AC 2012-4828: EMBEDDING LABORATORY ACTIVITIES IN "APPLIED MECHANICS" COURSE

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Embedding Laboratory Activities in "Applied Mechanics" Course

Fast paced transformations in Engineering Technology (ET) area require new and enhanced learning and teaching strategies in engineering technology education. More than ever, the educational advance is leaning towards meeting the demands of industrial world. Engineering Technology curricula needs to adjust to novel technologies by enabling students to acquire meaningful and relevant practices. Laboratory activities should be incorporated into dry-lectured courses, being vital to ET programs, since they are ultimately enhancing the understanding process, leading towards developing experience-led engineering technology degree. Laboratory activities are the main promoters of creativity and critical thinking, a place where students develop, practice and improve the required skills, and a place where theory meets the real-like scenarios.

One way to lead the students to become creative and innovative is building a systematic approach of the knowledge to be conveyed during class time by combining laboratory activities with a well-structured in class lecture. Based on this perspective, we developed a series of experimental activities to complement the existent lecture material. While most of engineering or ET programs offer different classes for the theoretical and experimental approach in teaching mechanics courses, our approach is to combine the two of them in one course. During laboratory activities, students are fully involved in creating and analyzing the experiments based on prior knowledge gained from previous courses as well as in class lectures (delivered prior to each lab activity and closely linked to each lab activity). In this way the student has the opportunity of becoming an active learner and applying what he learned in lectures. **The main purpose of this paper is to describe the efforts of developing the lecture/experimental activity package and also the preliminary results of beta-testing of this package.** Upon successful implementation, the newly improved course will be offered starting next AY 2012-2013. The efforts of building a new laboratory for mechanical experiments will also be described.

We propose several mechanical experiments such as*: tensile test*: a metal bar (tensile specimen) is loaded in longitudinal tension; *elastic behavior of metal in torsion*: strains are measured on the surface of a metal tube or solid shaft loaded in pure torsion; *elastic-plastic behavior of a simply supported beam*. The objectives of the experimental activities are to correlate theory with practical approaches and to enable students to better understand the applications of theoretical concepts presented (i.e. strain and shear stress, Young's Modulus etc.). Students will observe, and analyze several phenomena such as the bar's behavior to fracture and the material's stiffness, strength and ductility, they will use load deflection data to measure of Young's modulus, the tensile stress at yield and ultimate load carrying capacity of the beam. All these experiments will be also enhanced by modern simulation software and data acquisition hardware that will generate real-like industrial scenarios. Therefore, student will gain a broader perspective over the subject taught with a more in-depth understanding, enabling them to use this knowledge in other courses such as manufacturing, dynamics, quality control, sensors and measurements etc. In this way, the course gains multi- and interdisciplinary character, enabling students to acquire necessary skills in developing their future projects including "Senior Design".

Introduction and Background

Industrial advances in the past decade demands Engineering Technology (ET) curricula to continuously adapt by adopting new and improved strategies in engineering technology education[1, 2]. The general trend of today's ET education is moving rapidly towards meeting the demands of industrial world in terms of skills development and degrees offered. ET curricula need to adapt to emerging technologies by enabling students to acquire meaningful and relevant practices. Although new courses based on novel approaches are implemented in order to answer the new industrial and technological challenges, the existing courses need to be re-designed to answer to these challenges. Introducing the integrative multidisciplinary approach of teaching lecture-based courses such as Applied Mechanics is beneficial in terms of improving teaching and learning, motivating students to further their academic progress and faculty to improve their industrial experience and to gain more insight into industry. Laboratory based courses are vital to ET programs, since they are the backbone of skills-building process, ultimately leading towards developing experience-led engineering technology degree [2, 3]. Also laboratory activities developed should become more and more a place where students can and will be creative, where they will be able to develop not only required skills, but also a place where to practice and improve them. Creative design can be productively taught throughout several courses in ET, but their effective translation and integration into the engineering technology curricula are sorely lacking[3, 11]. One way to lead the students to become creative and innovative in ET is building a systematic approach of the knowledge to be conveyed during class time by combining laboratory activities with a well-structured in class lecture[13, 14, 15]. Benson et-al of Clemson University clearly demonstrated a successful implementation of this approach in their SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) format which is a specialized active learning format that relies largely upon social interaction among students, instructor, and learning assistants[14]. Our curriculum changes and improvements also are being supported by The Foundation Coalition partners having a goal of graduating a new generation of engineers who can more effectively solve the increasingly complex, rapidly changing societal problems[15, 25]. Our program is based mainly on hands-on type of curricula and most of our courses are either laboratory based or project-based courses. Very few of them though remained to be taught in the traditional way: dry-lecture type, having topics that are difficult to treat and to be understood by the students that are mostly kinesthetic and visual learners. These students are forming the vast majority of our student body. The main idea of incorporating laboratory activities into a classic lecture-based course stemmed from our ET students' feedback received over the past years. After a careful analysis of the course content in our attempt to teach the Applied Mechanics course in a more cohesive and integrative manner, we developed couple laboratory activities that will complement and /or replace the pure theoretical approach used to teach the material, combining the traditional students' exposure to theoretical concepts and notions with hands-on activities strictly linked to a real-life industrial setting [11]. These experiments will enable students to become cognizant of the multidisciplinary aspects of the subject taught. Also, this approach promotes student-centered learning and problem-solving as well as develops teamwork skills [13, 14, 15].

Course Re-development – Organization and Content

Most of the mechanical engineering and mechanical engineering technology programs offers lecture-based courses in mechanics (statics and dynamics) and separately courses in experimental mechanics. Since our program curriculum already includes 187 credit-hours for its engineering technology degrees, adding a new laboratory type core curriculum course in applied mechanics is not possible. The only way to introduce hands-on activities into Applied Mechanics course is to combine in one course both the theory and the laboratory applications. It is a challenging endeavor since we strive to not curtail the theoretical foundation and yet we aim to introduce new lab activities to complement the theory in the same 3 hours credit course.

In redeveloping the course we mainly focused on improving student understanding of the concepts of statics and mechanics of materials with applications in manufacturing. This three-hour credit course is addressed to sophomore and pre-junior level undergraduate students, being a core curriculum course for Mechanical Engineering Technology, Electrical Engineering Technology and Industrial Engineering Technology concentrations. The new re-developed course will be offered starting AY 2012 - 2013. Also, a continuous improvement process will be performed based on the evaluation and assessment of each course offered. Due to the time constrains, since our university is a quarter-based institution, course materials are divided in ten modules. The modules are divided into three parts: ***basic principles, system technology, and experimental aspects of the topics***. The imparted knowledge is divided into two parts: the first part is the basic knowledge, and the second part is the deepened knowledge, additional contents of teaching, and references. Students are assessed on midterm and final exams, covering theoretical aspects of the topic and based on the laboratory activity reports.

The students will follow a sequence of lectures on the topics including Force vectors, Force system resultants, Equilibrium of a rigid body, Structural analysis, Stress and Strain, Torsion and Bending. The lectures will be supported and integrated with laboratory experience. Students are also introduced to manufacturing and measurement tools for creating experiments as an active and interactive interface between the physical setting and the theoretical notions.

The main objectives of the course are to expose the students to principles of the moments and couples using a variety of equilibrium of simple force systems, to analyze the simple stress, shear and axial strain by coplanar parallel force systems and concurrent force systems, to determine reactions, centroids, moment of inertia, shear and moment in beams, the flexure formula and load capacity of a beam.
Upon completion of this course students will be able to:

1. Add forces and resolve them into components using parallelogram law.
2. Express force and position in Cartesian vector form and obtain vector's magnitude and direction.
3. Understand the concept of the moment of a force and how to calculate it in 2D/3D. Define a moment of a couple.
4. Develop equations of equilibrium for a rigid body. Establish the free body diagram for a rigid body. Solve rigid-body equilibrium using equations of equilibrium.
5. Determine the forces in the members of a truss using methods of joints and sections.
6. Know the concepts of centroid, moment of inertia and be able to compute them for composite structures.

7. Use the method of sections to determine the internal shear and moments.
8. Understand the meanings of normal and shear stress and strain. Know about the Hook's law and mechanical properties.
9. Apply the above concepts to specific applications such as torsion and bending. Learn how to calculate the torsional deformation of a circular shaft as well as the maximum power transmitted.
10. Draw the shear-moment diagrams in beams.
11. Determine maximum bending stress in beams and understand the flexure formula.

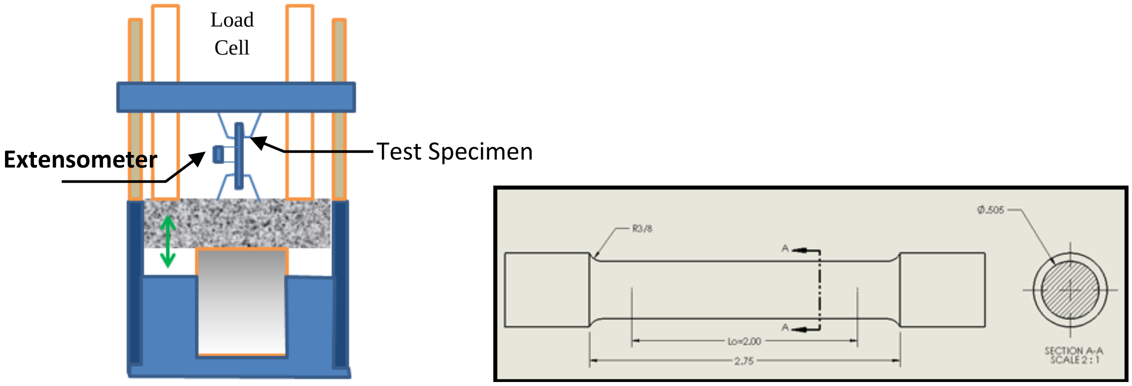
To achieve these goals and outcomes, besides the traditional lectured material, student will be asked to perform the experimental activities described in the paper. One important aspect in Engineering Technology is experiment design – including both the parameters of the actual experiment to be conducted, as well as the specifics of how to go about performing the actual experiment. In order to provide ET students with valuable experience in experiment design, we have designed a series of exercises to walk students through the design, construction, and implementation of an experiment. These exercises introduce students to the many variables and potential problems involved in designing a typical scientific experiment. In addition, students gain familiarity with typical scientific concepts such as strain and shear stress, Young's Modulus, etc. Required test bars and specimens for mechanical testing will be produced in the Engineering Technology-Mechanical laboratory using Computer Numerical Control (CNC) machining equipment that is being acquired by a recent NSF-TUES grant, specifically a CNC lathe with a tail stock support[26]. Test bars will be machined from solid stock material using standard sizes recommended by ASTM. Mechanical lab houses another CNC milling machine for rectangular test bar machining. These manufacturing capabilities enhance integration between laboratory based courses such as Applied Mechanics and Computer Numerical Control.

Laboratory Activities

Tensile Test

In this experiment, students may observe the bar's behavior to fracture and also they can measure the material's strength and ductility. Students will gain experience in uni-axial testing of a wide range of materials.[10, 18, 22, 23].

In this test, a metal-tensile specimen bar is loaded in longitudinal uni-axial tension. The material and equipment needed for this experiment are: a tensile specimen of a ductile/brittle metal, machined to standard ASTM specifications; a micrometer/caliper to measure specimen diameter, and a modern universal testing machine equipped to measure and automatically record the specimen's tensile load (P) and its elongation per unit length, or engineering tensile strain. Students will use Tinius-Olsen (T/O) Universal testing machine located at the Engineering Technology Mechanical Lab during this experiment. A double acting piston drives the table up, or down, when pressurized hydraulically. The test specimen is fixed relative to the top bar and the shaded cross bar by the grips; the shaded cross bar is fixed in space. Hence, the specimen is subject to a tensile load as the table moves downward. The test bar materials are AISI1018 CRS, 6061-T6 Al and Cast Iron to observe different facture characteristics of these materials.



(a) **(b)**

Figure 1. **(a)** Schematic view of Tinius-Olsen Tensile Testing machine **(b)** Metal tensile specimen recommended by ASTM (Gage length L_0= 2.00in, D=.505in)

During the testing, T/O machine will apply the load and an extensometer will record the corresponding elongation during experimentation. The unit will record the load-elongation data during the experiment so this data can be plotted once the procedure is complete. Students will gain experience while setting the machine up by installing extensometer sensor and setting test speed (ex. 0.025 in/min) and preloading and loading the test specimen to rupture while observing safety precautions such as wearing safety goggles.

(a) **(b)**

Figure 2. (a) Existing Tinius Olsen Universal Testing machine with 25kTon capacity
(b) Rockwell Hardness tester at DU Engineering Technology Lab.

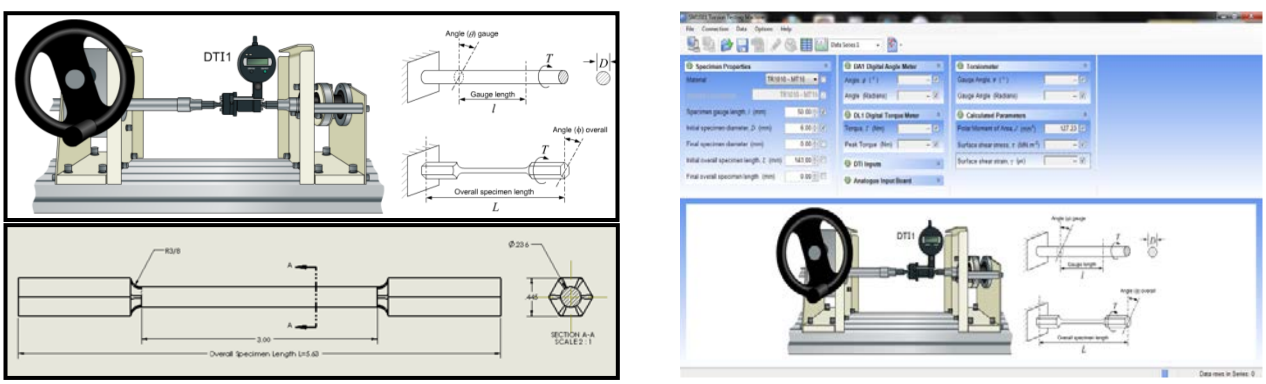
Students will determine and tabulate quantities such as % Elongation, Reduction in Area (%) Modulus of Elasticity (Young's Modulus), Yield Strength and finally Ultimate Tensile Strength (AKA UTS)

Students will be required generate two stress-strain graphs for each sample, one showing the linear portion of the curve to just after the yield point and the other showing the entire response curve from initial loading to failure. On these graphs, students will clearly label important regions, areas and/or points on the plot that correspond to the data that were calculated.

Torsion Test-Elastic Behavior of Metal in Torsion:

The main learning objective of this activity is the enhancement of students' understanding of concepts such as material's shear modulus, the critical shear stresses at yield and ultimate stresses, and ultimate torque capacity of the shaft.[10, 16, 22, 23, 24]. To achieve that, students are required to measure the above mentioned parameters.

The Torsion Testing Machine is a compact machine, ideal for classroom demonstrations and for safe use by small groups of students. The machine has a maximum capacity of 30 Nm. An accurate encoder measures the strain (angular movement) at the strain head. The encoder has a digital display that will be connected to TecQuipment's Versatile Data Acquisition System (VDAS). For increased strain measurement accuracy, students will use the Torsiometer. The increased accuracy is useful to help find the modulus of rigidity (shear modulus). The Torsiometer has a digital display of angular movement, calibrated to the strain angle (in radians).



(a) (b)

Figure 3. **(a)** SM1001 Torsion Testing Machine and Torsiometer (Top), Standard Torsion Specimen (Bottom) **(b)** VDAS data acquisition software.

Using Torsion Testing Machine a torsion test is relatively easy to perform by ET students. A solid, ductile metal (AISI1018 CRS or 6061-T6 Al) torsion test specimen is loaded in pure torsion. The angle of twist is increased at a constant rate and the corresponding torque is measured at predetermined increments. These values will be graphed to find a number of engineering values. As in a tensile test, there will be an elastic or linear portion of the curve where a proportional relationship can be used to determine engineering values. In a Torque vs. Angle of twist relationship, the value that will be determined is the modulus of rigidity, also known as the shear modulus.

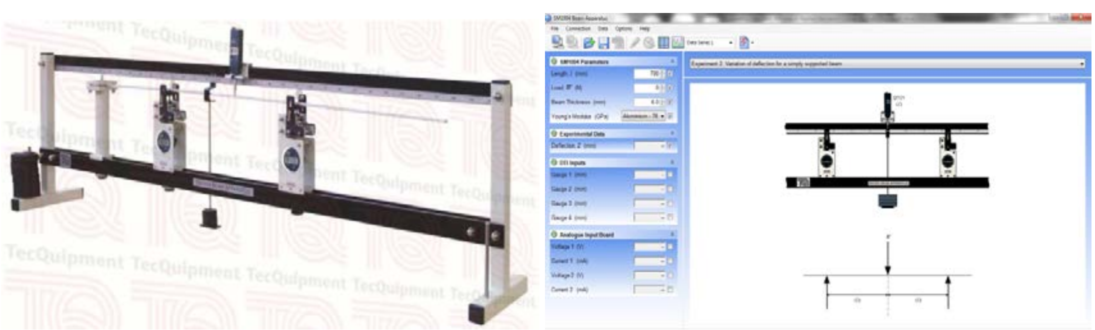
During testing with Torsion Testing Machine students will measure the overall length and test diameter of the specimen. They will draw a line down the length of the degree of the section of the specimen with a pencil which serves as a visual aid to the degree of twist being put on the specimen during loading. After mounting the specimen firmly in the Torsion Testing Machine, for each increment of strain, students will be recording the angle of twist of the specimen as well as applied torque in the elastic limit. After elastic limit has been passed, torsion test will be continued until destruction.

After torsion testing, students will determine the modulus of rigidity for each specimen; calculate the proportional limit shear stress for each specimen and calculate the torsional modulus of rupture for each specimen by plotting curves of torque vs. angle of twist for both the aluminum and steel specimens.

Elastic-Plastic Behavior of a Simply Supported Beam

During this experiment, students will use load-deflection data to give measures of Young's modulus, tensile stresses at yield and ultimate, and the load carrying capacity of the beam.[10, 16, 22, 23, 24]. To achieve this we use a simply supported ductile metal beam, loaded at mid-span as presented in the figure below.

A beam is typically defined as a slender bar capable of supporting transverse loading perpendicular to the bar. An applied transverse load to a beam results in internal forces of shear and bending moments. In the earlier experiments described above testing various materials in the lab, axial and torsional loads carried similar internal forces that were constant within the test portion of the sample. With beams, this may not be the case. Depending on how the beam is loaded, shear forces and bending moments may vary continuously along the length of the beam. It is importing in analyzing a beam and its corresponding loading to construct accurate shear and bending moment diagrams to visually determine what forces are acting on the member.



(a) (b)

Figure 4. (a) Experimental Setup for Testing Elastic-Plastic Behavior of a Simply Supported Beam using Beam Apparatus (TecQuipment 1004) (b) VDAS data acquisition software.

There will be two types of stresses on the transverse section of the beam, normal stress caused by bending moments as well as shear stresses due to shear forces applied to the beam. The distribution of these shear forces and bending forces must be visually shown in order to accurately compute stresses and deflections of the beam. For this experiment, ET students will be using a simply supported beam (Figure 4a) that has a pinned support at one end and a roller support at the opposite end.

The Beam Apparatus allows an extensive range of experiments to cover virtually all course requirements relating to bending of beams. The basic unit provides facilities for supporting beams on simple, built-in and sinking supports, applying point loads, and measuring support reactions and beam deflections. During the experiments, three standard test beams will be used. The beams are in 6.4mm thickness and include three different materials. They are suitable for the complete range of experiments covering different loading and support configurations.

Test System applies a controlled load on a specimen slowly and steadily, thereby bending it. The user specifies test parameters such as type of test, units, preload, crosshead speed, and extensometer while the computer controls most of the testing process, including recording the applied load, deflection and the load-deflection curve.

Assessment and Evaluation of the project

The “Applied Mechanics” courses using the laboratory applications and the methods described in this paper will be offered for the first time in the AY 2012-2013. However, this course has been part of our core curriculum for the past 10 years in the traditional dry-lecture format. The overall students’ evaluation scores for this course in the past academic years were above average, ranging from 3.4 to 3.8 out of 4.0. However, students’ comments stressed the necessity of incorporating hands-on activities in this particular course to enhance their understanding of basic principles. The preliminary assessment of the course will be performed based on the questions listed in table below:

Table 1: Questionnaire for the evaluation of the senior project design courses

Q1	Are the new course laboratory activities challenging and interesting?
Q2	Have you learn more than expected with the course?
Q3	Are the lab activities useful to you?
Q4	What was the level of “hands-on” experience has been achieved through the laboratory exercises?
Q5	Please, provide an overall evaluation of the course.

Since the course was not offered yet in this format, we are in progress of performing only a partial based on “beta-testing”. We are developing the laboratory activities with the help of our senior undergraduate students and we recruited volunteer students to perform laboratory activities described here. The volunteer students will be requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisfactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 1, and based on their feedback we will refine and improve the laboratory activities and manuals. Similar surveys were or are planned to be conducted at the end of each quarter of the current and next academic years. Also, more in-depth evaluation and assessment of this course will be performed starting with the next academic year. The future procedure is described below.

Evaluation of the course and data collection will begin soon after the start of the course. On the first meeting of each course, students will be administered a preliminary assessment test to gauge students' background and preparation for the course. For example, their knowledge of appropriate physics and statistics will be evaluated. Based on the results of the test, students will be divided by groups according to the think-share-report-learn (TSRL) process, which will involve student peer coaching to help each other during the laboratory procedures.

Evaluation evidence will be generated through activities integrated into the natural flow of the course. Both qualitative and quantitative data will be collected to assess course performance. The formative evaluation will provide evidence of the strengths and weaknesses of the proposed course. The preliminary and intermediate analyses made by the students also provide numerous metrics to the instructors, which can be used to monitor the competency and understanding of the students' use and application of statics and mechanics of materials concepts.

Standard course evaluation forms will ask students to compare their level of competence in areas identified in the course objectives at the end of the course to their level before taking the course. This provides immediate feedback on the success of the course in meeting its objectives. The form will include the Likert-type questions, which assess the students' perception of their confidence, knowledge, and competence.

Conclusions and Future Work

In this paper, the design and application of a tensile testing, torsion testing as well as beam testing system as a means of experiential learning in the applied mechanics were discussed. In the engineering education literature, it is well established that combining hands on laboratory experiments improve fundamental understanding of the covered topics in the traditional subject of applied mechanics and thereby increasing students' real-world knowledge. The effectiveness and impact of combining engineering analysis with hands on physical experiments will be measured using student surveys as well as student performances on term exams and quizzes.

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