Mechanics of Materials, Machine Design, and Vibrations Finite Element Learning Modules for Undergraduate Courses

Marwan Abumahaimed/Joseph J. Rencis
University of Arkansas, Fayetteville/Tennessee Technological University

Abstract

This paper presents four finite element learning modules that have been developed for mechanics of materials, machine design, and vibrations that can be integrated into these undergraduate courses. A simple cantilever beam example is considered, solved by hand and also, solved using the commercial finite element code ANSYS®. ANSYS© has been employed since it is widely used to analyze engineering problems in the industry. The cantilever beam is modeled using the plane stress four node quadrilateral element. The hand solution is included to emphasize the importance of verification when solving a problem using the finite element method. The four modules developed include: a static deflection module, static stress analysis module, modal module, and the fatigue module. The static deflection module and static stress analysis module are for a mechanics of materials course. The modal module is for machine design and vibrations courses and a fatigue module is for a machine design course. The four modules can be integrated sequentially throughout the mechanics of materials, machine design, and vibrations courses. The primary goals of these learning modules are to provide undergraduate engineering students with new visually oriented insight into the concepts covered in their courses, basic knowledge in finite element theory, and the ability to apply commercial finite element software to typical engineering problems. Each learning module provides a common step-by-step guide for solving a problem and also includes solution verification. The learning modules are accessible 24/7/365 on the World Wide Web. The target audience of this paper is an instructor who would like to integrate the four modules into a mechanics of materials course, machine design course, and vibrations course. The modules can also be used in a finite element course.

1. Introduction

Assisting students in the learning of imperative analysis tools is especially important with the current techniques used in the industry. One such technique is finite element analysis. The finite element (FE) method is a numerical procedure that is widely used to analyze engineering problems in commercial engineering firms. It has become an essential and powerful analytical tool in designing products with ever-shorter development cycles.[1-3] In the past, consulting firms needed Ph.D. and M.S. engineering graduates to analyze designs with FE, but recently these firms[1,2] are asking their B.S. and A.A.S. engineering graduates to learn and apply this complex analysis technique. In many undergraduate programs, the FE method is not taught as a required element, thus, graduates often lack knowledge of the proper use of this tool.[4,5] Two principle reasons for this are:

1. Introducing new material in curriculum typically requires the removal of other material (possibly essential by the faculty and ABET.) This approach must be balanced with the recent push to reduce total credit hours of programs nationwide.

2. FE coursework typically is organized around theoretical details considered more appropriate for graduate students who may have a more rigorous mathematical education than undergraduate students.

This paper will focus on the development of FE learning modules that can be integrated into undergraduate courses in mechanics of materials, machine design, and vibrations. An engineering education literature review will now be discussed in these three areas. The pedagogical foundation for developing the modules will then be addressed, and then the four modules will be presented.

2. Literature Review of Finite Elements Integrated into Undergraduate Courses

This section will carry out a literature review the integration of FEs into mechanics of materials, machine design, and vibrations courses at the undergraduate level. Particular focus will be on the integration of plane stress and plane strain triangular and quadrilateral elements into these courses.

Finite elements has been integrated into introductory and advanced mechanics of materials courses with most efforts focusing on truss and beam elements in textbooks[6-8], conference papers[9-15], and journal papers.[4,5] The integration of plane stress/strain elements into introductory and advanced mechanics of materials has seen very little activity in textbooks[6-7], conference papers[10,13], and journal papers.[4,5] Textbook examples includes a rectangular plate subjected to a uniform load[6] and a plate with a hole.[7] Examples using the commercial finite element code ALGOR include the analysis of a beam with a hole[10] and a plate with hole and notch.[13] A Java web-based finite element program[14] was developed look at a rectangular plate with a concentrated and uniform load, and a cantilever beam subjected to an end moment so students could visualize deformation patterns. MATLAB was used for the constant strain triangle models but no examples[4] were discussed. Therefore, no modules have been developed for introductory and advanced mechanics of materials courses.

The integration of finite element fatigue analysis is non-existent in machine design courses. Machine design textbooks briefly mention how valuable finite elements are as an engineering tool for analysis and design. The machine design textbook by Norton[16] has a comprehensive coverage of examples for static stress finite element analysis, however, no fatigue analysis is considered. The examples considered by Norton use plane stress triangular and quadrilateral elements. An early effort in 1987 integrating finite elements into machine design with plane beam elements and plane torsion elements based on static loading.[17] A conference paper by Hagigat[18] explains the general concept of fatigue and also emphasizes that a major contributor to high cycle fatigue failures is vibration, however, no fatigue analysis is presented, nor is any actual FE analysis used for determining fatigue life. Ryan[19] utilized solid elements using COMOSWorks© for static deflection and static stress analysis in a machine design course. A fatigue module using ANSYS© was developed, however, it was used in a finite element course.[20]

Finite elements have been integrated into some vibration textbooks[21-23] with a focus on truss, beam, and plate elements for modal analysis. Hagigat[24] has integrated finite elements into a vibration course using ANSYS© using solids elements in carrying out the modal analysis of a plane wing, however, no plane stress triangular or quadrilateral element examples were considered. ANSYS© was used to determine the frequencies and mode shapes of a two degree of freedom system and beam.[25] Baker[26] in a later paper used experimentation to verify ANSYS© solutions in a vibrations course. One example considered is the modal analysis of a two degree of freedom system using solid elements. Another example analyzed the frequency and mode shapes of a compressor stator vane using solid elements. There have been no efforts to integrate plane stress/strain elements into a vibration course.

The motivation of this work is to provide undergraduate engineering students with exposure to FE analysis as an engineering tool to enable students to rapidly design optimized solutions to engineering problems. The FE learning modules are targeted at aiding the students' comprehension and grasp of some of the complex topics covered in typical engineering courses. The FE graphical results will allow students to engage the material being taught using their visual senses along with their mental ability which will help them visualize critical concepts, i.e., enhance their learning outcomes. The use of FE software affords the students a means to perform perturbation studies, with relative ease, to increase their understanding.

3. FE Learning Module Design

The four FE learning modules presented in this paper were designed and developed using a pedagogical basis. The modules are based on an experimental learning approach. We will first provide an overview on experimental learning and then discussed various experimental learning models. Finally, the Kolb cycle, which is used to design each FE learning module, will be discussed.

3.1 Experiential Learning Overview

In the early ages of teaching, psychologists and educators noticed the importance of experiential learning in the learning process. Aristotle stated that in the prehistoric ages the use of the 'language of knowledge' was not an indication that early humans possess that knowledge. Later in modern time, John Dewey contended that the experiential learning is the fundamental base of educational settings. Dewey first identified experiential learning as a fundamental foundation in formal educational at the beginning of the 20th century. After Dewey, many psychologists and educators believed that experiential learning is a valuable process and could be added to traditional instructional methods rather than replace them. Others believed that experiential learning is an enhancement tool of the learning process that cannot be replaced.[27]

Experiential learning is a stage or process where the student is prepared to do more than just an observer. Labs, workshops, projects, presentations, class discussions, and teamwork all fall into the experiential learning category. Experiential learning prepares students to visualize real life engineering problems and opens their minds to think more broadly and innovatively.

Recent studies and research in undergraduate engineering programs proved that experiential learning plays a key role in enhancing engineering students' analytical and problem solving skills. The ability to apply knowledge of mathematics, science, and engineering to identify, formulate, and solve engineering problems is a major point stressed in these articles.[28,29] According to these studies, most of the students' feedbacks was favored to apply what they learned in class lectures during labs and workshops. Also, educational researchers propose that good experiential learning experiences increased lifelong learning.[30]

3.2 Experiential Learning Models

Various models have been developed in recent years to improve the process of student learning. The purpose of these models is to help the individual identify their preferred learning behavior. Additionally, the models reach out to students who have different learning styles. The Honey and Mumford Learning Questionnaire as shown in Figure 1 describes four stages used in enhancing the learning skills of students.[31,32]

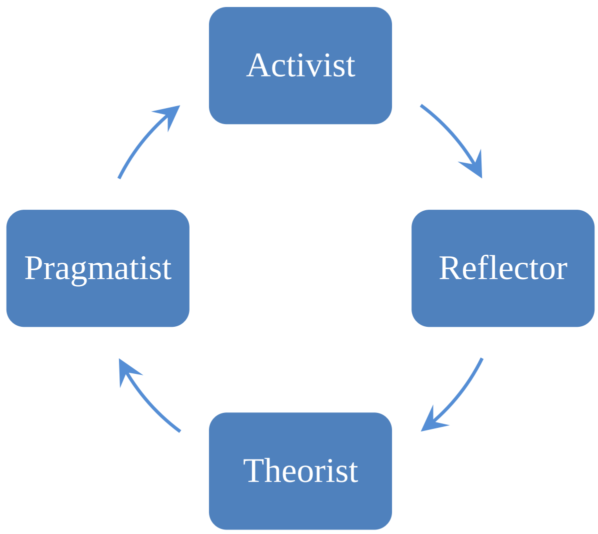


Figure 1. Honey and Mumford four stages of experiential learning.

The four learning stages of experiential learning shown in Figure 1 are defined as follows:

1. *Activist*. The student is faced with a plethora of new experiences and inevitably seeks attention, initiate actions, take on risks, and lead discussions.

2. *Reflector*. The student actively listens before acting and observes experiences from different perspectives before arriving at a conclusion.

3. *Theorist.* The student thinks logically and approach goals meticulously. The student typically concludes, thinks, and then analyzes material.

4. *Pragmatist.* The student is practical and as such solves problem and makes decisions by converting ideas and theories to practice.

The learning style questionnaire (LSQ), consists of four stages of learning where each stage has a different approach for all types of learners. Anthony Gregorc's model is based on mental imagery and these images indicate the individual learning strengths or styles.[33] The model defines two major phases and each phase has two stages as follows:

1. *Perceptual Qualities:*
   a. Concrete Stage. Information is registered directly.
   b. Abstract Stage. Enables the conception and visualization of ideas.

2. *Ordering Abilities:*
   a. Random Stage. Information is organized in clusters and in no particular order.
   b. Sequential Stage. Information is organized in a linear and cohesive manner.

Fleming's VAR/VARK model is one of the most commonly used models in the educational process. This model consists of four stages that identify individuals learning styles[34] as follows:

1. *Visual Learners*. Individuals learn information from graphs and charts more than words.

2. *Auditory Learners*. Individuals learn from spoken lessons and conservations.

3. *Read/Write Learners*. Individuals grasp concepts better from printed texts and notes.

4. *Kinesthetic Learners*. Individuals learn by applying a pragmatic approach to problems.

The VAR/VARK method measures four perceptual preferences (visual, auditory, read/write, and kinesthetic) since the same teaching technique will not be effective for all learners. Researchers have found that studying the tools and theories pertinent to each learning style will aid both teachers and learners in understanding and modifying the different learning environments.

The Kolb learning cycle model maintains that the learning process cannot be accomplished without experience. The cycle is categorized into four stages, namely concert experience, reflective observation, abstract hypothesis and conceptualization, and active experimentation. The Kolb cycle is capable of reaching students of all learning styles. Sharp and Terry[35] stressed the importance of the Kolb cycle. They maintained that in engineering teaching, the Kolb cycle has three main objectives: (1) to impact students by teaching to accommodate each learning style; (2) to stimulate students to use the four learning styles and enhance learning, and; (3) to facilitate completion of the cycle so students can think and learn independently. Unlike other models, the Kolb cycle allows learners to experience each of the learning styles at some point.

3.3 Kolb Learning Cycle

The Kolb learning cycle shown in Figure 2 is an important method used to enhance the applications of learning styles. Students have a variety of learning preferences, thus the Kolb cycle helps can be used to address these preferences from different perspectives. The cycle consists of four major learning types which are referred to as "teaching through the cycle". Also, the cycle identifies four quadrants and each one indicates a preferred way of learning. The Kolb cycle is an assessment technique used to recognize the different learning styles of students.

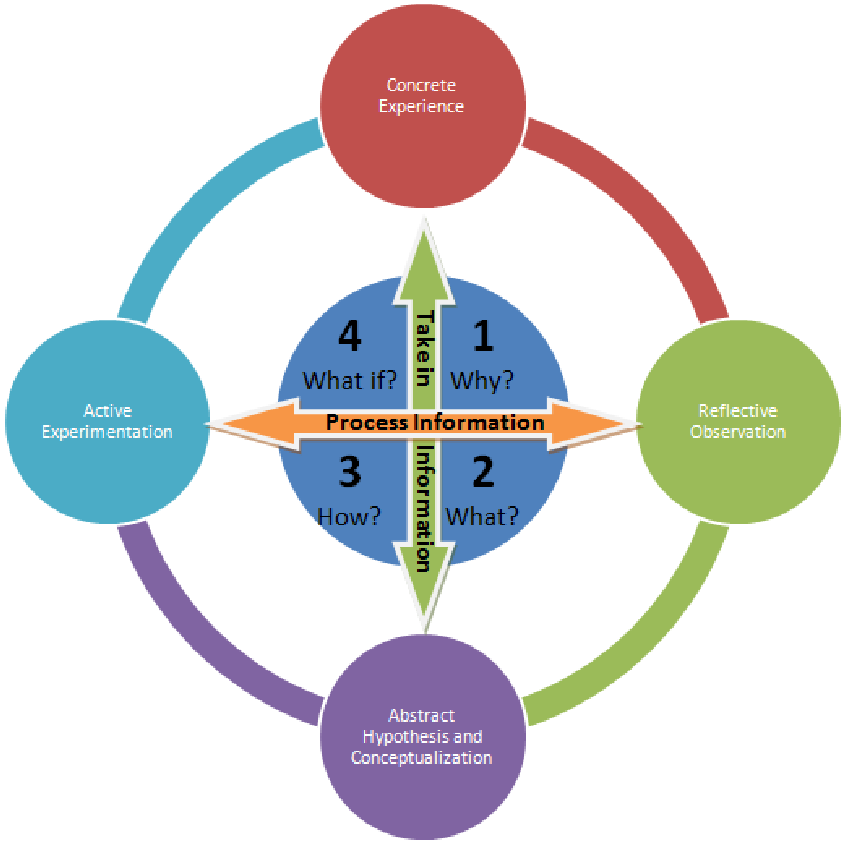


Figure 2. Kolb cycle of learning progression.

The cycle is divided into four quarters using a horizontal and vertical axis as illustrated in Figure 2. The vertical axis describes the step where the individual perceives information as "take in information". *Concrete experience* and *abstract hypothesis and conceptualization* are both classified as perception stages. In these stages, the individual perceives the new information either through their senses or through ideas and concepts. Conversely, the horizontal axis describes processing steps for the new information that the individual gained from the vertical axis. The stages of *active experimentation* and *reflective observation* represent the processing stages. Processing new information can be done by observing or by getting actively involved in experiments. Alternative definitions for these stages are doing, thinking, modeling, and checking.[36,37]

In concrete experience, the learner is exposed to new information. Learners are overwhelmed by feeling and valuing in this stage. It relies on feeling over logic, and later in the course the individual can be more open minded and adaptable to change. Reflective observation in the second stage of the cycle, learners prefer to make judgments from their point of view before taking any actions while analyzing problem from different perspectives. Abstract hypothesis and conceptualization contradicts the earlier stage, as logic is emphasized more. The learner tends to organize their thoughts to theories, concepts, and ideas to solve the problem. Active experimentation is the last stage of the cycle in which the learner tends to work and get things done in a practical manner.[38,39]

Each quadrant of the cycle is characterized by a question that is essential in grasping the concept of teaching through the cycle. These questions are used as the basis for the learning cycle. Through personal experiences, questions such as "why", "what", "how", and "what if?" are developed as shown in Figure 2. The purpose of the first quadrant is to provide a clear image of the overall subject and to discuss future plans by providing a better understanding of the materials to aid in establishing goals. Additionally, the questions provide answers for real life applications.[39] In the second quadrant, the question asked was "what". Students are presented with organized information pertinent to the materials that were introduced in the first quadrant. Also, this quadrant creates an opportunity for thinking and reflection which process information. The third quadrant represents "how". In this stage, students are given the chance to implement what they learned in the first two quadrants to create a learning environment that facilitates practical experience of the materials learned. The last quadrant addresses "what if". This allows students the opportunity to revise concepts and discover solutions.

3.4 Application of Kolb Learning Cycle to FE Learning Modules

There are numerous learning activities that incorporate the Kolb cycle. For the past three years, the Kolb learning cycle has been utilized as an instructional tool for introductory undergraduate courses. In *Teaching Finite Element using the Kolb Learning Cycle*[40], Brown applied the cycle in the finite element course and related each activity in the class to a part of the cycle. Brown stated that "the Kolb Learning Cycle has proved to be an excellent technique to improve student retention of this complex numerical procedure used to analyze engineering problems". In the early weeks of the course, Brown introduced students to the FE method in addition to the fundamental mathematics of FE. This part of the course relates to the *abstract hypothesis and conceptualization* of the cycle. At this stage of the cycle, students begin to develop ideas on the real life applications of the theory.[40] Additional activities that apply to this stage of the cycle are modeling, analysis, and theory.[32,41] Later in the course, Brown narrated the active experimentation portion of the cycle to homework assignments, course projects, and the FE learning modules. Other types of activities associated with this part of the cycle are laboratory experiments, product teardowns, simulations, projects, field work, and testing using engineering tools and methods.[32,41]

Later in the course, the students are asked to make changes in the physical geometries of problems and analyze changes in results for better understanding of concepts. Subsequently, this puts students in the concrete experience phase of the cycle.[40] Additional activities that are appropriate for this stage are direct experience, in-class experience, and recall of experience.[32,41] After completing the fatigue FE learning module, students were asked to do a comparison between FE method results and analytical results. This comparison allowed students to be categorized in the reflective observation portion of the cycle. More activities that can be included in this stage are class discussions, brainstorming, keeping a journal or notebook collection, and questions during reading.[32,41] Figure 3 shows the activities that were used in each stage of the Kolb cycle that was integrated into the four FE learning modules presented in this paper.

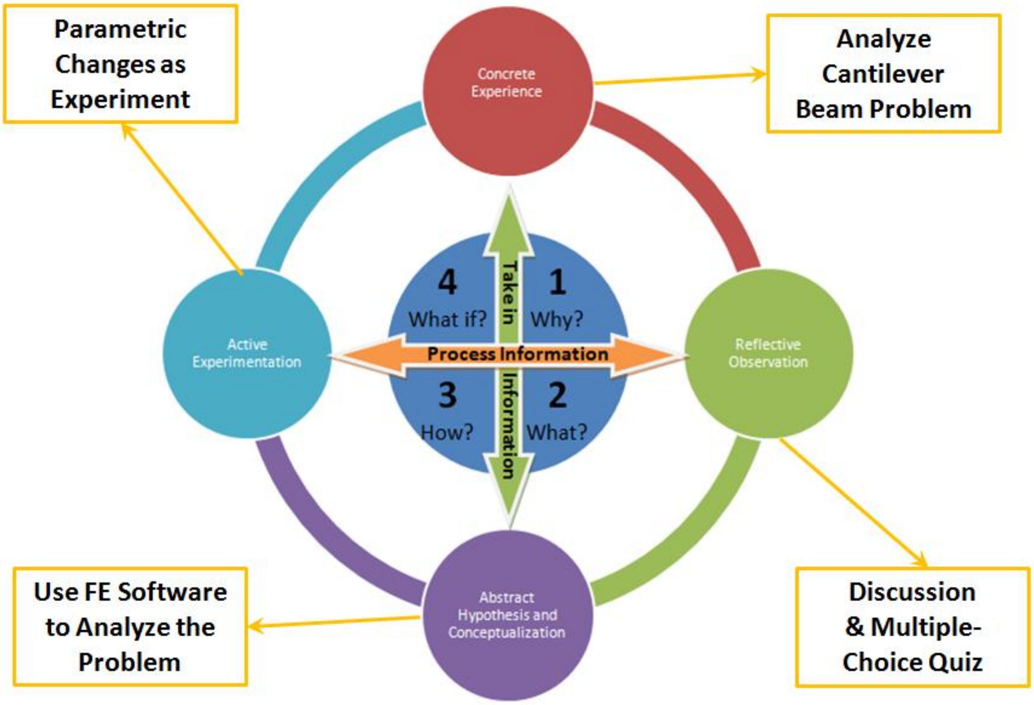


Figure 3. Activities used in each stage of the Kolb cycle for the FE learning modules.

4. FE Learning Modules

4.1 Module Development and Layout

A starting point for our educational objectives is the development of the FE learning modules. Each learning module is pedagogically rooted in active learning based on Kolb's learning cycle discussed in Sections 3.3 and 3.4. By completing the cycle fully, the student will have a stronger grasp on the difficult engineering and FE material. The Kolb Learning Cycle improves student retention of the complex numerical procedures involved in FE analysis. As an accompaniment to traditional lectures, the learning modules help guide students through active experimentation, concrete experiences, and reflective observation.

The modules are designed for those students who have little to no experience using the FE analysis. Therefore, the basic nature of the problems makes it more possible that the students will grasp the correlations between the physical solution and the computational model. Each module was developed in Microsoft® Office PowerPoint® and are available in a PowerPoint® ppt file and Adobe® Acrobat® pdf file. Each FE learning module was developed with a common template as follows:

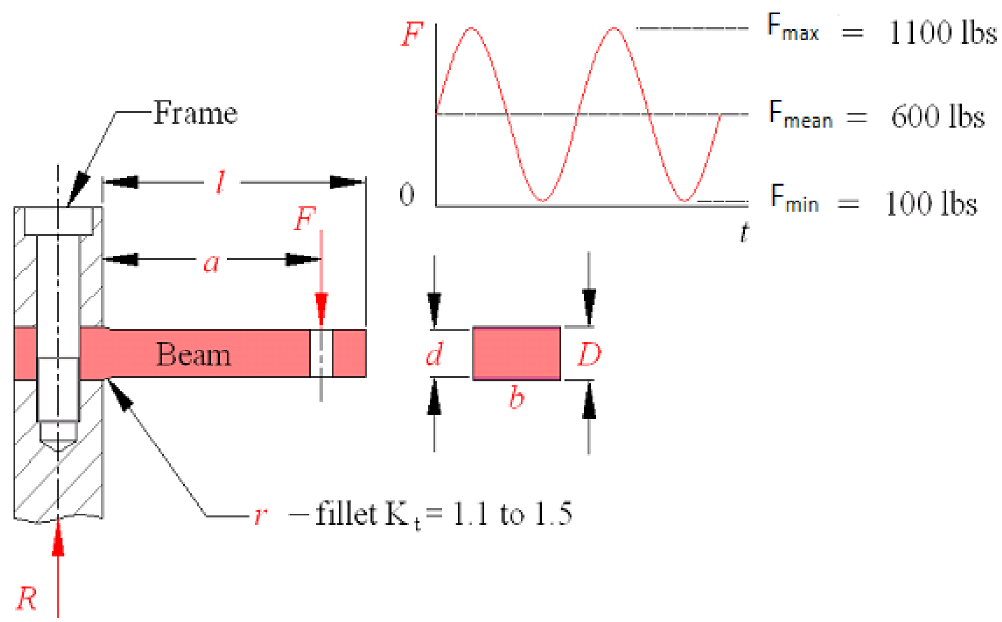
- Module title, author, author contact information, expected completion time, and references.
- Table of contents.
- Project educational objectives based upon ABET Criteria 3 for Engineering Programs.
- Problem description.
- Problem analysis objectives.
- General steps and specific step-by-step analysis.

- Viewing the results of the FE analysis.
- Comparison of FE analysis to another technique.
- Summary and discussion.
- Background information on finite element theory.

The four FE learning modules are based on the commercial finite element code ANSYS® Academic Teaching Introductory Release 12.1.

4.2 Problem Used in All Modules

The problem used in all four FE learning modules is a feed-roll assembly is fixed at the ends by cantilever brackets as defined in the machine design textbook by Norton as shown Figure 4.[16] A fluctuated load with a minimum value of 200 lb to a maximum value of 2200 lb is applied to the end of the cantilever beam. The design requirement is that the maximum vertical deflection doesn't exceed 0.02 in. The operating environment is at a maximum temperature of 120° F. The maximum length of the cantilever beam is 6 in, and only ten brackets are required. The cantilever beam properties, i.e., geometric, material, and applied fluctuating loads, are shown in Figure 4. The brackets are clamped between rigid plates. The load is applied in a small hole near the tip of the beam. The cantilever brackets will allow 10^9 cycles with no failure.



Geometric Properties	Material Properties	Applied Loads
l = 6.0 in	SAE 1040 Normalized Carbon Steel	F_{max} = 1100 lbs
a = 5.0 in	E =30 x 10^6 psi	F_{mean} = 600 lbs
r = 0.5 in	ρ = 0.2834 lb/in^3	F_{min} = 500 lbs
d = 1.0 in	υ = 0.28 (Poisson's ratio)	
b = 2.0 in	S_{ut} = 80 kpsi	
D = 1.125 in	S_y = 60 kpsi	

Figure 4. Cantilever beam subjected to a fluctuating load.[16]

4.3 Overview of Modules

The cantilever beam discussed in the previous section and shown in Figure 4 has been divided into the following four FE learning modules:

1. *Static Deflection Analysis Module.* The static deflection analysis module can be introduced into a mechanics of materials and a machine design courses. The background necessary is beam deflection theory, commonly introduced in a mechanics of materials course and reviewed in a machine design course.

2. *Static Stress Analysis Module.* The static stress analysis module can be introduced into a mechanics of materials course and a machine design course. The background necessary is flexural normal stress, flexural shear stress, stress concentration factors, and static failure theory of von-Mises for ductile materials. These topics are introduced in a mechanics of materials course and machine design course, with the exception of static failure theories that is usually introduced in a machine design course. If the static failure theory is not covered in mechanics of materials, then this topic can be skipped in this module.

3. *Fatigue Analysis Module.* The fatigue analysis module can be introduced into a machine design course. The background necessary is the same as the static stress analysis module with the addition of high cycle fatigue. High cycle fatigue is found in a machine design course.

4. *Modal Analysis Module.* The modal analysis module can be introduced into a machine design course and vibrations course. Background knowledge necessary includes frequencies and mode shapes for continuous axial bars and beams. Students are introduced to these topics in a vibrations course and may have a brief overview in a machine design course. If modal analysis is not covered in the machine design course then this module can be eliminated.

The finite element model used for the four modules above will first be discussed then each module will be discussed in-depth.

4.4 FE Model Used in All Modules

The cantilever beam was modeled with the commercial FE code ANSYS® Academic Teaching Introductory Release 12.1. The plane stress, PLANE42, four node quadrilateral element was used to model the cantilever beam. The geometry and material properties and loading are shown in Figure 5. The same FE mesh was used in all four modules, i.e., for the displacement, stress, fatigue, and modal analyses. The mesh size was determined based on a convergence study of stresses since a finer mesh is required to obtain accurate stresses compared to deflections and frequencies. The FE mesh consists of 1,329 nodes and 1,224 elements as shown in Figure 5. Each node has two degrees of freedom (DOF) and the mesh has 2,685 DOFs. The bracket mounts are located at the vertical left-hand side of the beam in Figure 5 and these DOFs were fixed in the horizontal and vertical directions. The construction of a finite element mesh is carried out in the static deflection analysis module.

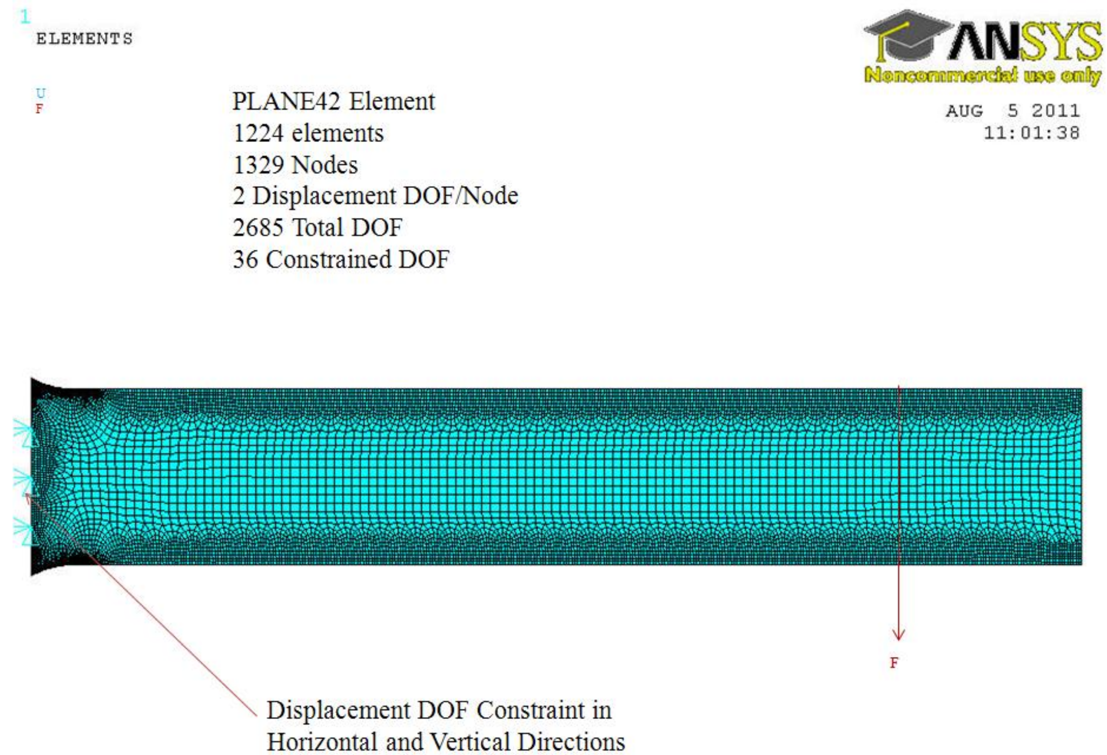


Figure 5. Plane stress FE mesh of cantilever beam.

4.5 Static Deflection Analysis Module

This module can be integrated into a mechanics of materials course and/or machine design course after the students are exposed to beam deflections. A maximum static load F_{max} of 1100 lbs is applied downward at the right end of the cantilever beam shown in Figure 1. The vertical deflection at the concentrated load based on a hand calculation is 0.0119 in. for a long uniform beam where transverse shear deflection is neglected. By considering the transverse shear deflection based on short beam theory and applying Castigliano's second theorem, the maximum vertical deflection increases to 0.01226 in. The maximum deflection determined by ANSYS® is 0.01207 in. The relative percentage error between the hand solution and FEM solution is 1.5%. Castigliano's second theorem is usually not covered in a mechanics of materials course and does not have to be considered. A mechanics of materials or machine design course that does not include Castigliano's second theorem for determining beam deflections can use Euler-Bernoulli beam theory.

4.6 Static Stress Analysis Module

As previously stated, this module can be integrated into a mechanics of materials course or machine design course after the students have been exposed to flexural stress, flexural shear stress, and beam stress concentrations. The first static analysis is the mean load of 600 lbs applied one inch from the right-hand side of the beam in Figure 4. The second static analysis is the alternating load of 500 lbs applied on the right-hand side as well. Both load cases are carried out for the fatigue module.

For the mean load, the maximum hand analysis bending stress is determined to be at the top and bottom fiber of the cantilever beam and is 9,000 psi at the wall. The maximum bending stress occurs at the left end of the radii fillet. After applying the stress concentration factor, the actual bending stress at the fillet is 10,454 psi. Furthermore, the FEM solution determined by ANSYS® is 10,264 psi. FEM von-Mises stress includes the shear stress in the calculation, which is the reason the value is lower than the hand calculation. Similarly, the alternative load of 500 lbs is applied at the end of the cantilever beam. The bending stress at the top and bottom of the cantilever beam is 7,500 psi. Knowing the stress concentration factor, the actual bending stress at the fillet is 8,711 psi at the top and bottom of the fillet. The FEM solution found by ANSYS® is 8,554 psi.

4.7 Fatigue Analysis Module

This module can be integrated into a machine design course. The background required is static failure theories for ductile materials and fatigue. The desired design should withstand 10^6 loading cycles. The ultimate tensile strength for the beam is S_{ut} = 80 kpsi. The endurance limit correction is 21.833 kpsi. The stresses' values are below the limit that is required for 10^9 loading cycles. The correction endurance limit is required to find the safety factors. The safety factors for the hand analysis are found from the modified-Goodman diagram.[16] Four methods are used in Norton to determine the lowest safety factor. The first safety factor (N_{f1}) is found by assuming a constant alternating stress. The second safety factor (N_{f2}) is determined by assuming constant mean stress. The third safety factor (N_{f3}) assumes a proportional amount of both mean and alternating stress values. The fourth safety factor (N_{f4}) picks random values of alternating and mean values. The fourth value found to be the lowest value of 1.7. For the FEM the von-Mises stress that found using ANSYS® are used in the fatigue analysis. These stresses are applied on the four methods mentioned in the hand analysis to determine the safety factors. The minimum safety factor determined by ANSYS is 1.8. The difference in the two solutions is 5.88%.

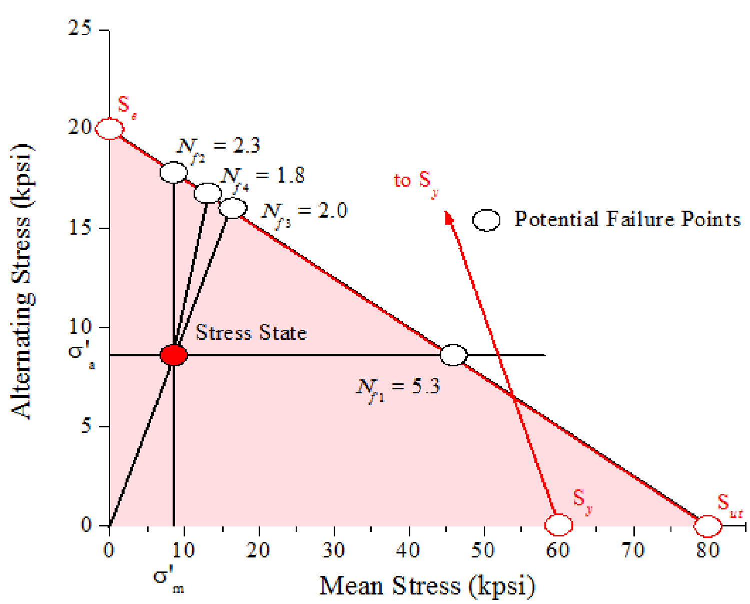


Figure 6. Safety factors from modified-Goodman diagram.

4.8 Modal Analysis Module

This module can be integrated into a vibrations course and perhaps a machine design course. The background required is frequencies and mode shapes for continuous axial bars and beams. This background is found in a vibration course and perhaps only introduced in a machine design course. Modal analysis is a good assessment tool in the design process. It can be used to identify the weakness in the design components and where to increase the component stiffness. Fatigue failure often occurs when the structure experiences large vibrational amplitudes. Fatigue failure is a direct consequence when the loading reaches the resonance condition.

The hand solution to determine the frequencies and mode shapes for a continuous cantilever beam was found in vibrations and structural dynamics textbooks.[42,43] For short beams, the effect of the rotary motion and shearing forces must be taken into account. ANSYS® is used to determine the frequencies and mode shapes of the beam. Table 1 illustrates both hand analysis and FEM solution. Table 2 compares the hand and FEM solutions for the mass and mass center.

Table 1. Natural frequencies of the cantilever beam for hand and ANSYS® analyses.

Mode	**Mode Type**	**Frequency (Hz)**		**% Difference of Solutions**
		Short Beam Hand Analysis	**ANSYS® Analysis (PLANE42 Element)**	
1	Bending	898.92	898	0.10%
2	Bending	5008	5051	0.86 %
3	Axial	8426	8457	0.36 %
4	Bending	12270	12442	1.40%
5	Bending	20923	21234	1.49%

Table 2. Total mass and mass center locations for hand and ANSYS® analyses.

Analysis Method	**Total Mass lbm.**	**% Difference in Total Mass**	**Mass Center Location (X, Y) in.**	**% Difference in Mass Center Locations**	
				X	**Y**
Hand	3.4094	0.08%	(2.9931, 0.5)	0.07%	0.0%
ANSYS®	3.4065		(2.9952, 0.5)		

5. Conclusion

This paper presents four FE learning modules that can be integrated into undergraduate mechanics of materials, machine design, and vibrations courses. Based on previous work by the co-author[15,44], when the FE learning modules are properly designed and implemented using "student-friendly" commercial FE software there is a significant improvement in a student's knowledge of undergraduate courses. The FE learning modules must be easily used by both instructors and students to be successfully implemented in a time-sensitive undergraduate engineering curriculum. The choice of commercial FE software is key to a student's capability of understanding and running the FE software within the reasonable time allocated to homework problems during a time-sensitive undergraduate engineering course.

6. Future Work

At the core of learning module development is the ability to assess the impact on learning. The co-author and colleagues have developed an assessment strategy targeted for the FE learning modules, which generalizes across active learning methods.[15,44] This technique of assessing active education has the potential to advance engineering education. By measuring students' abilities across learning styles and personality types, the equity of the learning modules may be assessed, as well as their impact in an engineering content area. The four modules presented in this paper will be assessed regarding student learning and the assessment results will be used to improve the modules.

Bibliography

1. Thilmany, J., "FEA in a Snap," *Mechanical Engineering*, pp. 60-62, July 2001.
2. Mahoney, D.P., "Go with the Flow," *Computer Graphics World*, pp. 30-36, March 1999.
3. Thilmany, J., "Analyzing up Front," *Mechanical Engineering*, Vol. 122, No. 10, pp. 88-91, October 2000.
4. Belytschko, T., Bayliss, A., Brinson, C., Carr, S., Kath, W., Krishnaswarmy, S., Moran, B., and Peshkin, M., "Mechanics in the Engineering First Curriculum at Northwestern University," *International Journal for Engineering Education*, Vol. 13, No. 6, pp. 457-472, 1998.
5. Brinson, L.C., Belytschko, T., Moran, B., and Black, T., "Design and Computational Methods in Basic Mechanics Courses," *Journal of Engineering Education*, Vol. 86, No. 2, pp. 159-166, 1997.
6. Hearn, E.J. (1997). *Mechanics of Materials 2: An Introduction to the Mechanics of Elastic and Plastic Deformation of Solids and Structural Materials,* Chapter 9 Introduction to the Finite Element Method, Third Edition, Butterworth/Heinemann, Woburn, MA, 1997.
7. Solecki, R. and Conant, R.J., *Advanced Mechanics of Materials*, Chapter 7 Numerical Methods II: Finite Elements, Oxford University Press, New York, NY, 2003.
8. Armenàkas, A.E., *Advanced Mechanics of Materials and Applied Elasticity*, Chapter 15 The Finite Element Method, CRC Press, Taylor & Francis Group, Boca Raton, FL, 2006.
9. Dally, J.W., et al., "Experiences in Introducing Finite Elements in Mechanics of Materials," *Proceedings of the 1994 American Society of Engineering Education (ASEE) Annual Conference & Exposition*, Edmonton, Alberta, Vol. 1, pp. 385-389, June 26-29, 1994.
10. Boronkay, T.G., and Dave, J., "Introduction of Finite Element Methods in the Lower Division Mechanical Engineering Technology Curriculum," *Proceedings of the 1997 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Milwaukee, WI, June 15-18, 1997.

11. Baker, J.R., Capece, V.R., and Lee, R.J. “Integration of Finite Element Software in Undergraduate Engineering Courses,” *Proceedings of the 2001 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Albuquerque, NM, June 24-27, 2001.
12. Coyle, M.F. and Keel, C.G., “Teaching Finite Element Analysis to Second Year Students,” *Proceedings of the 2001 American Society of Engineering Education (ASEE) Annual Conference & Exposition*, Albuquerque, NM, June 24-27, 2001.
13. Logue, L.J., and Hall, K.A., “Introducing Finite Element Analysis in an MET Strength of Materials Course,” *Proceedings of the 2001 American Society of Engineering Education (ASEE) Annual Conference & Exposition*, Albuquerque, NM, June 24-27, 2001.
14. Steif, P.S., and Gallagher, E., “Transitioning Students to Finite Element Analysis and Improving Learning in Basic Courses,” *34th ASEE/IEEE Frontiers in Engineering Education*, Savannah, GA, October 20-23, 2004.
15. Brown, A., Wood, K., Kaufman, K., Jensen, D., Rencis, J.J. and White, C., "A Novel Assessment Methodology for Active Learning Modules to Equitably Enhance Engineering Education," *Proceedings of the 2009 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Austin, TX, June 14-17, 2009.
16. Norton, R.L., *Machine Design: An Integrated Approach*, Fourth Edition, Chapter 8 Finite Element Analysis, Pearson Prentice Hall, Upper Saddle River, NJ, 2011.
17. Gessel, G.R., Rieder, W.G., and Tennyson, S.A., “Integration of Microcomputer Based Finite Element Analysis into the Undergraduate Mechanical Engineering Curriculum,” *Computers in Education Journal*, Vol. 7, No. 2, pp. 7-10, 1987.
18. Hagigat, C.K., “Using Commercially Available Finite Element Software for Fatigue Analysis” *Proceedings of the 2005 American Society of Engineering Education (ASEE) Annual Conference and Exposition*, Portland, OR, June 20-23, 2005.
19. Ryan, R.G., “Using a Finite Element Stress Analysis Program to Enhance Learning in a Machine Design Course,” *Proceedings of the 2004 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Salt Lake City, UT, June 20-23, 2004.
20. Coffman, J., Terdalkar, S.S., Rencis, J.J. and Brown, A.O., "Introducing Fatigue Analysis into a Finite Element Course," *Proceedings of the 43rd American Society for Engineering Education (ASEE) Midwest Section Meeting*, The University of Tulsa, Tulsa, OK, September 17-19, 2008.
21. Weaver, W., Timoshenko, S.P., and Young, D.H., *Vibration Problems in Engineering*, Chapter 6 Finite-Element Method for Discretized Continua, John Wiley & Sons, Inc., New York, NY, 1990.
22. Fertis, D.G., *Mechanical and Structural Vibration*, Chapter 6 Finite Element Method, John Wiley & Sons, Inc., New York, NY, 1995.
23. Fahy, F., and Gardonio, P., *Sound and Structural Vibration: Radiation, Transmission and Response*, Second Edition Chapter 8 Introduction to Numerically Based Analyses of Fluid-Structure Interaction, Academic Press, Burlington, MA, 2007.
24. Hagigat, C.K., “Using Finite Element Software for Enhancing a Vibration Analysis Curriculum,” *Proceedings of the 2004 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Salt Lake City, UT, June 20-23, 2004.
25. Baker, J.R., Capece, V.R., and Lee, R.J., “Integration of Finite Element Software in Undergraduate Engineering Courses,” *Computers in Education Journal*, Vol. 12, No. 2, pp. 10-19, 2002.
26. Baker, J.R., “Effective Use of Experimentation and Finite Element Analysis in a Vibration Course,” *Proceedings of the 2005 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Portland, OR, June 20-23, 2005.
27. Dewey, J., “Experience and Education: The 60th Anniversary Edition,” *Kappa Delta Pi International Honor Society in Education*, West Lafayette, IN, 1998.
28. Esterman, M., “Development of Integrated Project Tacks for a College-Wide Multidisciplinary Engineering Design Program at RIT,” *Proceedings of the 2007 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Honolulu, HI, June 24-27, 2007.
29. Bailey, M., and DeBartolo, E., “Using the Experiential Learning Model to Transform a Multidisciplinary Capstone Design Course,” *Proceedings of the 2007 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Honolulu, HI, June 24-27, 2007.
30. Bailey, M., and DeBartolo, E., “Using The Experiential Learning Model and Course Assessment to Transform a Multidisciplinary Senior Design Course Sequence,” Mechanical Engineering Division, *Proceedings of the 2007 American Society of Engineering Education (ASEE) Annual Conference & Exposition*, Honolulu, HI, June 24-27, 2007.

31. Durrant, S.O., Harp, J.N., and Terry, R.E., “Use of the Kolb Learning Cycle and the 4MAT System in Engineering Education,” *Journal of Engineering Education*, Vol. 82, No. 2, pp. 93-101, 1997.
32. Wyrick, D.A., and Hilsen, L., “Using Kolb’s Cycle to Round Out Learning,” *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, Montréal, Quebec, Canada, June 16-19, 2002.
33. Mills, D.W., *Applying What We Know: Student Learning Styles*, 2002, Retrieved July 10, 2011, from http://www.csrnet.org.
34. Hawk, T.F., and Shah, A.J., “Using Learning Style Instruments to Enhance Student Learning,” *Decision Sciences Journal of Innovative Education*, Vol. 5, Issue 1, pp. 1-19, January, 2007.
35. Sharp, J.N., and Terry, R.E., “Combining Kolb Learning Styles and Writing to Learn in Engineering Classes,” *Journal of Engineering Education*, Vol. 86, No. 2, pp. 93-101, April, 1997.
36. Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development*, Prentice Hall, Englewood Cliffs, NJ, 1984.
37. Abdulwahed, M., and Nagy, Z.K., “Applying Kolb’s Experiential Learning Cycle for Laboratory Education,” *Journal of Engineering Education*, Vol. 98, pp. 283-293, July, 2009.
38. Stice, J.E., “The Kolb Learning-Style Inventory,” *Proceedings of the ASEE/IEEE Frontiers in Education Conference,* Arlington, TX, October 12-15, 1986, pp. 52-56.
39. Kolb, A.Y., and Kolb, D.A., “Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education,” *Academy of Management Learning & Education*, Vol. 4, No. 2, pp. 193-212, June, 2005.
40. Brown, A.O., “Teaching Finite Elements using he Kolb Learning Cycle,” *Proceedings of the American Society for Engineering Education Pacific Southwest Section Conference*, University of the Pacific, Stockton, CA, April 1-2, 2004.
41. Svinicki, M.D., and Dixon, N.M., “The Kolb Model Modified for Classroom Activities,” *College Teaching*, Vol. 35, No. 4, pp. 141-146, 1987.
42. Graig, R.R., and Kurdila, A.J., *Fundamentals Of Structural Dynamics*, Second Edition, John Wiley & Sons, Inc., Hoboken, NJ, 2006.
43. Paz, M., *Structural Dynamics: Theory and Computation*, Fourth Edition, Chapman & Hall, Norwell, MA, 1997.
44. Brown, A., Rencis, J.J., Jensen, D., Chen, C-C., Ibrahim, E., Labay, V. and Schimpf, P., "Finite Element Learning Modules for Undergraduate Engineering Topics using Commercial Software," Mechanical Engineering Division, *Proceedings of the 2008 American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Pittsburg, PA, June 22-25, 2008.

Biographical Information

MARWAN ABUMAHAIMED
Marwan Abumahaimed is a M.S. student in the Department of Mechanical Engineering at the University of Arkansas, Fayetteville. He received a B.S. in Mechanical Engineering from University of Arkansas, in 2009. V-mail: 832-278-9838; E-mail: mabumaha@uark.edu.

JOSEPH J. RENCIS
Joseph J. Rencis is Dean of Engineering, Clay N. Hixson Chair for Engineering Leadership, and Professor of Mechanical Engineering at Tennessee Technological University. He was a Professor in the Department of Mechanical Engineering at the University of Arkansas from 2004 to 2011, Department Head from 2004 to 2010, and the inaugural endowed Twenty-first Century Leadership Chair in Mechanical Engineering from 2007 to 2010. From 1985 to 2004 he was Professor and Director of Engineering Mechanics in the Mechanical Engineering Department at Worcester Polytechnic Institute. His research focuses on boundary element methods, finite element methods, atomistic modeling, and engineering education. He currently serves on the editorial boards of Engineering Analysis with Boundary Elements and the Journal of Online Engineering Education. He is an associate editor of the international Series on Advances in Boundary Elements. Currently he serves as Chair of the ASEE Midwest Section, Chair of ASEE Professional Interest Council (PIC) III, and is an ABET program evaluator. He also serves on the Academic Advisory Board of the College of Engineering at United Arab Emirates University. He received the 2002 ASEE New England Section Teacher of Year Award, 2004 ASEE New England Section Outstanding Leader Award, 2006 ASEE Mechanics Division James L. Meriam Service Award, and the 2010 ASEE Midwest

Section Outstanding Service Award. Dr. Rencis is a fellow of ASEE and ASME. He received a B.S. from Milwaukee School of Engineering in 1980, a M.S. from Northwestern University in 1982, and a Ph.D. from Case Western Reserve University in 1985. V-mail: 931-372-3172; E-mail: jjrencis@tntech.edu.