Developing Student Mastery and Confidence in using FEA Software through its Integration in Many Fundamental Mechanics Courses

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ABSTRACT

The Finite Element Analysis (FEA) is a numerical technique that is used in many engineering industries like civil, mechanical, aerospace, nuclear, and manufacturing. Most schools offer one FEA course in the undergraduate engineering curricula. This course imparts in students a good theoretical background of the finite element method as well as problem solving techniques using hand-based methods and commercial FEA software. We strongly feel that students do not acquire good skill, speed, and confidence in using the FEA software due to the following reasons: (a) The software is used in the FEA course only (b) Inadequate time is devoted in the FEA course to solution of problems using the software as the course also involves teaching both theory and hand-based solution method (c) Students are exposed to the software very late in the curricula, since FEA course is usually offered at junior or senior student years. Thus, students are not well prepared to execute senior capstone projects, seek internships and employment, as well as excel in jobs related to FEA. The engineering program at our institution offers only an undergraduate degree (B.S) in which two FEA courses- introductory and intermediate are offered as electives. The institution is a career oriented school with a strong focus on the employment of our graduates which is reflected in an employment rate of 97%. To meet the needs of our two customer groups- students and employers, we are constantly developing new educational programs and innovative delivery methods. This paper describes the integration of the FEA commercial software ANSYS across many courses in the mechanics area. The integration is an outcome of a project funded by an institutional grant.

Introduction

FEA today has become an indispensable tool in many industries because of the advent of high speed computers and increased storage capacity. Consequently, there has been an increased growth of job opportunities related to FEA. Many universities use commercial software in their FEA courses thus providing students an opportunity to learn and use of the software. Because a single FEA course is inadequate to expose students to both the theory of the finite element method and commercial software, many educators have integrated FEA into several courses across the curriculum. Most integrations have involved the introduction of the theory of finite element method[1, 2]. Papadopoulos et. Al[3] (2011) have mentioned that integrating FEA, as a tool only, has not been well articulated in the literature. Therefore, their paper discusses the integration of FEA, without requiring deep instruction in the underlying FE theory, across many

courses beginning from the freshman year. However, their integration included only two courses from the analytical mechanics area- Statics and Mechanics of Materials, which both involve time-independent phenomena. Furthermore, they do not mention the student survey questions and quantified survey results of their integration.

The present paper describes the integration of the FEA commercial software ANSYS[4] across four fundamental analytical mechanics courses- Statics, Dynamics, Solid Mechanics, and Vibrations which are offered prior to the two FEA courses at our institution. The main aim of the integration is to develop in students the familiarity, speed, mastery, and confidence in using the software without any discussion of the FEA theory. The courses chosen for this integration help students to apply ANSYS to time-independent problems (Statics and Solid Mechanics courses) as well as time-dependent problems (Dynamics and Vibrations courses). Furthermore, the integration addresses the ABET student outcome 'k'- *Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.* Three ANSYS based tutorials containing step-by-step instructions were developed for each course. Most problems analyzed were from the textbooks[5,6] used in the courses. In order to allow students to learn hand-based solutions prior to using ANSYS, the tutorials were introduced in the second half of each course. The tutorials were used as in-class lecture topic (50 minutes/tutorial, time permitting) or as homework assignments. The advantages of using a software like ANSYS is the ease in which loads and boundary conditions can be applied and changed (if needed) to solve problems, and to visualize deflection and stresses through superior graphics and animations, which otherwise are difficult in hand-based solutions. Since the chosen courses are in sequence in the Mechanical Engineering (ME) and Civil Engineering (CE) curricula, it is likely that students will develop mastery and confidence in using ANSYS. The integration of FEA is the outcome of an institutional grant, and was carried out for the first time in our institution.

FEA involves preprocessing, processing, and postprocessing, all of which can be performed using ANSYS. Preprocessing involves building models, meshing, assigning material and cross-sectional properties, and applying loads and boundary conditions. Processing deals with the solution of the problem. Postprocessing involves the outputs of nodal and element solutions of reactions, deflections, velocities, acceleration, stresses, as well as visualization and animation of the results.

Objectives

The objectives of the integration were to:

- introduce the use of ANSYS very early on to students of engineering and technology without dwelling on the finite element methodology.
- increase students' speed and confidence in the use of ANSYS as a tool through its integration in many follow-up courses.
- assist students in better understanding of the core lecture material (theory and hand solutions) through plotting, graphics, animation, and visualization of ANSYS results.
- increase student awareness of the user friendliness and wide range of capabilities of the FEA software.

- better prepare students for solving practical and involved projects in the FEA course offered in the engineering curriculum.
- better position students for seeking internships, senior capstone projects, and employment related to FEA .
- lay a foundation for future tutorials to be developed for courses in the thermal sciences area.

Tutorials Developed

The following tutorials for integrating ANSYS were developed.

- Statics
  - Tutorial 1: “Plane Trusses”
  - Tutorial 2: “Pin Connected Plane Frames”
  - Tutorial 3: “Analysis of Beams”
- Dynamics
  - Tutorial 1: “Impact of a Block on a Spring Scale”
  - Tutorial 2: “Ball Impacting a Flexible Surface”
  - Tutorial 3: “Large Rotation of a Swinging Pendulum”
- Vibrations
  - Tutorial 1: “Free Vibration of Two-DOF System”
  - Tutorial 2: “Free Vibration of a Simple Beam”
  - Tutorial 3: “Forced Vibration of a Simple Beam”
- Solid Mechanics
  - Tutorial 1: “Beam Deflections, Stresses, and Internal Loading Diagrams”
  - Tutorial 2: “Thin-walled Pressure Vessels”
  - Tutorial 3: “Combined Loading”

Course 1: Statics

This course is offered in the winter quarter and is the first in sequence of the four courses chosen. The tutorials developed for the structural analysis are: (a) 2D Truss (b) 2D Pin-connected Frame, and (c) Beam.

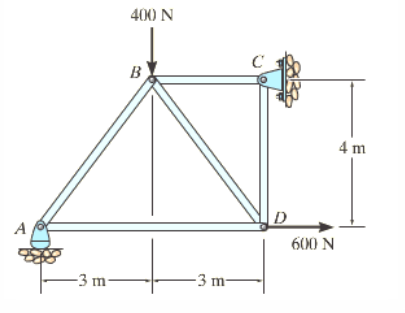


Figure 1

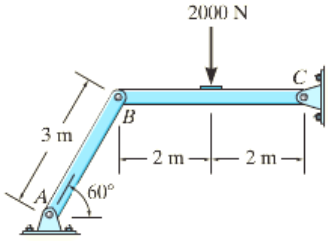


Figure 2

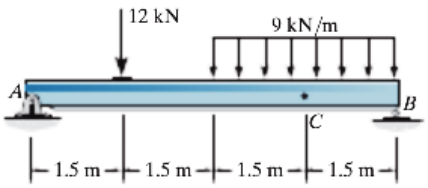


Figure 3

The three structures analyzed are shown in figures 1, 2 and 3 respectively. The analysis of pin-connected frames by ANSYS is not that straight forward unlike rigid-jointed frames. One of the features of this work is therefore the consideration of the pin-connected frame which has not been considered in the integration of ANSYS by other educators. Through these tutorials, students learned how to apply external concentrated and distributed loads, and boundary conditions like pin and roller/rocker supports.

Students were taught hand-based analytical solutions for these problems prior to the use of ANSYS. The ANSYS output sequence involved solutions to reactions, member end forces, and deflections. The deformed configuration and its animation were visualized. The ANSYS solution to support reactions and member forces were verified with those obtained from hand-based solutions.

Course 2: Dynamics

This course is offered in the spring quarter and its prerequisite is the Statics course. The tutorials developed were: (a) Impact of a Block on a Spring Scale, figure 4; (b) Transient Response of a Ball Impacting a Flexible Surface, figure 5; (c) Large Rotation of a Swinging Pendulum, figure 6. The three cases considered are from the ANSYS verification manual. In order to aid students in the understanding of the ANSYS input commands, the tutorials for this course uses the input files unlike the step-by-step commands used in tutorials of other courses. However, based on the feedback, students preferred the step_by_step approach over the use of input files. The authors expected this and feel that a step_by_step approach should be used in the Dynamics course moving forward, and the use of input files should be discussed in the finite element course which is offered later in the curricula. The displacements, velocity, and kinetic energy are output, and verified with the hand-based analytical solutions. The tutorials helped students in analyzing time-dependent problems.

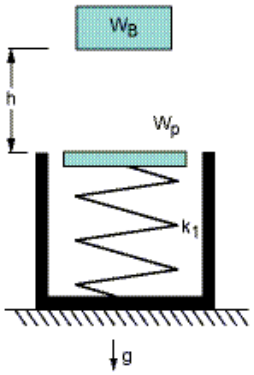


Figure 4

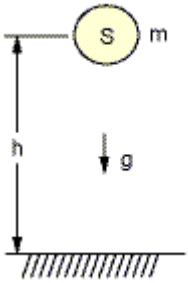


Figure 5

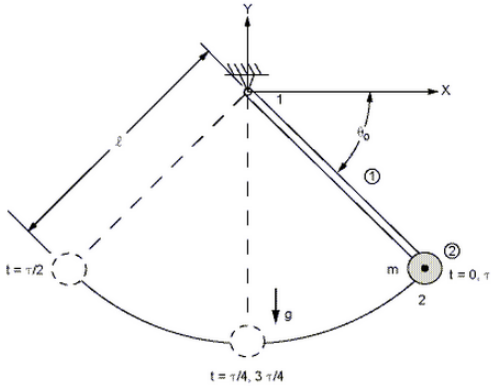


Figure 6

Course 3: Solid Mechanics

This course is offered in the fall quarter. The tutorials developed were: (a) Beam - Shear and Moment Diagrams, and Stresses, figure 7; (b) Stresses in a Long Thin-Walled Pressure Vessel,

figure 8; and (c) Combined Loading on a Bent Pipe, figure 9. The tutorials were incorporated in the lab portion of the course.

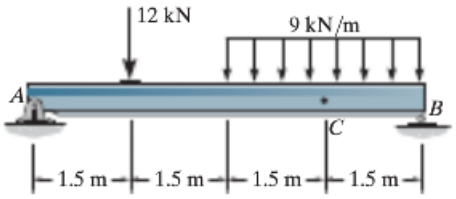
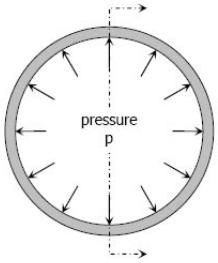


Figure 7



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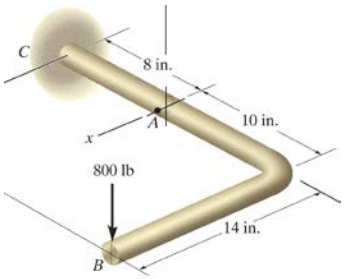

Figure 9

The first tutorial helped students in their ability to plot shear and moment diagrams. The tutorials benefitted students in their learning of the computation of stresses and internal loadings. The ANSYS results were verified with the hand-based solutions.

Course 4: Vibrations

This course is offered in the winter quarter in the senior year and its perquisite is the Dynamics course. The tutorials developed were: (a) Free Vibration of Two-DOF System, figure 10; (b) Free Vibration of a Simple Beam, figure 11; and (c) Vibration of a Simple Beam due to an Impulse Loading, figure 12.

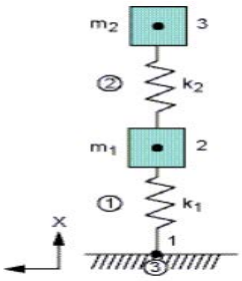

Figure 10

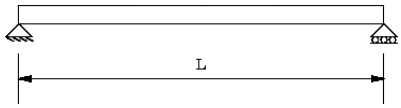

Figure 11

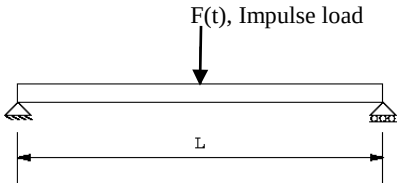

Figure 12

Most educators have used the vibration of basic spring-mass models in their integration. We felt that additional consideration of free and forced vibrations of simple beams would greatly benefit student learning in the vibration analysis of continuous systems using ANSYS. Using the tutorials, students were able to determine the natural frequencies and mode shapes. The visualization of the vibration modes which are enhanced by the animation capability of the ANSYS software significantly contributed to student learning.

Results

The twelve tutorials developed were deployed during the 2013-14 academic year in the following course sequence: Solid Mechanics in Fall 2013 and Fall 2014, Statics in Winter 2014, Vibrations in Winter 2014, and Dynamics in Spring 2014. The student population in the four courses was comprised of 17 students (from two quarters) from two different engineering disciplines in solid mechanics, 11 students from four different disciplines in statics, 4 students in the mechanical engineering program in vibrations, and 12 students from mechanical engineering in the dynamics course. Students in the statics and dynamics courses were in the sophomore year, and those in solid mechanics and vibrations in the junior year. Assessment data collected included student academic performance in each module, and student survey data.

Student surveys were administered at the end in all the four targeted courses. A scale of 1 to 5 was used to quantify students' answers, with 1 - Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, and 5 - Strongly Agree. The student survey results for the four courses are shown in tables 1-4. The tables contain 15 questions and students' answers to them. Furthermore, students were asked three additional questions to describe their experience with the tutorials in a sentence format.

Table 1. Student Survey Results Summary for ME211 "Solid Mechanics".

	Question	Average Score, Out of 5
1.	The Finite Element Analysis Software ANSYS Tutorials in the ME211L course were a good learning experience.	4.57
2.	**Tutorial 1:** "Beam Deflections, Stresses, and Internal Loading Diagrams" helped me understand the concept of reactions, deflections, stresses, and shear and moment diagrams.	4.43
3.	Tutorial 1 increased my confidence in solving problems related to statically determinate and indeterminate beams	3.86
4.	**Tutorial 2:** "Thin-walled Pressure Vessels" helped me understand the concept of stresses in thin-walled pressure vessels.	4.57
5.	Tutorial 2 helped me understand the difference in stresses between thin-walled and thick-walled pressure vessels.	4.29
6.	**Tutorial 3:** "Combined Loading" helped me understand the state of stress due to the combination of applied forces and moments	4.00
7.	Tutorial 3 increased my confidence in solving beams, columns, and pipes subjected to combined loading.	3.86
8.	Tutorial 3 enhanced my understanding of internal loadings due to combined external loads.	4.00
9.	The ANSYS tutorials increased my theoretical knowledge of solid mechanics.	4.29

10	The ANSYS tutorials helped me in understanding the complicated topics on shear and bending moment diagrams, pressure vessels, and combined loadings.	4.43
11.	The time dedicated to the tutorials was about right.	3.86
12.	Overall the ANSYS tutorials added value to the ME211 course.	4.43
13.	The ANSYS tutorials helped in exposing to a Finite Element software very early on in the mechanical engineering curriculum	4.43
14.	The ANSYS tutorials helped in developing speed, mastery and confidence in using FEA software through its integration in the Solid Mechanics Courses	4.29
15.	I would recommend including ANSYS based hands-on Tutorials related to course topics in other courses in my program.	4.29

Average scores to all questions except questions 3, 7, and 11 were above 4.0 (Agree or Strongly Agree), indicating a positive experience with the modules. All students agreed on recommending the inclusion of ANSYS based hands-on tutorials related to course topics in other courses in the program.

Table 2. Student Survey Results Summary for ME201 "Statics".

	Question	Average Score, Out of 5
1.	The Finite Element Analysis (FEA) Software ANSYS Tutorials in the ME321 course were a good learning experience.	4.6
2.	**Tutorial 1:** "Plane Trusses using ANSYS" helped me better understand support reactions, member forces and deflection in trusses	4.4
3.	Tutorial 1increased my confidence in solving problems related to trusses	4.1
4.	**Tutorial 2:** "Pin Connected Plane Frames using ANSYS" helped me understand the advantage of FEA in solving frames.	4.4
5.	Tutorial 2 helped me understand internal forces at the ends of each frame member.	4.3
6.	**Tutorial 3:** "Analysis of Beams using ANSYS" helped me understand how to apply distributed loads and moments on beams.	3.9
7.	Tutorial 3 increased my confidence in solving reaction, deflection, and internal loadings using ANSYS in beams.	3.8
8.	Tutorial 3 enhanced my understanding of analysis of beams.	4.0
9.	The ANSYS tutorials increased my theoretical knowledge of statics.	4.5
10	The ANSYS tutorials helped me in verifying hand solutions and visualizing deformed shapes.	4.3
11.	The time dedicated to the tutorials was about right.	3.5

12.	Overall the ANSYS tutorials added value to the ME201 course.	4.2
13.	Using the ANSYS tutorials I feel confident of building models and perform static analysis.	3.9
14.	The ANSYS tutorials helped in developing speed, mastery and confidence in using FEA software.	3.6
15.	I would recommend including ANSYS based hands-on Tutorials related to course topics in other courses in my program.	4.5

Average scores to most questions were above 4 (Agree or Strongly Agree) reflecting a positive experience with the modules. All students recommended including ANSYS based hands-on Modules to other courses in their program.

Table 3. Student Survey Results Summary for ME421 "Vibrations".

	Question	Average Score, Out of 5
1.	The Finite Element Analysis (FEA) Software ANSYS Tutorials in the ME421 course were a good learning experience.	4.5
2.	**Tutorial 1:** "Free Vibration of Two-DOF System" helped me better understand natural frequencies and mode shapes.	4.75
3.	Tutorial 1increased my confidence in solving problems related to vibration of spring-mass systems	4
4.	**Tutorial 2:** "Free Vibration of a Simple Beam" helped me understand the advantage of FEA in solving vibration problems.	4.75
5.	Tutorial 2 helped me understand the natural frequencies and mode shapes in cantilever beams	4.5
6	**Tutorial 3:** "Vibration of a Simple Beam due to an Impulse Loading" helped me understand transient vibration.	4.5
7	Tutorial 3 increased my confidence in solving vibration problems in beams.	4
8	Tutorial 3 enhanced my understanding of free and forced vibrations.	4.25
9	The ANSYS tutorials increased my theoretical knowledge of vibrations.	4.5
10	The ANSYS tutorials helped me in verifying hand solutions and visualizing mode shapes.	4.25
11	The time dedicated to the tutorials was about right.	4.25
12	Overall the ANSYS tutorials added value to the ME421 course.	4.5
13	Using the ANSYS tutorials I feel confident of building models and perform vibration analysis.	4.25
14	The ANSYS tutorials helped in developing speed, mastery and confidence in using FEA software	4.5

15.	I would recommend including ANSYS based hands-on Tutorials related to course topics in other courses in my program.	4.75

Average scores to all questions were above 4 (Agree or Strongly Agree), reflecting a positive experience with the tutorials modules. A high score of 4.75 on question 15 indicated that students recommended including ANSYS based hands-on tutorials related to course topics in other courses of the program.

Table 4. Student Survey Results Summary for ME321 "Dynamics".

	Question	Average Score, Out of 5
1	The Finite Element Analysis (FEA) Software ANSYS Tutorials in the ME321 course were a good learning experience.	4.33
2	**Tutorial 1:**"Impact of a Block on a Spring Scale using ANSYS" helped me better understand the modeling using spring, mass, and damper elements	4.08
3	Tutorial 1helped my confidence in solving problems related to two objects in contact	4.00
4	**Tutorial 2:**"Ball Impacting a Flexible Surface using ANSYS" helped me understand the advantage of ANSYS in solving impact problems using contact elements.	4.25
5	Tutorial 2 helped me understand the variation of displacement, velocity, and kinetic energy of the impacting object with respect to time	4.17
6	**Tutorial 3:** "Large Rotation of a Swinging Pendulum" using ANSYS" helped me understand how to perform large deflection analysis.	4.08
7	Tutorial 3 increased my confidence in solving geometric nonlinear analysis using ANSYS.	3.83
8	Tutorial 3 enhanced my understanding of the motion of a pendulum.	4.17
9	The ANSYS tutorials increased my theoretical knowledge of dynamics.	4.33
10	The ANSYS tutorials helped me in verifying hand solutions and visualizing responses with respect to time.	4.42
11	The time dedicated to the tutorials was about right.	3.75
12	Overall the ANSYS tutorials added value to the ME321course.	4.00
13	Using the ANSYS tutorials I feel confident of building models and perform dynamic analysis through use of input files as opposed to using step-by-step instructions.	3.67
14	The ANSYS tutorials helped in developing speed, mastery and confidence in using FEA software	3.92
15	I would recommend including ANSYS based hands-on Tutorials related to course topics in other courses in my program.	4.50

Average scores to most questions were above 4 (Agree or Strongly Agree), reflecting a positive experience with the tutorials modules. Based on answer to question 15 there was a strong recommendation to integrate ANSYS in other courses too.

Assessment data collected included student academic performance in each module, and student survey data. Average percentage scores earned by students in the three tutorials respectively were: Solid Mechanics- 90.3, 94.4, and 87.1; Statics- 90.0, 86.3, and 91.1; Vibrations- 95.0, 92.5, and 90.3; Dynamics- 84.7, 86.3, and 88.5; Academic performance data from the dynamics course reflected that the problems used in the tutorials were fairly involved. This is one of the reasons why many educators have not integrated ANSYS in the dynamics course. These tutorials need to be refined through selection of less complicated problems that complement hand solutions.

Some of the student comments from the survey were:
"ANSYS should be taught early on and integrated across courses throughout the curriculum."
"More homework using ANSYS."
"I recommend replacing some of the physical lab experiments with ANSYS exercises."
"I wish we had more time to use ANSYS."
"ANSYS was very helpful in understanding the theory"
"The use of input files was difficult to understand."
"Very helpful to get familiarity with a tool utilized in the industry."
"Include the ANSYS tutorials as part of the lab exercises.

Sustainability

Going forward the authors expect the modules/tutorials to continue to be deployed in the four courses, and it is expected that different instructors could teach these classes in any given quarter. With the developed materials being made available to instructors as Supporting Resources, the authors will be available to help answer questions as needed. The modules are being used in the statics and vibrations courses of the current quarter. The authors are interested in refining some of the modules based on feedback from faculty and students. Data from several runs of each course would be collected before revisions are made. In addition, we are considering integrating ANSYS for courses in thermal sciences, structural analysis, and mechanical design areas. Currently the developed modules mainly involve step-by-step instructions of ANSYS commands. As a future step, the modules will be rewritten with GUI (Graphical User Interface) instructions which is the most convenient way of using ANSYS. It provides an interface between the user and ANSYS program thus enabling the user to perform an analysis with little or no knowledge of the ANSYS commands. Many students felt the need for more time to use the modules. GUI driven tutorials will certainly reduce the time needed toward this end. More concepts will be added in future modules, and refinements of the existing modules will be envisioned.

Conclusion

The tutorials achieved their objectives as stated in this paper. The integration covered all analytical courses in the mechanics area. Students learned the use of ANSYS for both time independent and dependent problems. The tutorials in the statics and solid mechanics courses trained students to analyze pin-connected frames, define local axes for beams, and determination of stresses. The integration of ANSYS greatly benefitted students in the visualization of shear and moment diagrams, stresses, and vibration modes. It is hoped that through this integration, students are well prepared to understand the theory of the finite element method going into the FEA courses as well as work on challenging projects in their finite element and capstone courses, seek internships, and future careers. Students recommended integrating ANSYS in other courses in the curriculum as well. The survey results reflect the usefulness of the modules to improve students' conceptual understanding, ability to apply theoretical knowledge to practical problems, as well as students' perceived confidence in their competencies.

Acknowledgements

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Biography

Dr. Patabhi Sitaram is Associate Professor and Chair of the Department of Engineering at Baker College in Flint, Michigan. He worked in the automotive industry, primarily at GM, for fifteen years as crashworthiness simulation and methods development engineer. He hast taught

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Dr. Anca L. Sala is Professor and Dean of Engineering and Computer Technology at Baker College of Flint. In addition to her administrative role she continues to be involved with development of new engineering curriculum, improving teaching and assessment of student learning, assessment of program outcomes and objectives, and ABET accreditation. She is a founding member of Mi-Light Michigan Photonics Cluster, and is active in the ASEE, ASME, and OSA professional societies serving in various capacities.