Engineering Analysis with MATLAB Programming –
An approach to enhance teaching and learning effectiveness

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ABSTRACT

The aim is to develop a teaching process that can contribute to the success and improvement of students through the courses in engineering and technology programs. This process is based on a model that can enhance student's communication, critical thinking, teamwork, and problem solving skills through the core and design courses. For this model to be successful students are required to have a fundamental understanding in basic science and math courses and faculty must introduce and engage students with real applied problems/projects that incorporate research, analysis, and class presentation. Currently this model has been implemented through the core courses in Mechatronic Engineering, and Mechanical Engineering Technology programs at Vaughn College of Aeronautics and Technology. All those programs were able to produce a pool of talented students that can excel in workplace and graduate schools.

In this study MATLAB programming is implemented as a computing tool in engineering analysis course to stimulate student's critical thinking and problem solving skills. This exposure to MATLAB programming will also make it feasible for students to understand the behavior of an engineering system.

Keywords: Teaching and Learning Effectiveness, Closed-Form Analysis, Numerical Analysis, Assessment

1. INTRODUCTION

Today many students entering in colleges without profound foundation and preparation for the academic level education, this lack of education in college level expectation can weaken students understanding and performance through the program. Some of the problems that can contribute in lack of students learning and performance through the college level programs are

1. Communication – Lack of language in understanding course contents

2. Math and Science – Lack of math, and physics requirements

3. Accountability – Not willing to do work

We believe that supplemental remedial classes with skill and knowledgeable faculty in their subject of teaching with implementation of students learning outcomes assessment (H. Rahemi, and N. Seth, 2008) can help students to overcome those challenges before taking core classes through the program.

This study will concentrate on a process that can enhance teaching and learning effectiveness through core courses in achieving learning outcomes related to communication, critical thinking, teamwork, and problem solving. This paper will specifically address a case study in engineering analysis course based on teaching and learning effectiveness model.

2. TEACHING AND LEARNINEING EFFECTIVNESS

A methodology for a successful teaching and learning model has been developed based on student learning outcomes evaluation and its improvement (H. Rahemi, and N. Seth, 2008). The process is continuously refined to improve achievement of students' learning outcomes.

In today's information age, we as educators need to assess and refine our teaching delivery to our students (L.D. Camblin and J.A. Steger, 2000). This requires creating checks and balances model between faculty (delivering course materials) and students (observing/learning). Figure 1 is a graphical model of teaching and learning process.
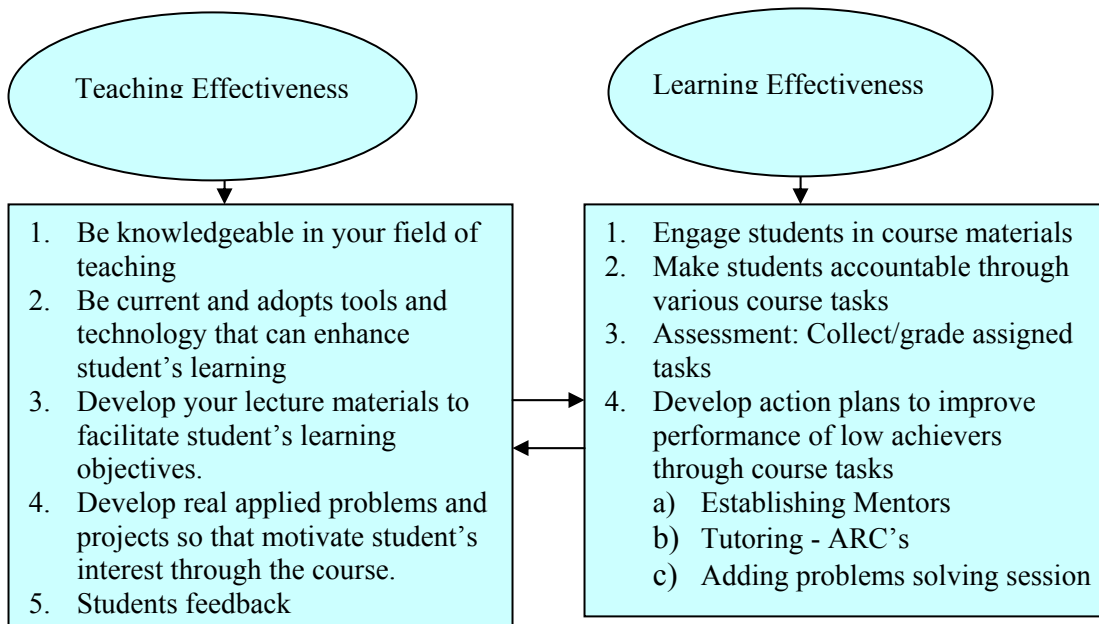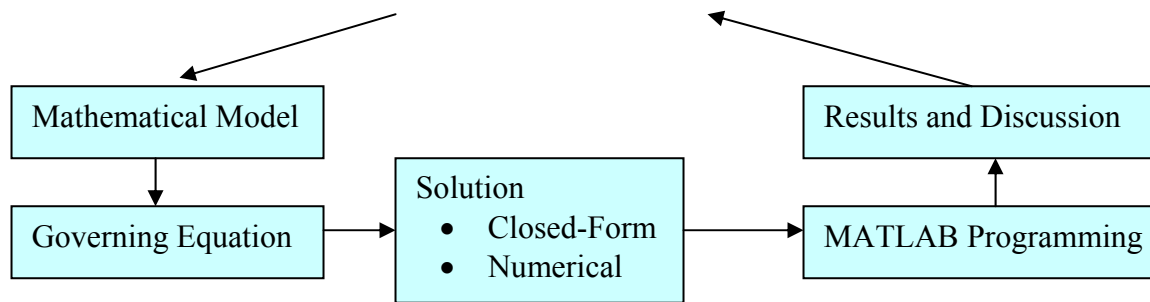

Figure 1: Teaching and Learning Effectiveness Model

In an effort to further increase learning effectiveness, during the spring of 2009 a formal supplemental learning program was introduced. As part of this program, students were paired with faculty teaching engineering and mathematics. The students were selected from among a pool of students who had already been highly successful in their previous course work. The students were assigned to sit in on the course with the instructor for a second time and serve as designated tutors for the course. In addition to this the students were also assigned the task of conducting problem solving and review sessions. This program was initiated in conjunction with the Academic Resource Center ARC.

3. ENGINEERING ANALYSIS

The aim is to implement a methodology based on teaching and learning effectiveness model to enhance student's learning objectives (communication, critical thinking, teamwork and problem solving skills) through the engineering analysis course. Figure 1 is a graphical model of teaching and learning effectiveness in engineering analysis course.

Figure 2: Engineering Analysis - A sample for teaching and learning effectiveness

The behavior of many engineering systems (deformation, vibration, heat transfer, and others) can be identified by the solution of the governing equation of the body (H. Rahemi, 2007). The focus of this course is given to both closed-form and numerical solution using MATLAB programming. In this investigation, the finite difference method will be implemented to develop numerical formulation of the governing equations of many engineering system.

In this course MATLAB is implemented as a computing tool to generate results and study behavior of an engineering system. Through this course students not only learn about problems and solution related to the engineering systems, but also, learn about the thinking process in developing programs to facilitate the solution of a physical system (H. Rahemi, 2008). Hence, this course can be used as a model to enhance student's critical thinking and problem solving learning outcomes.

This course is taken by mechanical and mechatronic engineering students at the third (fifth term) year of the program. The objective is to demonstrate the application of mathematics for development of engineering system governing equations and its solution.

4. ASSIGNMENT LEARNING OBJECTIVES

This course is developed in an approach to enhance student's critical thinking, problem solving, team work, and communication skills. The students are arranged in several teams, each team is assigned to a technical project with engineering application (Process for spring and shock absorber design, thermal analysis, structural deformation analysis, and structural reliability analysis). The assigned project must be studied and investigated in a manner such that it satisfies the learning objectives of engineering education. Some of the learning objectives that will be implemented and measured as follows:

1) Intention plan (Abstract): A proposal that outlines the details of a project and its application

2) Methodology: A brief description of methods and solution

3) Teamwork: Identify team members and their responsibility in project development

4) Modeling: Providing a complete and precise physical and mathematical model of the project

5) Analysis: Provide all necessary analysis based on both closed-form and numerical approaches with MATLAB as a tool to generate the results.

6) Conclusion: Discussing the result(s) and process for the improvement

7) Reference: Identifying research references

8) Presentation: The design team members present their work in PowerPoint format to the audience in the class room

The student's design projects will be measured based on all above learning objectives and will be graded based on the criteria such as proposal and model development, programming and analysis, report and presentation.

The following case study is introduced to show how theoretical topics learned through the course can be used to solve problems related to engineering system. In this investigation we will study engineering analysis of a problem related to the vibration analysis of a one-story structure with four beam columns (W8x24) supporting structure. For this problem both closed-form and numerical methods can be employed to determine the response of the structure. To generate the results and identify the vibration behavior of the structure, a MATLAB script can be developed based on the response equation.

5. CASE STUDY – VIBRATION ANALYSIS OF ONE-STORY STRUCTURE

In this case study we will examine a 2nd order non-homogeneous governing equation of motion for a forced one-story structure supported by four columns and air acting as damping.
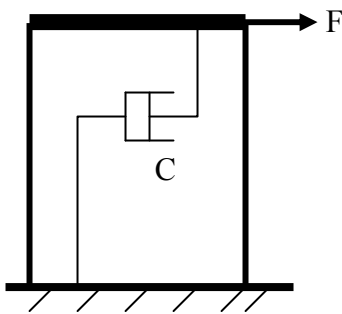
**Fig. 3a: Physical Model, One-story frame structure**
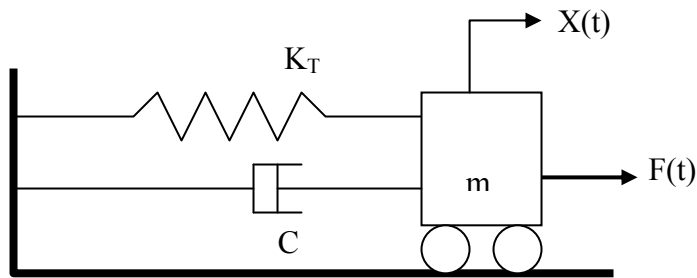
Fig. 3b: Mathematical Model (Spring-Mass System)

Knowing that columns are rigid to the flour slab (Fig. 4), the total spring rate (K_T) can be expressed as follow

$$K_T = 4K = \frac{48EI}{L^3} \qquad (1)$$

Let's consider W8x24 steel beam for the column With I = 82.8 in^4 and E = 30e6 psi, the spring Rate for four columns can be evaluated as

$$k_T = \frac{4(12)(30e6)(82.8)}{(18x12)^3} = 11,831 \ lb/in$$
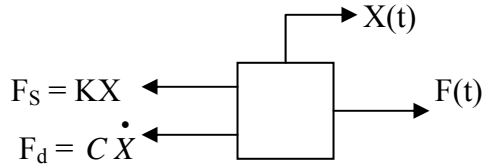

$$k = \frac{12\,EI}{L^3}$$
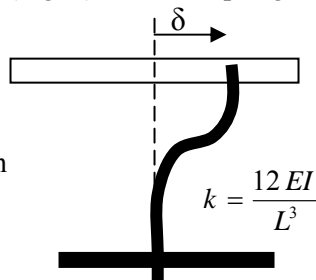
Fig. 4: The displaced form of the frame structure

The weight of flour slab with all other dead loads can be considered as 38.7 kips, hence, the mass can be calculated as

$$m = \frac{W}{g} = \frac{38,700 lb}{386.4 in/s^2} = 100 \ \frac{lb - s^2}{in}$$

5.1 HE GOVERNING EQUATION OF MOTION

Using Newton's 2nd law, the governing equation of motion for the one-story frame structure can be expressed as

$$\sum F = m\ddot{X} \qquad (2)$$

$$-KX - C\dot{X} + F(t) = m\ddot{X} \qquad (3)$$

Above can be rearranged as

$$m\frac{d^2x}{dt^2} + C\frac{dx}{dt} + kx = F(t) \qquad (4)$$

5.2 CLOSED-FORM ANALYSIS

Prior to applied force, the free vibration (homogenous response) response of the structure, $X_h(t)$, based on initial conditions (x(0) = xo and v(0) =vo) can be determined as

$$X_h(t) = \exp(-\zeta\varpi_n t)*[x_o Cos\varpi_d t + \frac{1}{\varpi_d}(V_o + \frac{c}{2m}x_o)Sin\varpi_d t] \qquad (5)$$

Let's consider a harmonic force, $F(t) = F_o Sin\varpi_e t$, excites the structure, the response of such excitation can be expressed as

$$X_P(t) = \frac{F_o}{k}\frac{Sin(\varpi_e t - \phi)}{\sqrt{[1-(\varpi_e/\varpi_n)^2]+(2\zeta\varpi_e/\varpi_n)^2}} \qquad (6)$$

where, $\phi = \tan^{-1}\dfrac{2\zeta(\varpi_e/\varpi_n)}{1-(\varpi_e/\varpi_n)^2}$

A MATLAB program based on above closed-form equation and system data can be developed to determine the dynamic response of the system vs. time. In this case study the following conditions has been considered to investigate dynamic behavior of structure

a) Structure is excited with a force of $F = 100Sin(0.5t)$

b) Structure is excited with a force of $F = 100Sin(0.5t)$ and initial displacement, $X_0 = 0.1\,in$, ignoring damping effect

c) Structure is excited with an initial displacement, $X_0 = 0.1\,in$, ignoring damping effect

d) Structure is excited with an initial displacement, $X_0 = 0.1\,in$, considering damping effect

5.3 MATLAB PROGRAM (ANALYTICAL SOLUTION)

```
% Exact solution of damped force vibration system;
% m(d^2X/dt^2) +c(dx/dt)+ kX = foSin(we)t
% The response equation can be expressed as
```

```
% X(t) = exp(-z*wn*t)*(A1*Sin(wd*t)+A2*Cos(wd*t)+
%        (fo/k)*Sin((we*t)-phi))*D
% Where A1 = (1/wd)(vo+z*wd*xo) and A2=xo
% D = 1/sqrt(((1-(we/wn)^2)^2)+(2*z*(we/wn))^2)
W = input('weight,lb, W:'); c = input('damping coef. c:');
L = input('Column length,in, L:'); I = input('Column Moment of Inertia,in^4, I:');
E = input('Column Elastic Modulus (psi),E:');
fo = input('Exited Amplitude Force, fo:');
we = input('Exited Freq., we:'); xo = input('initial displacement, xo:');
vo = input('initial velocity, vo:');
k = (48*E*I)/L^3; m = W/386.4; wn = (k/m)^.5;

z = c/(2*m*wn); wd = wn*((1-(z^2))^.5);
phi= atan((2*z*(we/wn))/(1-((we/wn)^2)));
D = 1/sqrt(((1-(we/wn)^2)^2)+(2*z*(we/wn))^2); A1=((1/wd)*(vo+z*wn*xo));
s = input('Starting Time s:'); f = input('final time f:');
d = input('time increment d:');
t = s:d:f;
x = exp(-z*wn*t).*((A1*sin(wd*t))+xo*cos(wd*t))+ (((fo/k)*sin((we*t)-phi))*D);
disp ('Response,x')
disp(x)
plot(t,x)
```

eight,lb, W:38700
damping coef. c:0
Column length,in, L:216
Column Moment of Inertia,in^4, I:82.8
Column Elastic Modulus (psi),E:30e6
Exited Amplitude Force, fo:100
Exited Freq., we:.5
initial displacement, xo:0
initial velocity, vo:0
Starting Time s:0
final time f:40
time increment d:.001

eight,lb, W:38700
damping coef. c:0
Column length,in, L:216
Column Moment of Inertia,in^4, I:82.8
Column Elastic Modulus (psi),E:30e6
Exited Amplitude Force, fo:0
Exited Freq., we:0
initial displacement, xo:0.1
initial velocity, vo:0
Starting Time s:0
final time f:6
time increment d:.001
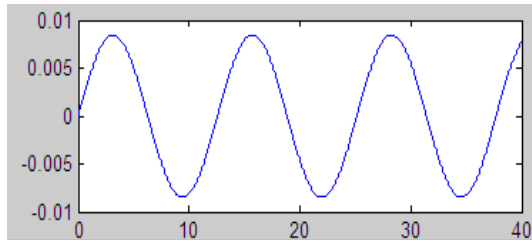
Xo=0. Vo=0. C=0. Fo=100. We=.5 Rad/S

Fig. 5: Response for the undamped forced vibration with no initial conditions
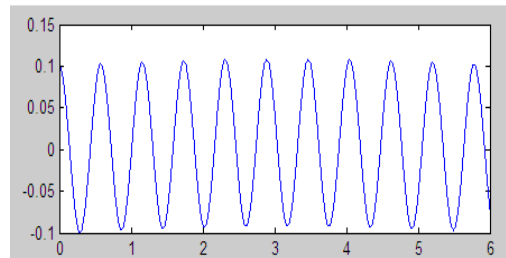
Xo=0.1. Vo=0. C=0. Fo=0. We=.0 Rad/S

Fig. 6: Response for the undamped free vibration with initial conditions

Xo=0.1. Vo=0. C=20. Fo=0. We=0 Rad/S
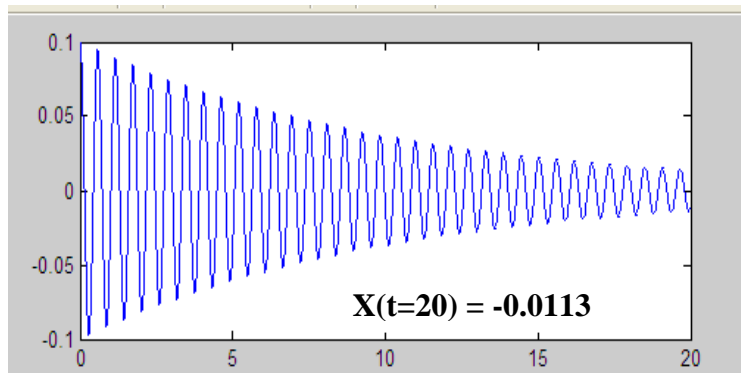
Fig. 7: Response for the damp free vibration with initial conditions

5.4 NUMERICAL ANALYSIS - 2st Order Approximation of Damped Forced Vibration

Here, we employ a centered difference approximation of 1st and 2nd derivatives to develop numerical form of equation of motion, that is

$$m\frac{d^2x}{dt^2} + c\frac{dX}{dt} + kx = F(t) \tag{7}$$

Using centered divided finite difference, first and second derivative (J. H. Mathews, 2004; S.C. Chapra, 2004) can be approximated as

$$\frac{dX}{dt} = \frac{X(t_{i+1}) - X(t_{i-1})}{2h} \pm O(h^2) \tag{8}$$

$$\frac{d^2x}{dt^2} = \frac{X(t_{i+1}) - 2X(t_i) + X(t_{i-1})}{h^2} \pm O(h^2) \tag{9}$$

The error associated with 1st and 2nd derivatives by centered difference approximation is in order of square of step size, $O(h^2)$. For example a step size of .02 will produce an error of $\pm 0.04\%$, very small error in comparison with forward and backward finite divided difference methods. Using Eq(8) and Eq.(9), the centered difference form of equation of motion can be expressed as

$$\left(\frac{X(t_{i+1}) - 2X(t_i) + X(t_{i-1})}{h^2}\right) + \frac{c}{m}\left[\frac{X(t_{i+1}) - X(t_{i-1})}{2h}\right] + \frac{k}{m}X(t_i) = \frac{1}{m}F(t_i) \tag{10}$$

Hence, numerical equation for the response at time t$_{i+1}$ can be developed as

$$X(t_{i+1}) = (\frac{2m}{2m+ch})\left[\frac{h^2}{m}F(t_i) + (2 - \frac{kh^2}{m})X(t_i) + (\frac{ch}{2m} - 1)X(t_{i-1})\right] \tag{11}$$

A general MATLAB program based on centered difference approximation of above finite difference numerical formulation is developed to determine the response of a damped and undamped free and force-vibration systems. By considering a step size, h = 0.001, the Associated error of numerical solution will be approximately $\pm 0.0001\%$.

### 5.5 MATLAB PROGRAM(Numerical Solution)

```matlab
% A general program for damped and undamped free and force vibrating
% system based on 1st & 2nd derivatives centered difference approximation
% m(d^2X/dt^2)+C(dx/dt)+kx=F(t), F(t)=(fo)Sin(we)t,                    %
Kt=4K=4(12EI/L^3)and m=W/386.4 with X(0)=xo in and dX/dt(0)=0.
W = input('weight,lb, W:'); c = input('damping coef. c:');
L = input('Column length,in, L:');
I = input('Column Moment of Inertia,in^4, I:');
E = input('Column Elastic Modulus (psi),E:');
fo = input('Exited Amplitude Force, fo:');
we = input('Exited Freq., we:'); ti = input('Initial time ti:');
tf = input('final time tf:'); dt = input('step size dt:');
xi = input('Initial disturbance xi:');
k = (48*E*I)/L^3; m = W/386.4; n = 1+((tf-ti)/dt);
t = zeros(n,1); x = zeros(n,1);

t(1) = ti; x(1) = xi; t(2)= ti; x(2) = xi ; h = dt;
j=2;
while (1)
    if t(j)+dt> tf
        h=tf-t(j);
    end
    x(j+1) =(2*m/(2*m+(c*h)))*(((h^2)/m)* fo*sin(we*t(j))+(((-
k*h^2)/m)+2)*x(j)+((c*h/(2*m))-1)*x(j-1)));
    t(j+1) = t(j)+h;
    if t(j+1) >= tf, break, end
    j=j+1;
end
disp ('  Time (t)    Response (X)')
disp([t x])
plot(t,x)
```

ti=0. tf = 20. Xo=0.1. Vo=0. C=20. Fo=0. We=0 Rad/S. dt=.001
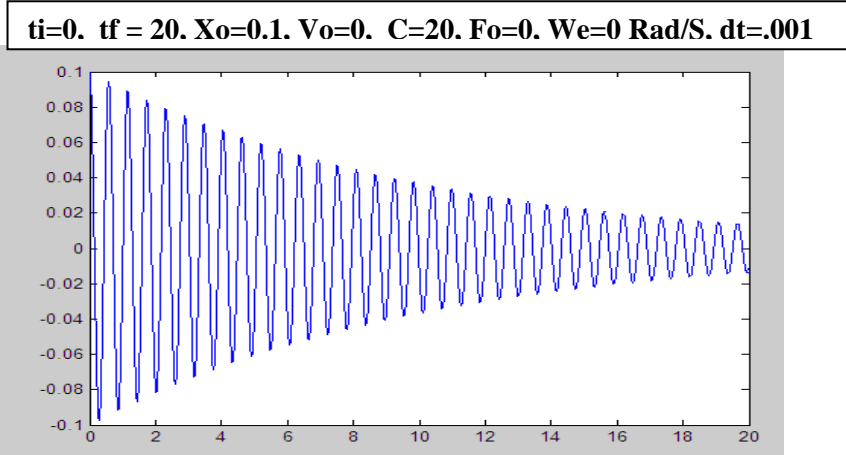
weight,lb, W:38700   Exited Freq., we:0
damping coef. c:20   Initial time ti:0
Column length,in, L:216   final time tf:20
Column Moment of Inertia,in^4, I:82.8   step size dt:.0001
Column Elastic Modulus (psi),E:30e6   Initial disturbance xi:0.1
Exited Amplitude Force, fo:0

dt = 0.001 ⟶ X(t=20) = -0.0113 same as exact solution

6. COURSE ASSESSMENT

The VGLU data based on rubric scores for Vaughn College of Aeronautics and Technology are developed as follows to close the loop on the course assessment process.

"V = 3" Very good performance- Demonstrates a very good understanding and performance through important concepts of the course materials. **V** can be used for a grade of B+ and A.

"G = 2" Good performance- Demonstrates a good understanding and performance through important concepts of the course materials. **G** can be used for a grade of C+ and B.

"L = 1" Low Performance - Demonstrates an average to minimal understanding and performance through the important concepts of the course materials. – **L** can be used for a grade of D and C.

"U = 0" Demonstrates unsatisfactory. **U** can be used for a grade of F.

Example: A VGLU score for a class with 8 students in which the task is the first exam might have a frequency distribution of (2, 1, 4, 1) i.e., 2Vs, 1 G, 4 Ls and 1 U. The score of such VGLU can be evaluated as follows:

$$\frac{2X3+1X2+4X1+1X0}{8} = 1.50$$, which is an average (C), representing what a student would need in order to satisfy the requirement for graduation.

6.1 STUDENT CLASS ROLL-BOOK DATA: Import student class roll-book data from any data base management program.

Table 1: Student Class Roll-Book Data – EGR340 Fall 2008

Student	Quiz # 1 5%	Quiz # 2 5%	Project 30%	Exam #1 15%	Exam #2 15%	Final 30%	Total	Grade
	70	80	80	78	80	77	78	C+
	70	70	85	75	72	75	77	C+
	75	80	90	83	80	80	83	B
	90	85	90	88	86	88	90	A
	80	85	85	80	78	74	80	B
	90	100	90	96	92	90	92	A
	75	70	85	76	78	72	77	C+
	85	80	80	78	82	78	80	B
	85	90	85	87	87	84	86	B+
	70	80	90	82	75	85	83	B
	90	87	80	88	87	86	86	B+
VGLU	(5,3,3,0)	(5,4,2,0)	(8,3,0,0)	(4,7,0,0)	(4,6,1,0)	(4,5,2,0)		
Score	2.18	2.27	2.73	2.36	2.27	2.18		

This course delivered and assessed the following **program outcomes**

(a) An ability to apply knowledge of mathematics, science, and engineering.
(c) An ability to gain the broad education necessary to function in a multi-disciplinary team.
(d) An ability to identify, formulate, and solve engineering problems
(f) An ability to communicate effectively through oral presentations and writing.
(j) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

6.2 STUDENTS FEEDBACK: Students were happy and comfortable with the pace and content of this course. However, they all recommended, projects and programming in this course helped them to appreciate the application of mathematics in understanding the behavior of engineering system.

7. CONCLUSION

The analysis and design of an engineering system and its components required a precise understanding of mathematics, method of solution, and programming. In this study, the vibration response of a one-story structure has been evaluated using both closed-form and numerical analysis. The results showed that the accuracy in numerical analysis can be achieved and improved by selecting an adequate numerical technique with proper step size.

From this study it can be observed that numerical analysis have *some* distinct advantages over exact analysis those could be classified as follows;

1. Developing the numerical form of a differential equation is less time consuming than finding the closed-form solution.

2. For certain type of problems it is not feasible to find the closed-form solution, however it is always easy to set up the numerical form of the governing equation.

The case study of engineering analysis model with MATLAB application delivered learning objectives that are required to motivate student's critical thinking and problem solving skills. It can be observed that MATLAB programming enable both researchers and students with a tool to understand different mathematical techniques in analyzing and studying behavior of an engineering system.

In summery, the implementation of teaching and learning effectiveness model in core courses will produce the following results

1. Motivate students interest through the course and program

2. Enhance and improve students learning outcomes

3. Produce a pool of talented students that can excel in work place and graduate schools.

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