Finite Element Learning Module for Improving Knowledge of Fatigue using Commercial Software

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Abstract

Finite element (FE) active learning modules have been developed for various undergraduate engineering courses. These FE learning modules are used to introduce basic and complex engineering problems to enhance student learning of the theory and fundamentals of the finite element method. A review of educational literature reveals that fatigue and finite elements are not addressed together. The fatigue FE learning modules were designed based on the Kolb Cycle of learning experience progression. The educational value of the fatigue FE learning module is assessed by short quizzes administered before and after students use the module. The results of the pre-quiz and post-quiz are used to identify any Felder-Soloman learning style and/or Myers-Briggs personality type bias in the module. Statistical study of these assessment results will allow the content and presentation of the module to be improved to better suit engineering students. Post-survey will be used as part of the module assessment process to include students' opinion.

Introduction

Fatigue is a material based phenomenon that causes failure in machine parts at stress values much lowers than static yield strength of the material. Fatigue failure is due to repeated or cyclic loading and unloading or fluctuating reversal in loading after a large number of cycles. Fatigue failures are estimated to occur in 80-90% of all machine component failures. Fatigue is a major topic that is addressed in undergraduate and graduate machine design courses and textbooks. A machine design course is required in most undergraduate mechanical engineering programs. In academia or industry fatigue problems have traditionally been solved by hand or an in-house computer program specialized for a particular type of fatigue application.

The finite element method (FEM) is a computational tool that has been used extensively the past thirty years in industry and is now a standard engineering tool for both analysis and design. When FEM first appeared in the 1960's it was introduced into the engineering curriculum at the graduate level. As the method and computer technology matured, FEM was introduced at the undergraduate level in engineering and engineering technology programs, even in some two-year engineering technology programs. Today, FEM is primarily offered as an elective undergraduate course in mechanical, civil, and aeronautical engineering programs.

Fatigue analysis that in the past was carried out by hand and/or in-house computer programs is now done using commercial FEM software. Fatigue design modules have recently been integrated into commercial FEM codes that include ABAQUS®, ALGOR®, ANSYS®, COMSOL®, COSMOSWorks ®, and Pro/ENGINEER®. The usage of FEM in fatigue analysis does have some limitations. An absence of actual loading data throughout components life limits the accuracy of life prediction results. A second limitation is the random variance in material performance even in materials of the same type.

Finite element (FE) learning modules have been developed for various undergraduate engineering courses. Modules have been developed for the following topics: curved beam, bolt and plate stiffness, lateral frequency of a cantilever beam, lateral vibration of a tapered cantilever beam, steady state heat transfer in a bar, transient heat transfer in a l-bar, cylindrical drag, friction flow in a pipe, probe feed patch antenna, specific absorption rate, transmission parameters of an infinitely long co-axial cable, and human head.[1,2] These FE learning modules are used to introduce basic and complex engineering problems to enhance student learning of the theory and fundamentals of the finite element method (FEM). Students are also introduced to best practices in modeling and problem solving through the use of commercial FE software. In the development of an earlier ANSYS® based fatigue FE learning module[3], a review of educational literature revealed that fatigue and finite elements are not addressed together. The intended usage of this fatigue FE learning module is to integrate fatigue design theory into a FEM course or fatigue FE in a machine design course. The fatigue FE learning module will serve as an online resource for students and a tool for effectively presenting the lecture material for instructors.

The FE learning module considered in this paper is the fatigue loading of a stepped shaft. COSMOSWorks®[4] was selected as the commercial FE software. The design of the fatigue FE learning module is based on student learning experience progressions using the Kolb Cycle. The different experiences found in the module will require students to think in ways not typically found in a traditional classroom lecture. Student assessment data will be used to evaluate and make improvements to the FE learning module. The students' opinion of the FE learning module will also be evaluated using a post survey upon completion of the module. The educational value of the FE learning module will be monitored using pre- and post-quizzes. Additional assessment tools will be used to identify any bias in the FE learning module towards any Felder-Soloman learning style and/or Myers-Briggs personality type. Statistical study of these assessment results will allow the content and presentation of the module to be continuously changed to better suit engineering students.

Learning Experience Progression

History and Overview

Experiential learning has been valued as early as the teachings of Confucius or Aristotle. At the start of the 20th century, John Dewey[5] first identified experiential education as a fundamental foundation in formal educational. During the decades following John Dewey, many psychologists and educators began to believe that experiential education was valuable and could be incorporated in addition to traditional instruction methods rather than replace them.[5] Building upon earlier works by John Dewey, Jean Piaget, William James, and Kurt Lewin, David A. Kolb determined that learning is an experienced based process.[6] From this work, Kolb[6] determined that "learning is the process whereby knowledge is created through the transformation of experience." The theory presents a cyclical model of learning that consists of four stages.

In developing the fatigue FE learning modules the Kolb Cycle has been selected for its ability to reach students of all learning styles. The importance of the Kolb Cycle as a guide for engineering education is stated in a journal paper, "The use of that model (Kolb Cycle) in the engineering teaching assists to three main objectives: to reach all the students through the teaching to each learning style; to stimulate the students to use all the four learning types; and, to teach the students to complete the cycle for themselves so that they think and learn in an independent way."[7] Learning styles will be discussed later in this paper.

Kolb Cycle

The Kolb Cycle has been proven to be an excellent technique to improve student retention of complex numerical methods used to analyze engineering problems.[6-9] The Kolb Cycle describes a cycle through which learning is achieved by various experiences. The Kolb Cycle, shown in Figure 1, displays four distinct stages used in the development of knowledge within an individual through the experiences found in a stage.

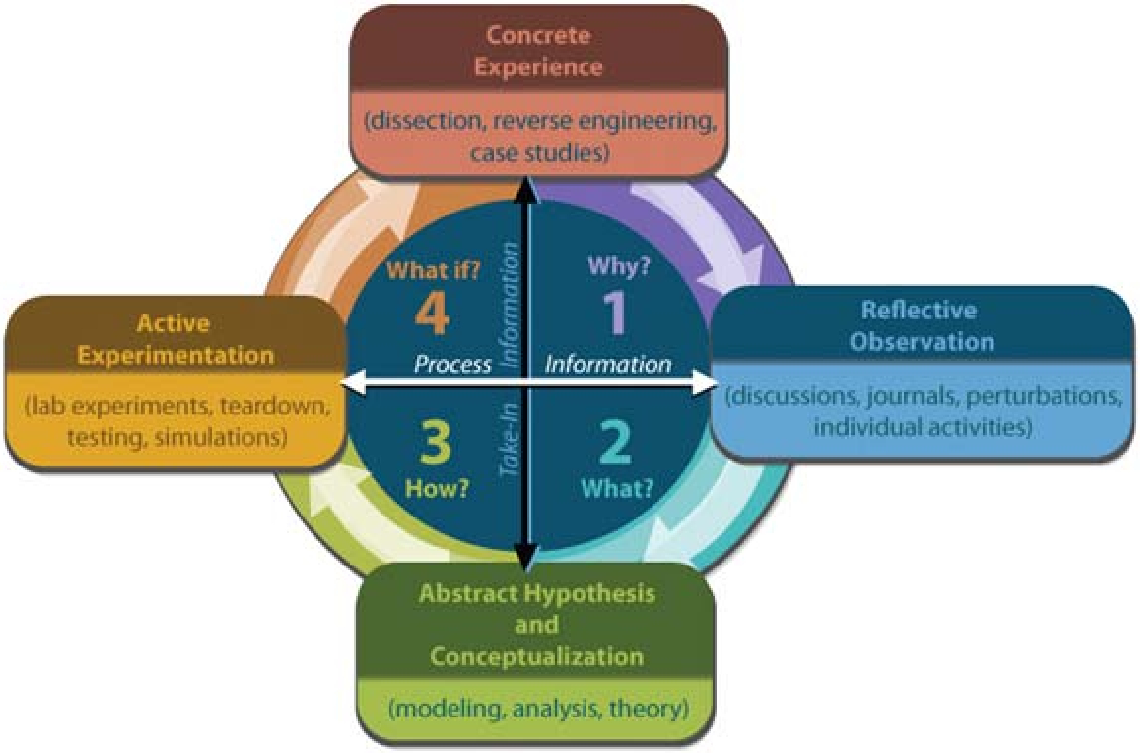


Figure 1. Kolb Cycle for learning experience progression.[6-9]

An individual will have strengths or preferences in both vertical and horizontal dimensions shown in Figure 1. The way this newly presented information is perceived correlates to an individual's learning styles and personality type.[6] The Kolb Cycle creates learning independent of how the information is perceived. Rather, the Kolb Cycle accommodates for all. Depending on the nature of the information, presentation method, learning styles, and personality types, new information may be difficult or easy to understand for a given individual. Within the stages of ***Concrete Experience*** and ***Abstract Hypothesis and Conceptualization*** learning takes place through the presentation of new factual or new theoretical information. These two vertical stages, as shown in Figure 1, are where an individual will "*Take-In Information.*" The vertical dimension within the Kolb Cycle describes how an individual will perceive this new information.[6]

In the stages of ***Active Experimentation*** and ***Reflective Observation*** knowledge is gained through the activities found in these stages of the Kolb Cycle.[6] The horizontal dimension of the Kolb Cycle describes the way an individual tries to "*Process Information*" previously perceived in the vertical dimension.[6] The activities found in the stage ***Active Experimentation*** are used to investigate the validity of new information by experimental methods. This stage may or may not match with the learning styles and personality types of an individual. Once again the Kolb Cycle contains a contingency. ***Reflective Observation*** uses much more passive and reflective activities, as shown in Figure 1, to verify the newly perceived information. Using the Kolb Cycle as a guide, classroom instruction may be developed to include all stages and encompass individuals of all types.

The inner loop of the Kolb Cycle shown in Figure 1, describes a pattern of possible thoughts that lead to a progression from one set of experiences to new experiences. Each of the following four questions are seen as transitional phases: "*Why?*", "*What?*", "*How?*", and "*What If?*".[7] These transitional questions will tend to arise, as a natural curiosity develops in the minds of a student.

Application of Kolb Cycle to Fatigue FE Learning Module

In a paper written by Brown[8], *Teaching Finite Elements using the Kolb Learning Cycle*, a global analysis of a FE course is made in regard to stages of the Kolb Cycle that are experienced in that course. Brown states that, " Students are provided ***Abstract Hypothesis/Conceptual*** Modules that begin with the background of the FE method, fundamental mathematics of FE, move through the concept of "stiffness-analysis", one-dimensional direct stiffness analysis of various structures, the topology of the various finite elements, error analysis of FE results, and concludes with how to model engineering problems using this technique."[8] The ***Abstract Hypothesis/ Conceptual*** stage in Figure 1 can have experiences encompassed in the following three areas: the modeling, analysis, and theory. One or more of these experiences may be used to engage students in the ***Abstract Hypothesis/Conceptual*** stage. Brown then goes on to say that experiences found in homework assignments, course projects, and the FE learning modules apply to the ***Active Experimentation*** portion of the cycle. Additional types of ***Active Experimentation*** classroom activities are stated in Figure 1. These activities include laboratory experiments, product teardowns, testing using engineering tools and methods, and performing simulations. The fatigue FE learning module focuses mainly on the simulation activity, but these other activities could certainly be used to connect new ideas and get students involved in the learning cycle. The problems considered in the FE course are often related to a "real-world" problem and are an example of a ***Concrete Experience***.[8] Activities within the ***Concrete Experience*** stage shown in Figure 1 can be used to reinforce or provide a ***Concrete Experience.*** These activities can include dissection, reverse engineering, and case studies. In the fatigue FE learning module the activity experienced most like a case study. After the student performs fatigue FE learning module, they are asked to compare the FE results with the analytical solution. Most importantly, they are asked to attempt to explain the differences between the FE and analytical results. This requires that they engage in ***Reflective Observation*** portion of Kolb's Cycle. Activities, shown in Figure 1, that are found to provide a ***Reflective Observation*** type experience include: having open discussions, keeping a journal or notebook collection, and perturbation by a course instructor. Individual activities require inner thought and reflection which require a student to engage in a ***Reflective Observation*** of activities or experiences recently completed. Designing around Kolb Cycle will reach more if not all students. Brown also describes a micro learning cycle for his FE learning modules that engages all areas of the Kolb Cycle.[8] It is in this same manner that that the fatigue FE learning module has been developed.

The fatigue FE learning module has been designed and interlaced within the four stages of the Kolb Cycle. Prior to the introduction of the module, the students will have partially covered the fundamentals of machine design theory. A brief introduction to FE theory may also be provided, but will be covered as well in the fatigue FE learning module. This prior knowledge starts the Kolb Cycle for the FE learning module at the ***Abstract Hypothesis and Conceptualization*** stage of the cycle. In this area some of the students may begin to develop ideas as to "*How?*" the theory may be applied to "real world" problems. This develops a progression towards applying theory as is done in the ***Active Experimentation*** stage of the Kolb Cycle.

The fatigue FE learning module is largely a listing of a step-by-step user's guide on how to carry out a FE analysis of a fatigue based machine design problem. In the stage of ***Active Experimentation*** the students will be asked to perform the required steps for the FE analysis. Later they will be asked to perform manipulations that will include changing physical geometries and/or loading conditions. This will lead the students to form opinions as to how these changes will affect the results, as well as reinforce guiding principles. These changes may lead the student to draw the conclusion "*What If?*" while making modifications. The problem selected for the fatigue FE learning module is a circular stepped shaft subjected to fully reversed fatigue loading. This problem presents a simple case study that is present in many everyday applications, such as power transmission shafts in automobiles. The example problem selected is from Shigley[9] and provides the student with a ***Concrete Experience*** as well as a reference to applicable fatigue theory.

Reflective Observation can be achieved by asking the students to compare the results from the FE analysis to the analytic solution from fatigue theory and compare the results match. If the FE solution results do not match the analytical solution, the students should be asked "*Why?*" the solutions are different. The instructor may prompt students with diagnostic questions to reveal errors in steps where mistakes are commonly made. Other possible ways to invoke ***Reflective Observation*** include group discussions and report writing. These types of assignments require the students to reanalyze what they have done and reflect "*Why?*" they have done these things in the three previous stages. Finally to complete the cycle, students will take what they have learned from the module and want to know "*What?*" other problems can be modeled and solved with FE methods. The students now have used commercial tools and developed skills to analyze more complex problems with further practice. It is in this manner they will be able to begin providing solutions to new problems using self conceived ideas in new areas.

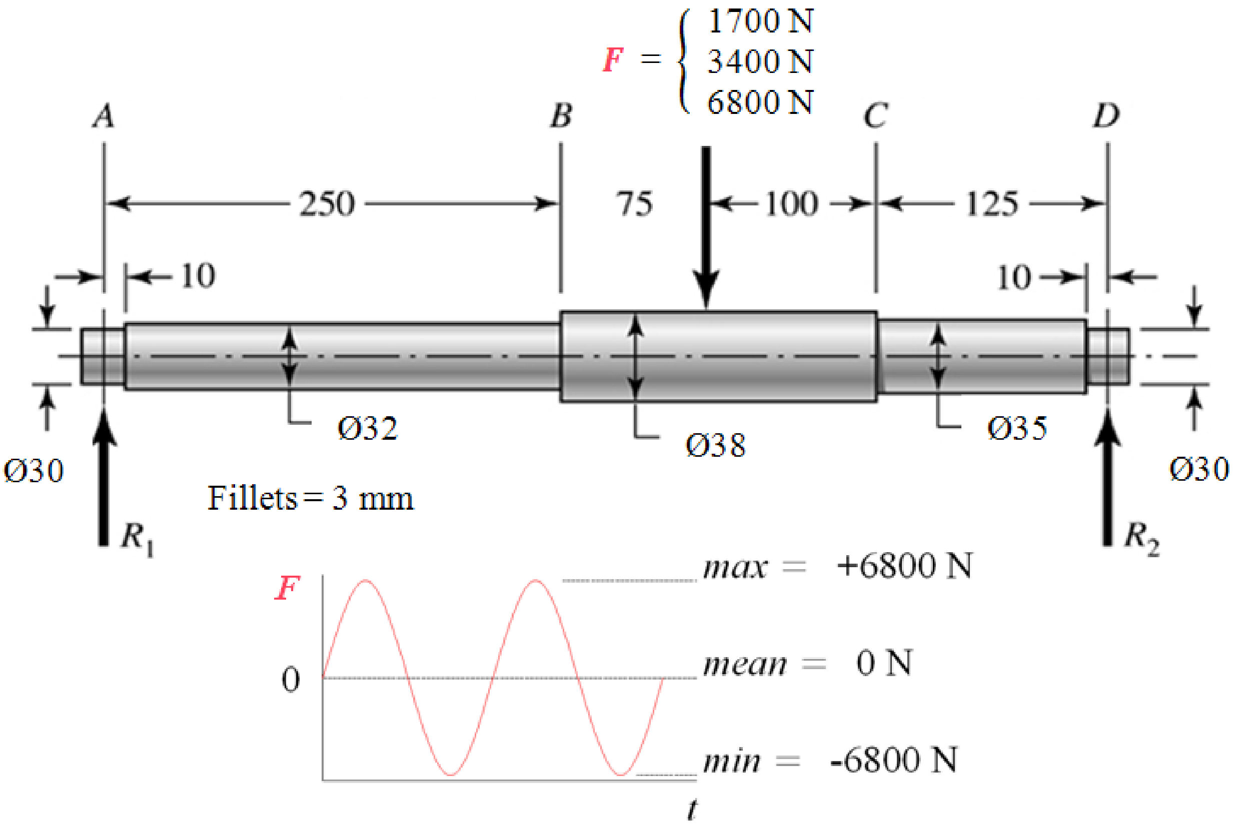
Fatigue FE Learning Module

Overview

This module was integrated into the senior level MECH 125 Machine Design II course at the University of the Pacific by Prof. Jiancheng Liu in the spring semester of 2009. The fatigue FE learning module is designed to be used as a classroom learning tool within an undergraduate machine design course or FE course. Very little knowledge of FE theory is required to complete the module. However, some introductory undergraduate machine design theory is required to understand the terminology and principles applied in the creation of the FE model. The background required before using the module are the fatigue equations for fully reversed loading. The fatigue problem selected is simple, so that the students may connect the solution to the pertinent machine design theory within the FE analysis. The fatigue FE learning module will be available in two file formats, Microsoft® Office PowerPoint® and Adobe Acrobat®. These file formats ensure ease of use and the ability to go back and review steps in the solution development process. An instructor can also change the PowerPoint® slides to meet his/her needs. As mentioned in a previous paper[1], certain aspects of the module will be included to create overall uniformity. These items include module title, author, author contact information, expected module completion time, table of contents, and references. Educational objectives based upon Bloom's Taxonomy[10] and ABET Criteria 3 for Engineering Programs[11] are stated at the beginning of the module. A detailed problem description and relevance is included along with the analysis objectives. A large majority of the module content will be the step-by-step process to create a FE model and carry out a FE analysis. Portions of this guide will be directed at properly viewing the FE results. A comparison of FE results to the analytic solution is included to emphasize the importance of solution verification. Finally, an overall summary and discussion section is included to review what the user has accomplished and the techniques and underlying FE theory involved.[1]

Example Problem

Choices of fatigue problems that are appropriate for both introductory undergraduate machine design and FE courses are quite limited in nature. Example 7-10 from Chapter 7 of Shigley's *Mechanical Engineering Design* was used.[9] The problem selected is a circular stepped shaft with ball bearing supports at points A and D. At each diameter change a fillet with a radius of 3 mm is present. The shaft is subjected to a fully reversed concentrated loading. The applied load is a non-rotational force (F) with a magnitude of 6.9 kN as shown in Figure 2. The shaft is machined from AISI 1050 cold drawn steel with a tensile yield, $S_{y,}$ of 580 MPa. The ultimate tensile strength, S_{ut}, is 690 MPa. The shaft is to operate at room temperature. The reliability factor is 1.0 and the fatigue endurance limit, S_e is 345 MPa. The problem requires that the shaft life be estimated for loads (**F**) of 1.7 kN, 3.4 kN, and 6.8 kN. Additional material properties for AISI 1050 cold drawn steel not provided by Shigley[9] are required for the three-dimensional FE analysis and they include Young's Modulus, E = 207 GPa, Poisson's ratio, ν = 0.29, and shear modulus G = 80 GPa.



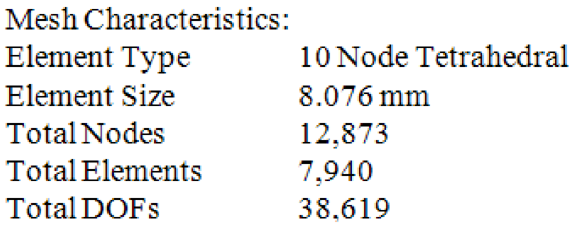
AISI 1050 Cold Drawn Steel:
S_y = 580 MPa; S_{ut} = 690 MPa; S_e = 345 MPa; E = 205 GPa; ν = 0.29; G = 80 GPa.

Figure 2. Stepped circular shaft (dimensions in mm.) subjected to a fully reversed loading.[9]

Finite Element Model

The commercial software COSMOSWorks®[4] is used for this fatigue FE learning module. COSMOSWorks® is widely used in industry and undergraduate engineering programs, and with the SolidWorks® three-dimensional solid modeling software. Within COSMOSWorks® there are several analyses that can be performed. This problem requires both static and fatigue analyses. COSMOSWorks® uses the static analysis to formulate the fatigue analysis. Essentially the loading is considered the same as the static analysis and an event is defined for the application of the fully reversing cyclic load with the loading ratio of (R = -1) for the defined static load for a specified amount of cycles. The failure analysis compares the applied alternating stresses against a fatigue strength curve (S-N curve) for the given material on the interval of the applied cycles.

The stepped shaft was modeled in SolidWorks® as a three-dimensional solid. The solid model is meshed with ten node quadratic tetrahedral elements by the high quality automatic mesh generator in COSMOSWorks®. The geometry, material properties, and loading are shown in Figure 2. The FE mesh consists of 12,873 nodes and 7,940 tetrahedral elements as stated in Figure 3. Each node has three degrees of freedom (DOF) and the mesh has a total of 38,619 DOF. The ball bearing end supports are shown in Figure 3. All DOFs were constrained on the cylindrical surfaces of the shaft that make contact with the bearings. These constraints resemble fixed-fixed boundary conditions. The concentrated load was defined as a normal force over a 5 mm radius circle on the top surface of the shaft in as Figure 3. This was done to eliminate stress concentrations in the vicinity of the concentrated load.



Mesh Characteristics:	
Element Type	10 Node Tetrahedral
Element Size	8.076 mm
Total Nodes	12,873
Total Elements	7,940
Total DOFs	38,619

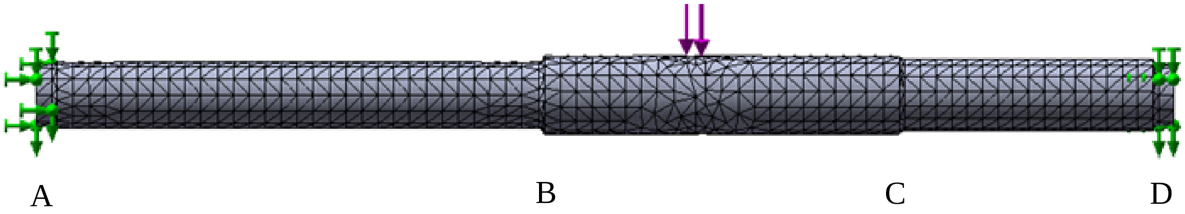


Figure 3. COSMOSWorks® FE mesh of the stepped circular shaft.

Static Deflection Analysis
A static deflection analysis of the shaft with a 6.8 kN load was carried out using COSMOSWorks®. The maximum vertical deflection occurs 298 mm from the left end of the beam with a magnitude of 0.3706 mm as shown in Figure 4. The maximum deflection is to the left of the applied load.

This result was verified with mechanics of materials principles considering a fixed-fixed uniform circular shaft of 38 mm, 35 mm, and 32 mm in diameter. The deflection value is -0.258 mm for a uniform 38 mm shaft, -0.359 mm for a uniform 35 mm shaft, and -0.513 mm for a 32 mm uniform shaft. The FE solution of 0.3706 mm for the stepped shaft is bounded between these values for the uniform shafts. The deflection may seem small, but it is actually too large if the shaft included gears. The recommended maximum deflection for a shaft with gears is 0.127 mm.[12]

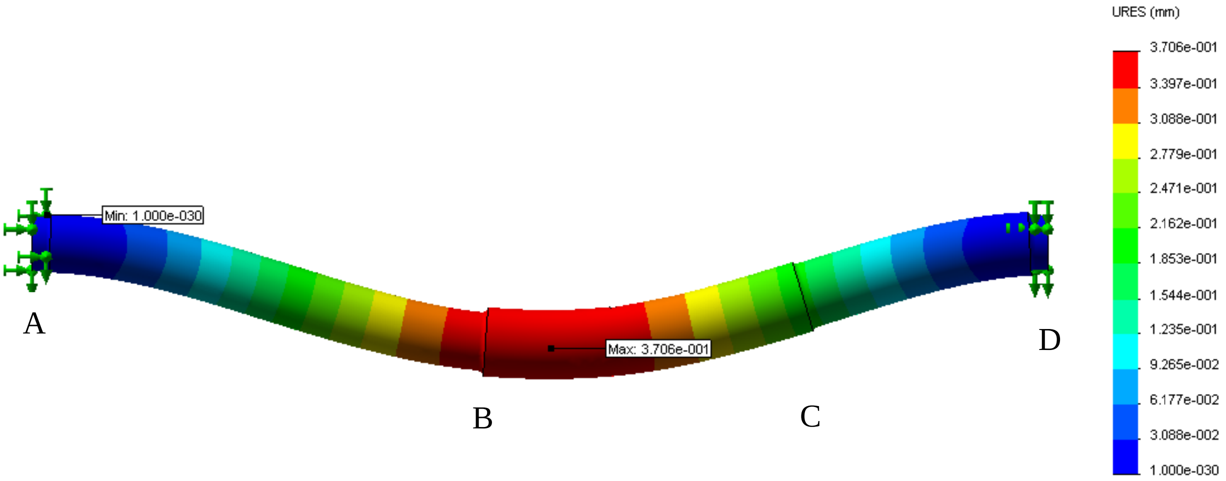


Figure 4. Resultant deflection (mm) analysis for the 6.8 kN load.

Static Stress Analysis

A static stress analysis was carried out in COSMOSWorks® as shown in Figure 5. The highest stress was found at the bottom surface of the right bearing support (point D) in the fillet radius. The magnitude of the von-Mises stress at that location is 296 MPa as shown in Figure 6. This value is approximately 56% of the tensile yield strength, S_y = 530 MPa on the first loading cycle.

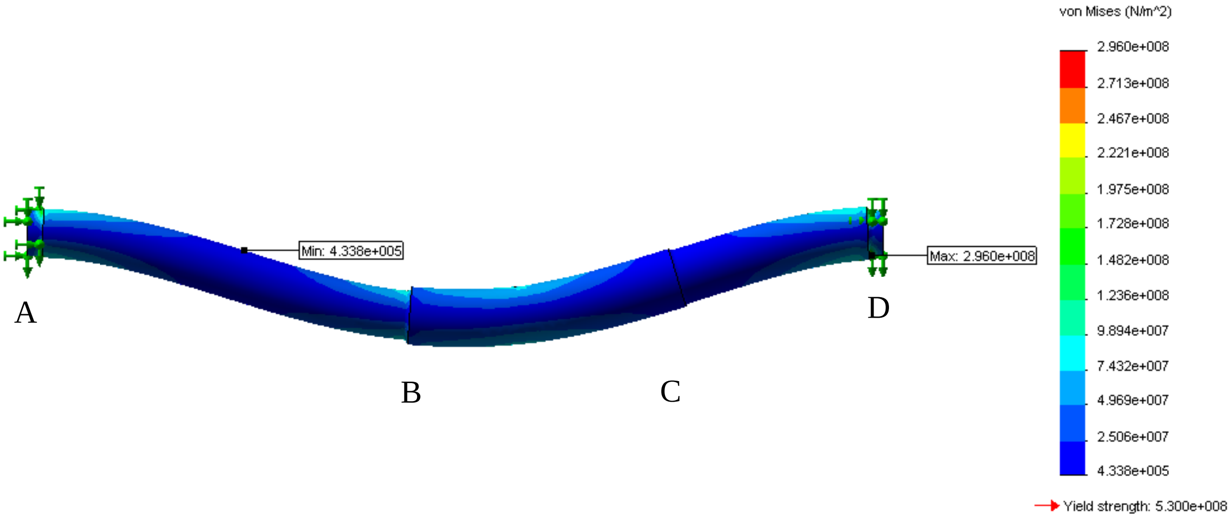


Figure 5. Static von-Mises stress (Pa) analysis for the 6.8 kN load.

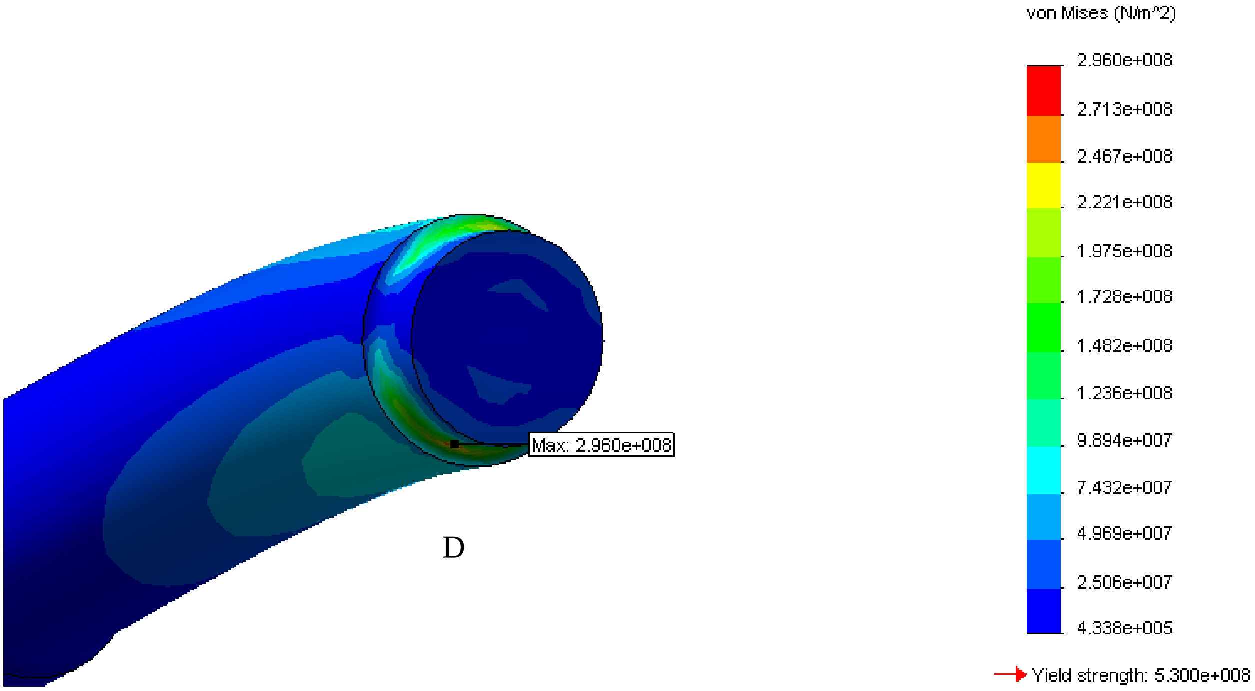


Figure 6. Highest von-Mises stress (Pa) location at the bottom right bearing support (point D).

Bending stresses were verified at the right bearing support (point D) using the mechanics of materials solution for a fixed-fixed beam. The stress concentration values at the fillet radii were determined from Shigley.[9] The bending stress at the fillet radius of the bearing support location was 312.30 MPa using mechanics of materials. There is a 5.2% difference in the two solutions types for the maximum static stress. Since the educational version of COSMOSWorks® was used, there was a limitation in obtaining a more accurate FE solution at the fillet locations, therefore, 5% is considered acceptable in this work.

Fatigue Analysis

COSMOSWorks®[4] was used to estimate the number of life cycles the shaft would survive subjected to reapplications of the 6.8 kN load as shown in the F-t curve of Figure 2. The shaft should be designed to withstand 10^6 loading cycles; however, the corrected endurance limit is 236 MPa and the highest applied static stress is 296 MPa which means that the shaft will have a finite number of life cycles.

In COSMOSWorks® a stress-life approach is used to carry out the fatigue analysis. Stress-life methods are commonly found in undergraduate machine design courses and textbooks. As previously discussed in the section on the finite element model, COSMOSWorks® uses the results from the static stress analysis to compute an alternating von-Mises stress for the defined fatigue event. This alternating von-Mises stress is compared to the material S-N curve. The ASME austenitic fatigue S-N curve for AISI 1045 cold drawn steel is shown in Figure 7. This material was selected since it most closely matches AISI 1050 in the COSMOSWorks® material library. AISI 1050 is not available in the COSMOSWorks® material library.

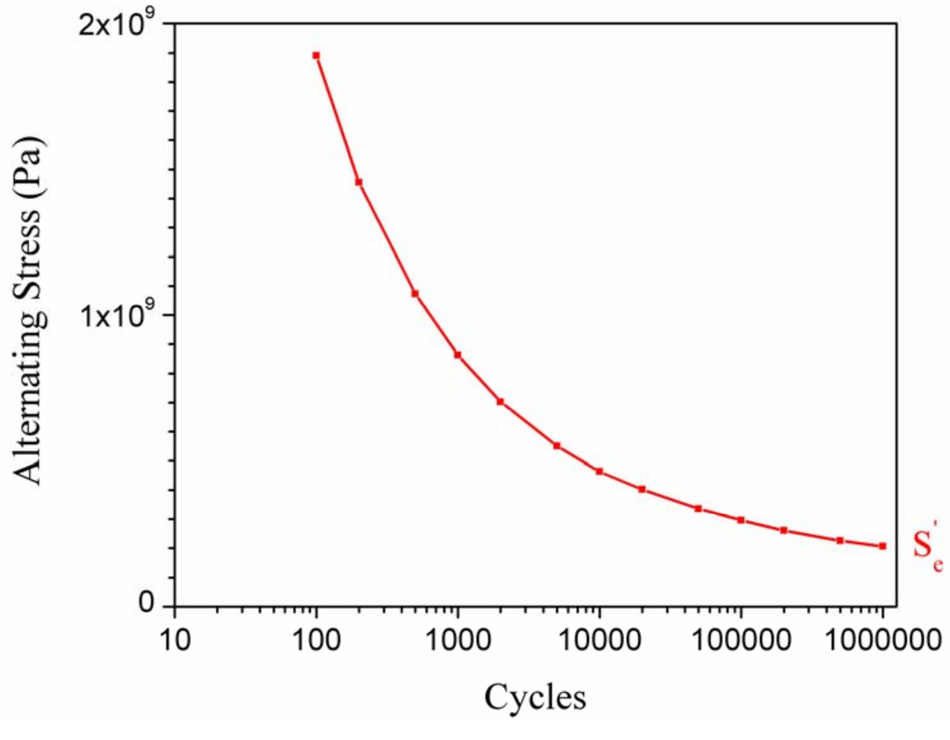


Figure 7. Semi-log scale S-N plot of AISI 1045 cold drawn steel from COSMOSWorks® material library.[4]

The life plot in Figure 8 shows the lowest number of cycles until failure at all locations of the shaft. The most probable location for failure is at the bottom right bearing support of the shaft (point D) as shown in Figures 8 and 9. The minimum number of cycles for the shaft is 99,280 until failure. The life plots in Figures 8 and 9 show a range of 99,280 to 339,500 cycles at the bearing support. This compares well with the analytic solution of 112,000 cycles stated in Shigley.[9] Therefore, COSMOSWorks® is more conservative than the analytic solution.

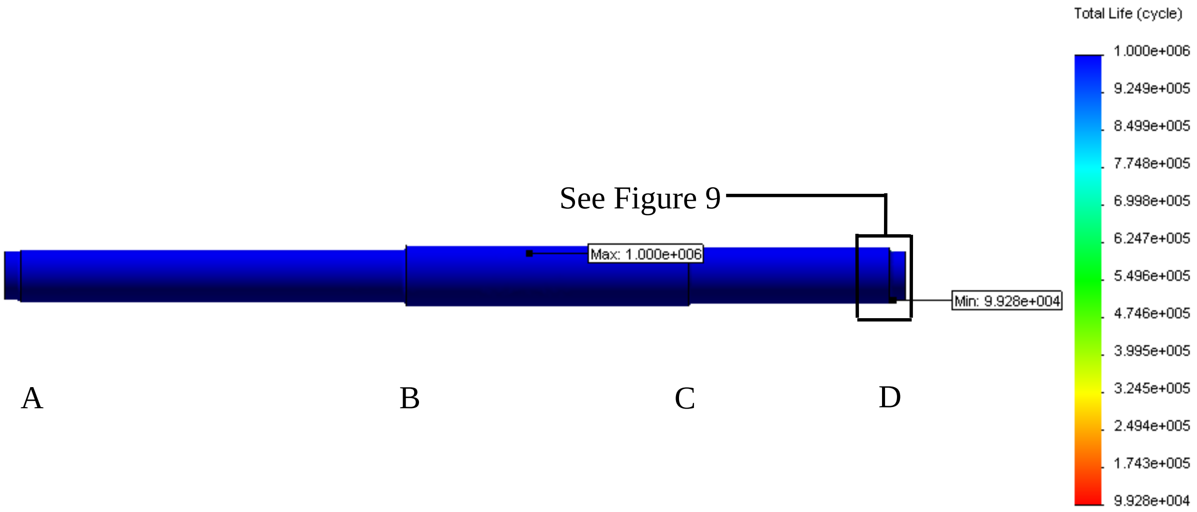


Figure 8. Life plot of shaft.

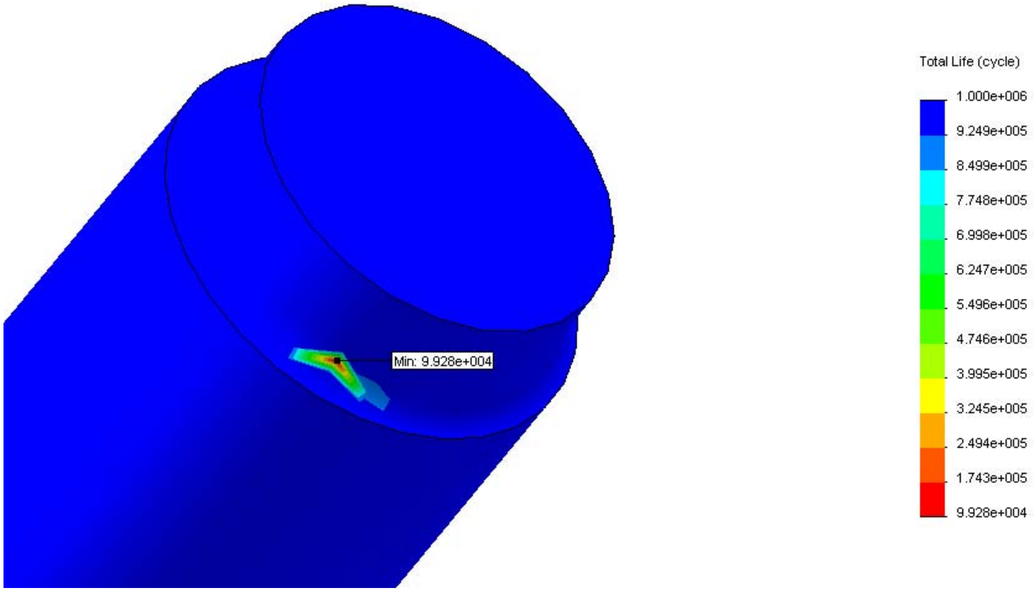


Figure 9. Enlarged view reveals fillet radii at the bottom right bearing support is the most probable failure location.

It is important to compare these results with applicable fatigue theory found in the textbook. This verification provides a secondary check to the FE analysis. Table 1 displays the life cycle predictions through the analytical and FE solution. It can be observed that the values for the 6.8 kN load are within a reasonable range of values. As one can see from the Table 1, the loading cases of 1.7 kN and 3.4 kN have an infinite life. The discussion of these loadings was not covered in this paper; however, it discussed in the module as a modification to the FE model. The solution from COSMOSWorks®[3] by its nature is slightly on the conservative side. If the results are not within a similar range with the analytical solution it is quite possible that an error has been made. Stepping through the portions of the analysis and checking the results will allow the student to develop skills on how to identify potential errors in future FE analyses.

Table 1. Comparison of solution methods for the fatigue analysis.

Loading Case (F)	**Solution Type**	
	Analytic[9]	**COSMOSWorks®**
1.7 kN	Infinite Life	Infinite Life
3.4 kN	Infinite Life	Infinite Life
6.8 kN	112,000 Cycles	99,280 Cycles

Learning Styles: Felder-Soloman

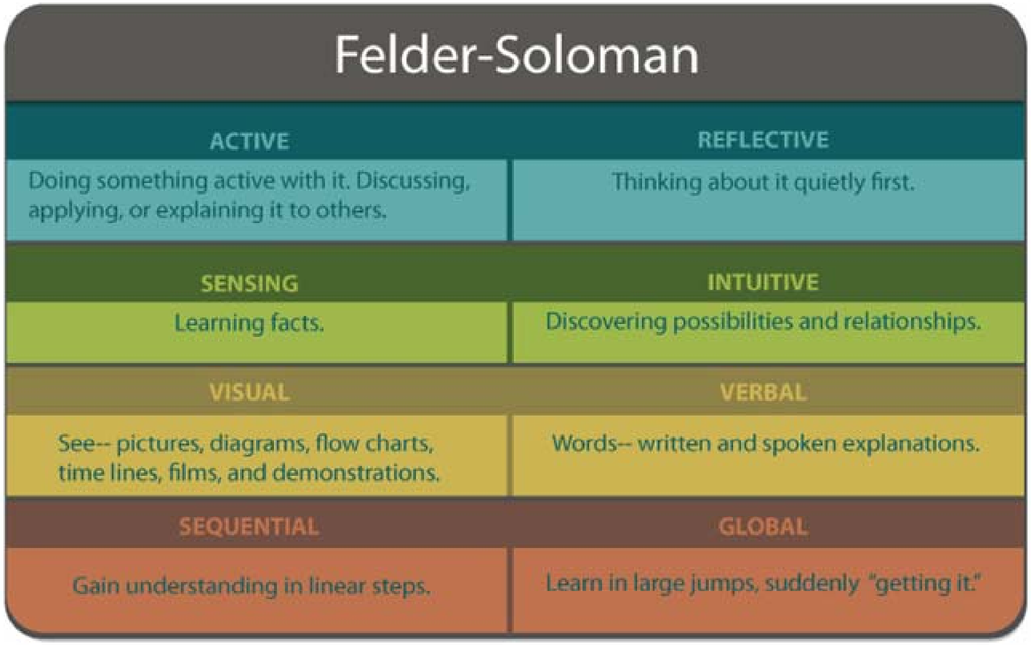
History and Overview

Learning styles have only been used as an important learning tool in formal education since the start of the 20th century. The Felder-Soloman learning style model is based on initial psychological theory of Carl Jung[13], the learning style work of David Kolb[6], and the Myers-Briggs Personality Types Indicator. In some cases, learning styles and personality types are discussed in unison. The Myers-Briggs personality types will be discussed in-depth later in the next sections of this paper. A large number of learning style models have been established for various fields. A few to be mentioned are models developed by Anthony F. Gregorc[14], David Kolb[6], and the Herrmann Brain Dominance.[15] These learning styles may have applications in certain educational programs; however, the work of Richard M. Felder and his associates have focused almost entirely on engineering students. This is the reason why this learning style model is used in this work to aide in the development and improvement of the fatigue FE learning module.

Felder-Soloman Model

Richard M. Felder Linda K. Silverman addressed a mismatch of learning styles reached by traditional classroom techniques and engineering student learning styles.[16] This paper was based on the prior psychological theory by Carl Jung[13] and included additional learning style information written by Kolb[6], discussed earlier, for his work in the development of the experiential learning cycle. Felder and Silverman proposed that identifying common learning styles in engineering students would allow for the creation of new styles for presenting lecture material that would more effectively educate students of all learning styles. Felder continued this work and with the help of Barbara Soloman created the Felder-Soloman *Index of Learning Styles*.[16-18] The Felder-Soloman Index of Learning Styles is shown in Table 2 and is used to identify the fixed learning styles present in an individual.

Table 2. Felder-Soloman Index of Learning Styles.[16-18]



Felder-Soloman

ACTIVE	REFLECTIVE
Doing something active with it. Discussing, applying, or explaining it to others.	Thinking about it quietly first.
SENSING	**INTUITIVE**
Learning facts.	Discovering possibilities and relationships.
VISUAL	**VERBAL**
See-- pictures, diagrams, flow charts, time lines, films, and demonstrations.	Words-- written and spoken explanations.
SEQUENTIAL	**GLOBAL**
Gain understanding in linear steps.	Learn in large jumps, suddenly "getting it."

The Felder-Soloman Index of Learning Styles is composed of four pairs **Active/Reflective**, **Sensing/Intuitive**, **Visual/Verbal**, and **Sequential/Global** as shown in Table 2. Felder notes that engineering students are typically, "…**Visual**, **Sensing**, Inductive (now omitted), and **Active**, and some of the most creative students are **Global**."[16] Felder identifies a discrepancy of engineering student learning styles and traditional instructional methods. Felder states that traditional instruction methods appeal to the following learning styles: "most engineering education is auditory (**Verbal**), abstract (**Intuitive**), Deductive (now omitted), passive (**Reflective**), and **Sequential**." [16] In 2002 a republication of the original learning styles paper by Richard M. Felder removed the Inductive/Deductive categories. These categories were removed since a sampling of Felder's students indicated that most students actually preferred the Deductive instruction type, contrary to his personal belief that Induction methods should be used in education until graduate school.[16]

Since Felder has focused specifically on engineering students, the Felder-Soloman model is used to develop and design the FE learning module. The initial goal of our fatigue FE learning module is to focus on designing the module to include the four typical engineering learning styles stated above. The FE learning module will accommodate **Active** learners since involvement or participation is required to complete the module during lecture/lab time periods. Students with a preference for **Sensing**, "prefer concrete information such as descriptions of physical phenomena, results from real and simulated experiments, demonstrations, and problem-solving algorithms".[19] The concrete nature of the example problem selected for analysis will appeal to students of the **Sensing** type. By knowing most engineering students have a **Visual** learning preference, we created a large amount of **Visual** instruction through computer screen captures of step-by-step instructions that are used to complete the FE learning module. **Visual** learners will also be captivated by the presentation of FE results that include deflection, stress, and life plots from the commercial software. Also, **Visual** learners will be taught how to model the problem in SolidWorks®, which is a visually stimulating and intensive process. Furthermore, the fatigue FE learning module is by its nature very sequential. Each step is clearly covered and builds towards the final goal of an accurate simulation of the problem, which will make it easier for the **Sequential** learner to grasp the content. **Global** learners may find it very easy to go through the module once the overall problem has been solved. **Global** learners may be able to avoid the step-by-step instruction methodology and can move faster through the module than their **Sequential** counterparts if the overall process is quickly learned.

Index of Learning Styles On-line Assessment

The Index of Learning Styles (ILS) is available online from Richard Felder's website at North Carolina State University.[18] The ILS provides instant results after completion of the 44 item questionnaire. This questionnaire measures the four classifications of the Felder-Soloman Model shown in Table 2. Each learning style classification has 11 questions. The responses of the 11 questions for each classification are used to compute the magnitude of a preference for a particular learning style. The magnitudes of each learning style preference will be presented as part of the assessment process for the FE learning module. The Felder-Soloman ILS may be found at the website http://www.engr.ncsu.edu/learningstyles/ilsweb.html.[18] The results of the learning style assessments are discussed later in this paper.

Personality Types: Myers-Briggs

History and Overview

Based heavily on the psychological types of Carl Jung[13], I.B. Myers and K.C. Briggs developed their personality type paper for twenty years before releasing it in 1962. The Myers-Briggs Type Indicator (MBTI) assessment is a psychometric questionnaire designed to measure psychological preferences in how people perceive the world and make decisions in their life. The personality type indicator assessment tool helped identify what kind of roles women, who were entering the industrial workforce of war-time production jobs, would be best suited for during World War II.[20] In a related way the MBTI may be used to analyze the best instructional methods for a range of personality types. Though the work of Carl Jung and the MBTI has no true scientific basis, it has been one of the most popular and widely used methods to classify personality types for the past half century.

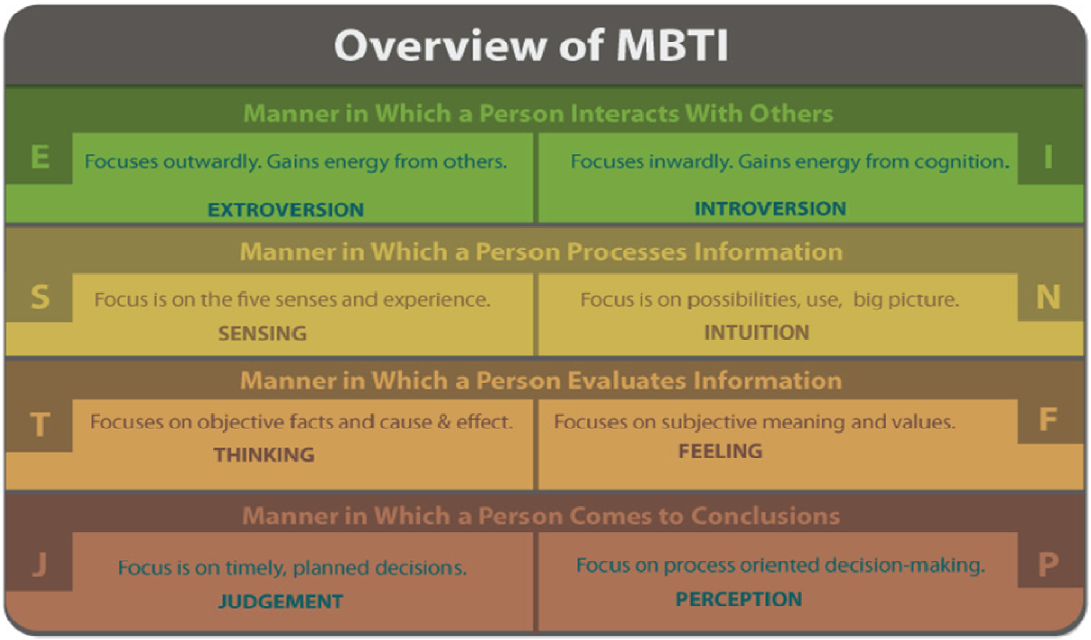
Myers-Briggs Type Indicator

The MBTI shown in Table 3 includes four categories of personality type preferences: **Extroversion/Introversion**, **Sensing/Intuition**, **Thinking/Feeling**, and **Judgment/Perception**. The first pair of **Extroversion** vs. **Introversion** regards the way an individual interacts with their environment. In the FE learning module **Extroverts** may find it easier to be involved and participate if the module is completed as a group or class, whereas **Introverts** would prefer to complete the module on an individual basis. The second of the four categories **Sensing** vs. **Intuition** provides insight into how a person processes information. People who tend to process and learn through their senses are referred to **Sensors**, versus people who process data based on the view that the information is of future use are referred to as **Intuitor**. The **Sensor** vs. **Intuitor** pair is seen by most researchers to be the most important of the four categories in terms of education. A major goal of this project is to design, use, and improve the FE learning module in ways that will be effective for students with different MBTI personality types. For example, the module proceeds in a deductive manner. First, the FE and machine design theory is presented, and then module is completed. **Intuitor** types prefer to contemplate theory and then quickly implement the use of the theory in an application. The modules also have content explicitly addressed to the **Sensor** types. In particular, the tremendous visual aspects of the FE analysis results appeal to the **Sensors**.[19] A number of researchers have used the knowledge of MBTI types to enhance engineering education. The third pair, **Thinking** vs. **Feeling**, for MBTI preference attempts to describe the manner in which a person evaluates information. Those who tend to use a logical "cause and effect" strategy **Thinkers** versus those who use a hierarchy based on values or on the manner in which an idea is communicated **Feelers**. The final MBTI type pair indicates how a person makes decisions or comes to conclusions. **Judgers** are people that tend to back up their decisions based on evidence. Those who tend to wait to be sure that all data has been thoroughly considered are known to be **Perceivers.**[20]

Personality Types On-line Assessment

The assessment of the personality types will be completed using the Jung Typology Test™. A 72 item questionnaire is completed to determine the MBTI types and their relative strengths. The MBTI on-line survey provides students with four letters (either **E** = **Extrovert** or **I** = **Introvert**; either **N**= **Intuitor** or **S** = **Sensor**; either **T** = **Thinker** or **F** = **Feeler**; either **P** = **Perceiver** or **J** = **Judger**) that indicate their personality component types. In addition, weights or strength values for each preference are provided to the students as well. From these strengths the personality type of a student may be analyzed and used further in the assessment process to identify any biases towards any one personality type. The location of the Jung Typology Test™ may be found at the website http://www.humanmetrics.com/cgi-win/JTypes2.asp.[21] The results of the personality type assessments are discussed in the next section of this paper.

Table 3. Myers-Briggs Type Indicator (MBTI) categories of personality types.[19,20]



Overview of MBTI			
	Manner in Which a Person Interacts With Others		
E	Focuses outwardly. Gains energy from others. EXTROVERSION	Focuses inwardly. Gains energy from cognition. INTROVERSION	I
	Manner in Which a Person Processes Information		
S	Focus is on the five senses and experience. SENSING	Focus is on possibilities, use, big picture. INTUITION	N
	Manner in Which a Person Evaluates Information		
T	Focuses on objective facts and cause & effect. THINKING	Focuses on subjective meaning and values. FEELING	F
	Manner in Which a Person Comes to Conclusions		
J	Focus is on timely, planned decisions. JUDGEMENT	Focus on process oriented decision-making. PERCEPTION	P

Assessment Tools and Results

Overview

An assessment program is carried out for the fatigue FE learning module. The results from these assessment tools are used for continuous improvement of the module. The four assessment tools used are as follows:

- *Post-survey.* The post-survey is administered following the completion of the fatigue FE learning module. The post-survey can be used to indicate what the students liked and disliked about the module. The post-survey will also ask the students how much they learned using the module in comparison to a traditional classroom approach.
- *Pre- and Post-quizzes.* A short quiz is administered before and after the implementation of the fatigue FE learning module.
- *Learning Styles.* The Felder-Soloman learning styles of each student are identified through an on-line questionnaire to determine whether the fatigue FE learning module is biased towards a particular learning style based on the pre- and post-quiz results.
- *Personality Types.* The Myers-Briggs personality types of each student are identified through an on-line questionnaire to determine whether the fatigue FE learning module is biased towards a particular personality type based on the pre- and post-quiz results.

Each assessment tool above will now be discussed in-depth.

Post-survey

One assessment tool used to assess the fatigue FE learning module was the post-survey, administered after using the module. The post-survey questions and format were developed to follow a common template for all FE learning modules.[1] This ensures present and future FE learning modules are evaluated in a common manner to analyze the educational and analysis objectives.[1] The post-survey questions were based on the module educational objectives and analysis objectives. The post-survey responses used a five point Likert scale. The Likert scale used has the following five point scale: “Disagree”, “Partly Disagree”, “Neither Agree or Disagree”, “Partly Agree”, and “Agree”. The post-survey for the fatigue FE learning module is shown in Figure 7. Multiple questions for each educational objective and each analytical objective were asked.

The post-survey results shown in Figure 7 were overall very positive. The results show that over 78% of the student responses were “Partly Agree” and “Agree” and including the “Neither Agree or Disagree” the positive response rate increased to 97%. We will now discuss the questions with shaded rows in Figure 7. A total of eleven students responded to the post-survey. Analyzing the 1st question of the post-survey, nine of the eleven students found that the module helped them to better understand “fully reversed fatigue loading.” The 4th question reveals that ten of the eleven students felt that the module improved their understanding of static and fatigue FE analysis, as well as increased their confidence about carrying out machine component analyses. The responses of these two questions indicate that the students feel more confident in understanding both fatigue and FE analysis. In the 5th question all eleven students selected either “Partly Agree” or “Agree” with a simple conceptual question about the fatigue FE solution. The only fully negative feedback regarding the module was in the 10th question, a student felt that the module was not helpful in learning how to select a suitable finite element type. In the 17th question, seven of the eleven students thought the self-learning in the module was more beneficial than an instructor led classroom demonstration. Additionally, seven out of eleven students found the module to be very clear in its purpose and intentions as according to the 18th question. The 19th question is of particular importance because it indicates whether students enjoyed the module and found it to be a more effective method than traditional instruction. Only two students were found to “Partly Disagree” that was not an effective method for presenting FE and fatigue when compared to the traditional approach. The 20th question indicates that eight of the eleven students would like to learn more about the FE method and how to apply it to other mechanical engineering problems. The post-survey confirmed the perception by the students that this module helped them understand the concept of fatigue and assisted them in understanding FE theory.

Figure 7. Post-survey results for the fatigue FE learning module administered at the University of the Pacific in Spring 2009.

This survey will be used to evaluate and improve active learning activities in this class. Your student ID is used only to match up the results of this survey with others used in the course. Your opinions will be used to improve course learning activities. We will not correlate your survey response with your name or the assessment of any individual. Thank you in advance for your cooperation in our research efforts to improve learning here at the University of the Pacific under this NSF Grant. Prof. Jiancheng Liu

Student ID:____________________

Please put an X in the box below that corresponds to your answer.

#	Question	Disagree	Partly Disagree	Neither Agree nor Disagree	Partly Agree	Agree
1.	This activity helped me understand “fully reversed fatigue loading” in a conceptual manner?			2	9	
2.	This activity helped me to understand the assumptions of “fatigue theory?”		1	2	7	1
3.	This activity helped me understand the limitations of “finite elements and usage for fatigue theory?”			4	7	
4.	This activity helped me understand the topic of “static and fatigue finite element analysis,” so that I have the ability to carry out finite element analysis of other machine components?”			1	8	2
5.	This activity showed me that the finite element method determines an approximate solution for the “life cycles of a rotating shaft fatigue” problem?				9	2
6.	Activities like this one, and similar ones done by commercial finite element software vendors, are only required to understand finite element theory?		2	7	2	
7.	This activity showed me that an understanding of “fatigue” theory can be reinforced with finite elements?			1	8	2
8.	This activity helped me create the correct geometry to model a “three-dimensional stepped shaft?”			2	5	4
9.	This activity helped me identify the material properties required to model the “static and fatigue finite element analysis?”			2	5	4
10.	This activity helped me to select suitable finite element type to model “the static and fatigue analysis of the rotating stepped shaft?”	1			6	4

Figure 7. 'Continued' Post-survey results for the fatigue FE learning module administered at the University of the Pacific in Spring 2009.

Student ID:____________________

Please put an X in the box below that corresponds to your answer.

#	Question	Disagree	Partly Disagree	Neither Agree nor Disagree	Partly Agree	Agree
11.	This activity helped me understand that accuracy (not the correctness) of the solution is dependent on the quality of the mesh?			1	6	4
12.	This activity helped me to the correct boundary conditions (loads and constraints) to model the "rotating shaft"?			1	8	2
13.	After completing this activity, I was able to implement a suitable finite element type and construct a correct finite element model using commercial software?			2	8	1
14.	This activity helped me understand why it is important to check if the "applied loads" are specified correctly?			1	6	4
15.	This activity helped me to understand why it is important to check if the "constraints" were specified correctly?			1	6	4
16.	This activity helped me to understand why it is important to verify a finite element solution "i.e., deflections, stresses, and loading cycles" through an independent method, e.g., hand and/ or experiment?			3	6	2
17.	Personally seeing and developing the finite element model on my own was better than a classroom demonstration?			4	5	2
18.	This activity was very clear?			4	3	4
19.	This activity was more effective than using class time for lectures or board-work?		2	1	7	1
20.	I would like to learn more on using the finite element method to solve other mechanical engineering problems?			4	5	3
	Totals	1	5	42	126	46
	Percentage of Students Selecting Response	0.4%	2.3%	19.1%	57.3%	20.9%

Pre- and Post-quizzes

A pre-quiz and post-quiz shown in Figure 8 was administered to the students before and after using the fatigue FE learning module. The quiz should take no more than fifteen minutes to complete. Table 4 presents the results of the students' scores on the pre- and post-quizzes.

The average scores for the pre- and post-quiz is approximately 61 percent as shown in Table 4. Table 5 summarizes the statistical analysis of Table 4. Analysis reveals that the statistics of the data was not significant. This was due to the average of the pre-quiz and post-quiz being equal. The pre-quiz and post-quiz scores indicate that there was no overall improvement in student learning for the course. Furthermore, some students saw individual improvement while other students did not. This could be attributed to the quiz administered. The quiz may not be a good assessment tool since some of the students already understood the material better than before using the module. The authors plan to develop a new quiz that has multiple choice and true/false question to eliminate any subjectivity in grading by the instructor. Furthermore, the quizzes did not count as part of the course grade, therefore, the instructor will be suggested to count the post-quiz grade as part of the course grade. The module will be evaluated and modified before it is introduced in a future course.

Table 4. Individual student performance on the pre- and post-quiz.

Student ID	Pre-quiz Results	Post-quiz Results
1	70%	60%
2	60%	40%
3	50%	40%
4	55%	50%
5	65%	60%
6	45%	55%
7	50%	90%
8	85%	70%
9	85%	85%
10	40%	50%
11	65%	70%
Average Scores	**60.9%**	**60.9%**
	0% Improvement	

Table 5. Statistical analysis of the pre- and post-quiz results.

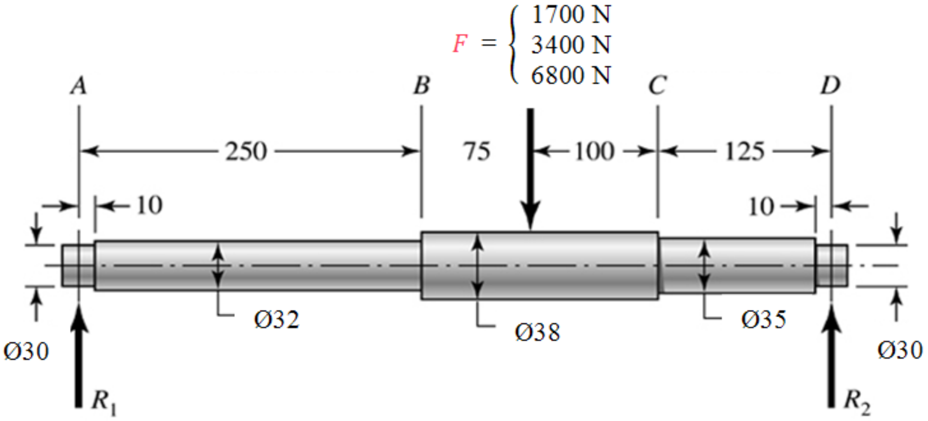
Quiz	Mean	Standard Deviation	Standard Error of the Mean
Pre-quiz	60.91%	14.97%	4.51%
Post-quiz	60.91%	16.55%	4.99%
95% Lower Bound For Mean Difference = 5.71		t-value = 0	p-value = 1.0

Figure 8. Pre- and post-quiz administered at the University of the Pacific in Spring 2009.

MECH 125 Machine Design II
Spring 2009

Your Student ID:______________________ Your Name:___________________________

Your responses will not be used for assessing your grade in MECH 125.



1.) The fatigue may first occur at which cross section location?
a) A b) B c) C d) D e) The cross section where the load is applied.

Answer: Prior to FE analysis: 2) Point B.
After FE analysis: 1) and 4) Points A and D.

2.) With a decrease of the external load, the shaft's life will increase. This statement is
1) True 2) False 3) Both have no relation.

Answer: 1) True

3.) What is the difference between a static analysis and a fatigue analysis?

Answer: Static analysis estimates the stress level and compares the stress level to its yielding or ultimate strength. Fatigue analysis has to simultaneously take the stress level and operation time into account. The analysis procedures are also different when using FE analysis tool.

4.) The discrepancy between the analytical results and FE analysis results is large. Explain why?

Answer: For both methods, it is hard to get a real accurate result since there are many assumptions when conducting hand calculations or FE analysis using computer. But, it is clear from FE analysis results the life decreases with the increase of the load level.

One goal of this research is to create FE learning modules that span the spectrum of learning styles and personality types. As previously noted, we have chosen to measure learning styles using the Felder-Solomon model and measure personality preferences using the Myers-Briggs Type Indicator (MBTI). In order to gain insight into the effectiveness of the modules across different learning styles and personality types, the pre-quiz and post-quiz results will be separated based on these demographic data. Statistical analysis of these correlations will allow us to determine if the modules are more effective for certain demographic groups than others. This data will be used to change the modules in a closed-loop feedback manner where the goal is serving the learning needs of students with diverse learning styles and personality types.

Table 6 shows the average pre- and post-quiz scores for each learning style pair based on Felder-Soloman. The learning styles in Table 6 denoted by capital letters are common for engineering students.[16] The learning styles for each student was determined using the Felder-Soloman ILS.[18] The third learning style pair in Table 6 has eleven **VISUAL** students (N = 11**)** and zero **Verbal** students (N = 0). Most engineering students are typically **VISUAL** learners; this can be seen in Table 6. No students of the **Verbal** learning style are present in this course.

Table 6. Felder-Soloman learning style pairs with pre- and post-quiz percentage results.

Learning Style Pairs	**N**	**Pre-quiz**	**Post-quiz**	**Delta***	**Standard Deviation**	**Weighted Pre-quiz**	**Weighted Post-quiz**	**Weighted Delta**
ACTIVE**	7	56.43	61.43	5.00	18.93	56.49	60.21	3.72
Reflective	4	68.75	60.00	-8.75	4.79	77.08	65.00	-12.08
SENSING**	4	53.75	60.00	6.25	25.62	52.88	60.00	7.12
Intuitive	7	65.00	62.14	-2.86	8.09	76.72	71.90	-4.83
VISUAL**	11	60.91	60.91	0.00	16.43	60.11	59.89	-0.21
Verbal	0							
SEQUENTIAL**	7	52.14	55.00	2.86	19.55	53.29	57.14	3.85
Global	4	76.25	71.25	-5.00	9.13	75.36	67.50	-7.86

*Delta = (Post-quiz – Pre-quiz)
**Common engineering student Felder-Soloman learning styles.[16]

We are interested in determining if the "Deltas" [(post-quiz score) – (pre-quiz score)] are statistically different between the pairs of learning styles. In order to determine this, the data is treated as a sample of a theoretical larger population. "Student-t" distributions are used for the statistical analysis as the sample sizes are relatively small. Note that the last three columns in Table 6 refer to "weighted" data. The on-line learning styles survey[18] returns results indicating learning style for the individual in each of the four learning style pairs and also includes a weight or strength for that learning style. This allows one to differentiate, for example, between someone who is only slightly **ACTIVE** over **Reflective** in their learning style and someone who very strongly prefers an **ACTIVE** over **Reflective** learning environment. The data in these last three columns were weighted (using a linear interpolation) according to the weights reported from the learning style survey for each student.

Standard statistical "t-student" analysis is used to determine the confidence intervals that are used that determine the likelihood that the "Deltas" for different learning styles are actually different (in a statistically meaningful manner). Table 7 shows the confidence intervals and the **VISUAL** vs. **Verbal** pair is missing. This is because all of the students in this data set were determined to be all **VISUAL** learners as shown in Table 6. So, for example, the unweighted confidence interval of 88.9% for **ACTIVE** vs. **Reflective** learners indicates that there is an 88.9% likelihood that there is a real (statistically speaking) difference between the Deltas for these two opposing learning styles. It is somewhat common to set the threshold of "statistical significance" at a confidence interval of 95%. As can be seen from Table 7, if this standard is used, there is no statistically significant differences between effectiveness of the fatigue FE learning module for the different learning styles for either weighted or the unweighted cases. This would indicate that the fatigue FE learning module has relatively equal effectiveness across the different learning styles. This is a very positive result as one goal is to avoid significant bias toward one learning style over another.

Although the confidence interval threshold of 95% is commonly used to indicate statistical significance, it may be informative to consider any occurrences where the confidence interval is greater than 50%. This would indicate that there was greater than 50% likelihood that one learning style benefited more than another from the fatigue FE learning module. If this criterion is used, noting from Table 8 that the **ACTIVE** learners had a higher positive Delta than the **Reflective** learners and noting from the first row of Table 7 that the confidence intervals were 88.9% and 92.6%, respectively, for the unweighted and weighted values the implication is that the module was more helpful for **ACTIVE** learners than for **Reflective** learners. This result is not surprising as the FE learning modules are, by nature, a very active process where the students participate in each step of building and analyzing the computational model. This being the case, the statistical analysis provides us with an opportunity to refine the FE learning module process in an "active feedback loop" manner. Perhaps the **Reflective** learners would be more effectively engaged in the process if, along with the step-by-step FE learning modules, reflective oriented questions were part of the process. This will be considered before the module is integrated the next time in the course.

Table 7. Confidence interval percentage for differences between Felder-Solomon learning style pairs.

Learning Style Pair Differences	**Unweighted Confidence Interval**	**Weighted Confidence Interval**
ACTIVE[*] vs. **Reflective**	88.9	92.6
SENSING[*] vs. **Intuitive**	46.1	56.9
SEQUENTIAL[*] vs. **Global**	60.8	78.6

[*] Common engineering student Felder-Soloman learning styles.[16]

In a manner very similar to what was done for the learning styles, Myers-Briggs Type Indicator (MBTI) personality type data is correlated with pre- and post-quiz scores. The goal is the same as with the learning styles data; to determine if certain student groups (in this case certain personality types) benefit differently from the fatigue FE learning module. Table 8 has the pre- and post-quiz average scores as well as the Deltas (difference between the pre- and post-quiz score) and standard deviations all separated based on MBTI pairs. In the same manner as was done for the learning styles, Table 8 includes weighted data as well as unweighted data. The personality types in Table 8 denoted by capital letters are common for engineering students.[20] The learning style for each student was determined using the on-line MBTI survey.[21]

Table 8. Myers-Briggs personality type pairs pre- and post-quiz percentage results.

Personality Type Pairs	N	Pre-quiz	Post-quiz	Delta*	Standard Deviation	Weighted Pre-quiz	Weighted Post-quiz	Weighted Delta
Extrovert	6	58.33	58.33	0.00	11.40	57.50	57.30	-0.20
INTROVERT**	5	64.00	64.00	0.00	22.64	69.38	65.00	-4.38
SENSOR**	6	61.67	57.50	-4.17	9.70	63.06	58.33	-4.73
Intuitor	5	60.00	65.00	5.00	22.36	53.74	59.17	5.43
THINKER**	6	59.17	65.83	6.67	17.68	62.01	63.32	1.31
Feeler	5	63.00	55.00	-8.00	11.51	62.79	50.45	-12.34
JUDGER**	8	65.00	59.38	-5.62	10.16	64.20	62.60	-1.59
Perceiver	3	50.00	65.00	15.00	22.91	50.00	68.85	18.85

*Delta = (Post-quiz – Pre-quiz)
**Common percentage of engineering students' Myers-Briggs personality type.[20]

Standard statistical "t-student" analysis is again used to determine the confidence intervals for the four relevant Myers-Briggs personality type pairs. Table 9 displays this data. Recall that the confidence interval is the statistical likelihood that there is a difference between the Deltas for the different personality type pairs. For example, as can be seen in the Table 9, the likelihood (weighted) that the **Extrovert** students have a statistically significant Delta than do the **INTROVERT** is 27.70%. As previously mentioned, the threshold for statistical significance is set at a confidence interval of 95%. Using this criterion there is no statistical differences, weighted or unweighted, between the different personality type pairs. This indicates that, at least for this fatigue FE learning module, different personality type pairs do not have significantly more or less benefit from the module. In other words, the fatigue FE learning module is not biased toward one student group based on a personality type. This is a very desirable result!

Table 9. Confidence interval percentages for differences between Myers-Briggs personality type pairs.

Personality Type Pair Differences	Unweighted Confidence Interval	Weighted Confidence Interval
Extrovert vs. **INTROVERT***	0	27.70
SENSOR* vs. **Intuitor**	49.95	56.72
THINKER* vs. **Feeler**	86.34	83.78
JUDGER* vs. **Perciever**	72.86	72.56

* Common percentage of engineering students' Myers-Briggs personality type.[20]

Conclusion

The fatigue FE learning module did not show any improvement of student learning based on no change in the pre-quiz and post-quiz scores. Past FE learning modules[1,2] have shown improvement of student learning. The fatigue FE learning module will be modified and the quiz will be improved before the module is implemented again into the classroom. It has been statistically shown that the fatigue FE learning module is not biased towards a particular learning style or personality type. Ultimately, the goal is to refine the FE learning modules and overall modeling experience in order to remove any bias toward specific student groups and to maximize the effectiveness of all the FE learning modules developed in this project.

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