Q2.2	3	86.7
Q3.1	6	100.0
Q3.2, Q4.1	7	90.6
Q4.1, Q4.3	8	87.9

As shown in Table 4, all SLO's assessed were achieved at very good level. Data from SLO's 3 (Transfer Functions), and 8 (Stability) shows these were topics where students had slight difficulties. The analysis of the quiz results prompted the instructor to spend more time on topics related to SLO's 3 and 8, in order to clarify students' questions.

Final Exam:
Four problems were given on the final exam, focusing mostly on SLO's 3, 4, 5, 7, and 8. The results are given in Table 5, and show very good achievement of all SLO's. It is interesting to compare students' achievement in SLO's 3, 7, and 8 which were covered both in quizzes and in the final exam. While for SLO's 7 and 8 the average score in the final exceeded the corresponding score in quizzes, the opposite was true in the case of SLO 3, related to Transfer Functions and their use in modeling control systems. As this is a fundamental topic in this course, this type of feedback is very useful for the instructor teaching the course in academic year 2007-08 who will need to devote more time and examples, and check more often for student understanding of the topic.

Table 5: Assessment of Final Exam

Problem	SLO	Average Score
F2	3	82.1
F3.a	4	90.8
F1	5	90.7
F3.b	7	93.7
F4	8	97.5

Project:

The project required students to choose a first or second order mechanical, electrical or fluid system, and decide on realistic parameters to describe it. The system was to be represented by a block diagram, and analyzed using the transfer function approach. The response of the system to unit step, unit impulse and unit ramp excitations needed to be obtained and plotted using MathCAD. A power point presentation summarizing the results from the project was also required, which was used for presenting to the class during the last class session.

The average grade on the project was 86.7, which showed very good achievement of the corresponding SLO. However, this grade was slightly lower than the grades obtained by students in homework assignments, quizzes and exams. This was due to students not including all required elements in the project write-up, and one student including a hand-written calculations sheet in the project. These observations will be used by the instructor next time teaching the course to stress the importance of a complete and professionally written project report.

Throughout the entire course, MathCAD was used successfully by students to perform direct and inverse Laplace transformations, and to compute and plot the response of the systems to various input excitations. Students were already familiar with MathCAD basics from previous courses, which allowed a smooth transition to solving the specific problems encountered in control systems.

Grading Scheme:

100 points each for each of: homework (H), quizzes (Q), midterm exam (M), final exam (F), and project (P) have been assigned for a total of 500 points. The grade distribution is shown in Table 6. A statistical analysis similar to the one in Table 3 for "Course 1" is not given, due to the small number of students in the course. Also, the project for this course is an individual effort. Each student chooses their control system, and performs the modeling and analysis. However a short power point presentation is prepared and given in the final class session by each student and comments are received from peers and instructor which are incorporated in the project grade.

Table 6: Grade Distributions

No	**H**	**Q**	**M**	**F**	**P**	**Total**	**%**
1	76	89	89	91	88	433	87
2	87	78	91	87	75	418	84
3	89	99	91	94	98	471	94

Course 3: Machine Design – I (Taught at KU)

Course Description:
This course deals with the application of theory and concepts learned in the mechanics courses to the design of simple mechanical components such as shafts, bolts, bearing, springs, gears, etc. Through lectures, class examples and homework problems the students are introduced to the design methodology. This methodology requires learning to develop and set-up a mechanical component design problem: through properly understanding and solving the problem based upon the given data, design constraints and making and verifying assumptions, selection of the proper analytical tools as required, producibility and maintainability of the design, materials selection, safety, and cost considerations. Take-home project problems enhance and demonstrate the type of study and research required for design.

Topics to be studied include strength and fatigue considerations, shaft design, threaded fasteners, lubrication and bearings, springs, and fundamentals of gear analysis, including terminology, forces, and stresses. One additional requirement for this course is working on a team-based design project. For the Fall 2002 and 2003 classes, a common feature of such design project was to present a case study on any one of the ethical issues that are available in the literature along with some engineering calculations to appreciate how engineering ethics play a very important role in the design of a system or a component[5,6].

Course Learning Objectives (CLO's)

1. Develop, set-up, and solve mechanical component design problems based upon given data and requirements
2. Develop corrective action (define the cause for a problem and the design fixes) for field problems
3. Recognize the need for proper design actions via discussions of current, news worthy, design-related incidents
4. Through mechanical component design homework and team-based problems, develop an appreciation for design tools and the ever-changing materials, processing and analytical techniques available to design while providing an understanding of the basics of design

Assessment Tools and Analysis of Results:
Several in-class problems have been assigned and the students are asked to work in groups of 2 or 3 members on an assigned problem. In addition, several mini-projects, and one comprehensive final project were assigned for working as a team. Individual or group quizzes and individual midterm examinations and an optional comprehensive final examination were also given during the term. The entire course work closely followed the course learning objectives (CLOs) identified for this course. These CLOs are mentioned in the above section.

Class work:
Several class work problems have been assigned during the term after sample problems are solved by the instructor. These problems cover the static and dynamic of power transmission shafts, engineering fasteners, rolling contact bearings and gears. Pulleys are also covered to understand the recommended belt tensions for various torque transmission applications. The class average on class works is around 9.3% out of 10%, which is excellent by Kettering

University standards. Many of these class works are team based and so the students with weak Statics and Solid Mechanics background are expected to review these concepts from their group members. The drawback of the team work is that the students usually tens to select their own group members and hence a few students either chose to work alone or work with another person(s). Careful selection and controlling the activities of the groups and the individual team members by the instructor is a challenging task.

Quizzes:
Five quizzes were given during the term. Some are based on group participation while a couple of them are to be attempted individually. Some times they are open book type while other times they can open a formula sheet only. The performance on the quizzes is 11.4% out of 15%, which is around 76% (Poor to Fair grade). The main reason for this is their average knowledge on the pre-requisites, namely, Statics and Solid Mechanics. This was later rectified to some extent by having them practice more problems from the pre-requisite subjects.

Mini projects:
Based on their (average to poor) performance on each quiz, the instructor assigned several mini projects to review and to reinforce the basic concepts of the prerequisites and also from the current course topics, which are essentially the real life applications of those basic concepts. Thus, the students are assigned several mini projects throughout the term that are based on real life engineering problems with realistic initial data and design parameters. They used engineering standards while designing or selecting the components. They are also expected to use math tools such as Maple, MathCAD and/or Excel for performing iterations to the open ended project problems and also to obtain several design iterations using parametric studies. Few students also performed finite element analysis using a CAE tool such as UG-NX or Solidworks, etc.

If each mini project work along with a formal report is done in a careful fashion, this will lead to the easy completion of the final project, which is an assimilation of all individual component designs in to the design of the total system or subsystem. Five to six mini projects were assigned that are based on static design of shaft, fatigue design of shaft, design of bolts for the bearings, rolling contact and sliding contact bearing analysis, and finally, the bending and contact stress analyses of spur gear teeth. They then assemble the work from all these mini projects to realize the final project. The average performance on mini projects is 13.7% out of 15%, which is around 91% (Very Good). This shows that the students like to work in groups while also learning difficult material from their team members.

Midterm Exams:
Two midterm exams and an optional comprehensive final examination were given during the term. Both the midterm exams were based on individual effort with open textbook and notes or open formula sheets only. Exam 1 was problems based while Exam 2 covered a combination of multiple-choice questions and problem questions. The overall performance on the midterm exams showed some improvement compared to the quizzes. Doing class work based on just in time learning and doing group mini projects might have helped improving the grades on the exams. The average on midterms is 41% out of 50% (which is just about average to Good).

Final Project:
As mentioned before, the final project consisted of a subsystem of shaft mounted on two bearings with two torque transmitting components such as a gear and another gear or pulley. The shaft configuration and the boundary conditions were either a single overhang or a simply supported type. The project was open-ended with only a couple of design requirements specified as input such as horsepower and speed. Students are asked to pick a realistic application to input the appropriate horsepower and speed. Examples ranged from transmission shaft of gasoline automobile, large marine diesel engines and turbo-generator sets, etc. They used internet or other resources to obtain the data and to start the project. They were expected to carry out hand calculations first and then use a math and a CAE tool to do further analysis and to provide one or more alternative and workable design solutions by changing the material selection, or load, or the geometry of the subsystem. Since the students were also taught ASME Codes and Standards, they were expected to use and reference the Standards used such as AISI and SAE standards for shaft materials and bolt materials, AFBMA and AGMA standards for bearings and gears, etc. After carrying out the design and the analysis, they are expected to use internet resources and catalogs for selecting the standard components of the system.

The overall performance on the final project was just about Average since grade weightage for final project is only 10% compared to the rest of the assessment tools used (quizzes, mini projects, etc). Being the final project, when once submitted, the students do not get any time or chance to review and to correct any deficiencies in their work. The overall average grade on the Final Project was around 80%. However, the student feedback on the final projects has been very good sine it is an assimilation and application of all the concepts learned in the class. Sample students feedback on the final project is presented in Appendix – II.

Comprehensive Final Examination:
The comprehensive final examination was made optional for students who wished to improve their course grades. The final examination grade replaces one of the lower midterm examination grades. From the author's experiences and in a system where incremental testing is adopted, the students' performance on the final examination is usually not very good. There are several reasons for this, the main reason being that the students do not necessarily prepare well for the finals due to lower overall weightage on the final exam. Besides, it was made optional and therefore, not all students took the exam. The average score on the finals is 85%, which is a satisfactory grade.

Figure 1 shows the chart of the various assessment tools discussed in this paper. The assessment tools 1 thru 6 showed on the chart correspond to: Class work, Quizzes, Mini-Projects, Final Project, Midterm Exams, and Comprehensive Final Exam.

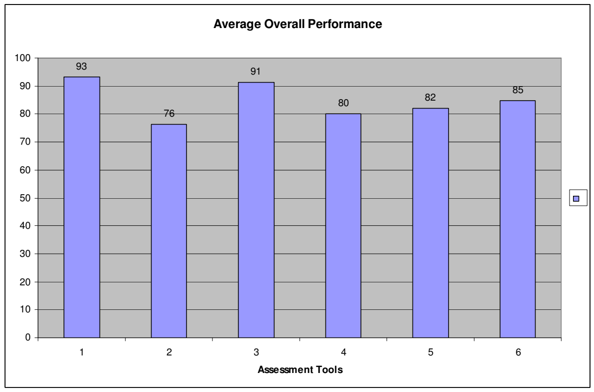

Figure 1: Assessment Tools and Students Performance

Conclusions

In this paper, both an integration of the math and CAE tools and course assessment are presented for three sample courses, namely, Numerical Analysis, Dynamic Systems and Control and Machine Design taught at three different universities. Use of math and/or CAE tools in the class provided them 'what if' scenarios to study the effect of different design requirements and variables on the problem or on the subsystem considered in each course. Students seem to like the group projects and found open ended problems challenging. Such studies can be extended to other engineering courses for their assessment and for continuous improvement of both the course material and performance by the students taking such classes.

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Appendix – I: ABET Program Outcomes

a. An ability to apply knowledge of mathematics, science, and engineering.
b. An ability to design and conduct experiments, as well as to analyze and interpret data.
c. An ability to design a system, components, or process to meet desired needs.
d. An ability to function on multi-disciplinary teams.

e. An ability to identify, formulate and solve engineering problems.
f. An understanding of professional and ethical responsibility.
g. An ability to communicate effectively.
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
i. A recognition of the need for and an ability to engage in lifelong learning.
j. A knowledge of contemporary issues.
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Appendix – II: Student Feedback

"Machine Design class was one of my first experiences with the "real world" engineering in a school application. This class was integrated to provide us with real life situations, that engineers encounter every day. All of the four learning objectives were touched in this project, with more weighing more than the other.

The first learning objective of this course was to develop, set-up and solve mechanical component design problems based upon given upon given data and requirements. Each person was given a starting point (design requirements) and an end point (common goal of making a complete subsystem). The stuff in between was solely up to each group. With that in mind, our group was responsible for setting up and solving each component in order to create a whole.

The second learning experience was to develop corrective action. We learned this early on in the project. We had our shafts and gears finished and when designing the bearings, we quickly arrived at the decision that we forgot to include the axial forces on the shafts. At that point, we needed to act accordingly and change our shaft designs. We also redesigned our gears in order to achieve a higher and more suitable safety factor by altering material, pitch, etc.

I think the most important learning objective was learning objective #4. In fact, the most important part of this objective was team-based to find a solution. I must admit, I managed our project. Our group had a rocky start, and instead of working as a team, we worked as individuals. It wasn't until everyone did a part and pulled it together that made the pieces start to fit together like a jigsaw puzzle. With that in mind, I think this is the most valuable learning objective in life. We work in groups in school all the time, and we always wonder why our Professor's like these projects, but in all reality, they are setting us up for the real world. There will never be a time in our engineering careers that working alone. After realizing this, machine design has taught me this through this project as well as all assignments for the class" – *2006 batch senior student*

"This project combined everything that I have learned in the entire class into a multi component problem. The final project was very open ended with only a case study to use as reference and a sheet of directions. This correlates with course learning objective one in the syllabus. With only have a rough outline of the problem we had to develop each component that was related to the next by forces, size and safety factor. In our project we did variations of different designs keeping the same safety factor uniform for each design package.

The second course learning objective was developing a corrective action. The first design that was created was a baseline, this was the simplest design that we did to come up with base numbers. This allowed us to see how our other modified designs matched up.

This was a design for a hydroelectric generator. In hydroelectric generators there is very little human contact so a high safety factor is not needed; however it may be the primary or secondary electricity source, therefore this cause there to be moderate safety factor to insure the components do not fail. This required us to use a proper design that would be adequate for this type of application as referenced in learning objective three.

The forth learning objective deals with develop an appreciation for design, analytical techniques and changing materials. The outline for this project did give some material specifications however it was just a minimum for material strength. Our project also used common materials that allowed it to be practical.

I found this project to be very open-ended, this allowed us to the have design freedom, but in the same regard it was difficult to choice dimensions and materials that would yield realistic results. I used techniques and formulas from chapter one through chapter fifteen in completing this project" – *Senior, Mechanical Engineering Student*