Student Designed Experiments in a Traditional Mechanics of Materials Laboratory Course

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Abstract
Criterion 3 of *ABET 2004-2005 Criteria for Accrediting Engineering Programs*[1] requires that all engineering programs seeking accreditation manifest that their graduates have an ability to "design and conduct experiments as well as to analyze and interpret data." The *ASCE Civil Engineering Body of Knowledge for the 21st Century*[4] supports this requirement and expands on its merit as related to the work of typical civil engineers. Many structural, transportation, environmental, and geotechnical engineers conduct onsite, laboratory, or computer modeling experiments on a regular basis. These studies often culminate in technical reports. Civil engineering programs often attempt to prepare students for such activities by requiring all students to participate in laboratory exercises and to prepare formal reports of the resulting data analysis and interpretation. Although a traditional mechanics of materials laboratory course can meet this goal, commonly used experiments do not prepare students to conduct a critical part of the process described in ABET Criterion 3; *designing* the experiment. Through the help of a benefactor, the Department of Civil and Environmental Engineering at The Citadel has attempted to address this issue in its Mechanics of Materials Laboratory (CIVL 307) course by replacing over fifty percent of the experiments. Students now design their own experiments with various pieces of equipment that attach to a large structural frame. Beam bending, column buckling, and shear and bending moment are a few of the subjects studied in the new exercises. In addition, all students are required to write a formal report to a product developer describing the experimental testing that would likely be required for his/her new product to obtain approval by the International Code Council Evaluation Service, Inc. This paper presents the laboratory design process used by the students for several exercises performed in CIVL 307, an evolutionary summary of student responses to the design process, and the results of a student attitudes assessment survey performed at the end of the semester.

Introduction
For civil engineering students, the value of laboratory experimentation cannot be overstated. It would be advantageous to solve all problems in the engineering field analytically; however, that is neither practical nor achievable. In most disciplines of civil engineering, engineers are at times required to conduct and/or design onsite, laboratory, or computer modeling experiments and it is essential for students to understand the basic concepts needed to design and conduct these experiments. Moreover, ABET Criterion 3 indicates that students must have a clear

understanding of the basic principles of an experiment including designing and conducting the experiment as well as analyzing the resulting data.

Many civil engineering departments, including The Citadel's, use laboratories as a means to teach students these principles. However, a traditional student laboratory does not necessarily cover all of the requirements set forth by ABET. In fact, the major component of "designing" an experiment can easily be overlooked in a mechanics of materials laboratory. The ability to design requires not only knowledge of appropriate ASTM testing protocol, but also an understanding of what needs to be tested in order to prove a specific principle. To learn such principles, students must have experience designing experiments themselves. In this paper, experiments are referred to as "professor designed" or "student designed." Professor designed experiments (such as tension tests) require little preparation by the student, but are valuable to the learning process. Student designed experiments require students to prove a specific engineering principle by using available equipment combined with prior knowledge of engineering mechanics.

Student involvement in the design process encourages active learning. The literature suggests that an active learning laboratory style is required for students to achieve the highest knowledge level of the course material. Upchurch and Thai[10] describes a interactive laboratory that allows all electrical systems students to participate in the exercises. Specifically, on independent computers, students can mimic the teacher, work independently, or work with other students. The professor can intervene at anytime. Miller et al.[7] presents the results of laboratory improvements that include increased emphasis on report writing, peer review, and student planning of experiments. Adams et al.[2] presents the use of hands on experiments to generate student interest in digital signal processing prior to the achieving senior status. Alexander and Smelser[3] present the redesign of a mechanics of materials laboratory course to include multimedia experiments and portable hands on equipment to allow distance learning with an active component. Mosterman et al.[9] shows that students that participate in virtual laboratories prior to performing experiments learn more and perform more efficiently. Guessous et al.[6] discusses the use of commercial software to enhance learning in laboratory courses and computational fluid dynamics.

By focusing on the design of laboratory experiments, Chaplin[5] and Most et al.[8] are most relevant to the subject of this paper. For a biology laboratory, Chaplin[5] describes how students can focus on experimental design and hypothesis testing and avoid getting caught in the routine of professor designed experiments. The biology laboratory concentrates on statistical analysis at the beginning, primary literature for interpretation in the middle, and students designing their own experiments at the semester's end. Most et al.[8] focuses on meeting ABET requirements in laboratory courses and contains specific findings regarding design. The author states that there is much confusion over how "design," as intended by ABET, can really be implemented in many laboratories. According to the author, some faculty question the role of design in the laboratory and state that time constraints may not allow for adequate inclusion of design in the laboratory.

In an effort to address the issue of design and to create an environment that encourages active learning, The Citadel's Mechanics of Materials Laboratory (CIVL 307) course has been revamped. Approximately half of the traditional professor designed laboratory exercises have been replaced with new equipment and new exercises that allow for student design experiences. Figure 1 shows some of the outdated equipment from the old exercises and Figure 2 shows some of the new equipment used in the fall 2004 course. The initial five laboratory exercises remain professor designed for several reasons. The focus of these labs is on the broad understanding of the laboratory as well as developing well-written formal reports. In addition, all of the professor designed exercises require loading the specimen to failure making it expensive to have each student run their own test. The remaining laboratory exercises are student designed and implemented using various apparatuses that attach to a structural frame. Students are allowed the freedom to design and conduct an experiment, but are also required to write a formal report analyzing and interpreting the data to ensure accuracy and appropriate design.

Figure 1. Outdated equipment used in mechanics of materials laboratory prior to fall 2004.

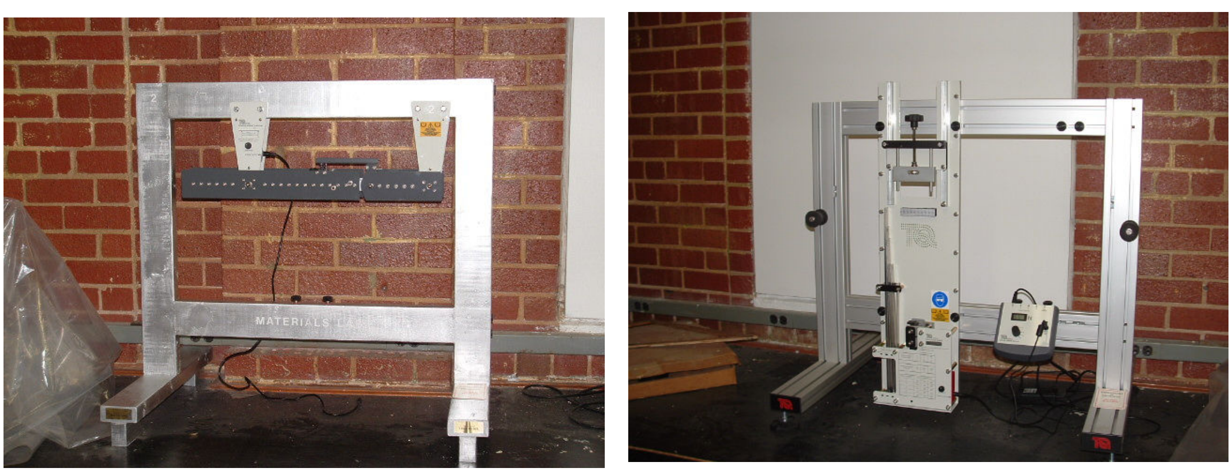

Figure 2. New equipment used in 2004 mechanics of materials laboratory.

Summary of 2004 Mechanics of Material Laboratory Course (CIVL 307)
The mechanics of material laboratory course begins with traditional professor lead experiments and concludes with student designed laboratories. The initial experiments allow students to participate in the experimental process by operating various testing machines and equipment under strict supervision by the professor. Students are required to write a technical lab report, which presents their results and reflects upon their understanding of the exercise. The design process for the initial labs is non-existent and each lab requires a preliminary setup by a laboratory technician and assistance from the professor during the experimental process. Following the completion of the five professor designed experiments, student designed experiments are introduced to create an environment of active learning.

The student designed exercises cover bending stresses in a beam, shear and bending moment in a beam, beam deflections, and column buckling. Each of the aforementioned experiments are conducted on fixed structural frame that allows students to accurately conduct their own individual exercises. As shown in Figure 3, whether hanging their own weights from the beam or taking their own measurements, students are actively involved in learning and proving engineering principles through design. Without specific laboratory manuals or precise professor guidelines, students are able to use the equipment in anyway that is advantageous to their own personal learning style and understanding of the core material. For example the student shown in Figure 3 is working on the bending moment experiment station and using weights, measurements, strains, and individual setup and design to prove certain relationships between external loading and internal bending moments in a beam.

Figure 3. Student working on a student designed experiment.

Whereas the professor designed laboratories take a significant amount of time to prepare and discuss, student designed exercises require less assistance. Students are also able to run more than one trial if needed, and more importantly, students have time to perform calculations in class. It should be noted that about 25 percent of students involved in the CIVL 307 course voluntarily remained in the laboratory to check their calculations following the completion of the student designed experiments.

An anonymous ten-question survey was conducted upon completion of the 2004 CIVL 307 course. The survey was composed of remarks to which the students responded with their level of agreement ranging from strongly agree to strongly disagree. Some of the questions and results included the following:

- Relative to professor designed labs, student designed labs required better understanding of all components of the experiment. (Responses: agree- 84%, undecided- 16%, disagree- 0%)
- Relative to professor designed labs, student designed labs better taught me how to design and test for a condition. (Responses: agree- 79%, undecided- 18%, disagree- 3%)
- The labs that were student designed resulted in a better overall understanding on the part of the student. (Responses: agree- 89%, undecided- 11%, disagree- 0%)

The above results represent the general sentiment that the student designed labs offered more practical experience to the students than the professor designed labs. The results of the final survey question are shown graphically in Figure 4. For brevity, the entire survey results are not shown here, but all results support the conclusion that students prefer the student designed laboratories over the traditional professor designed exercises.

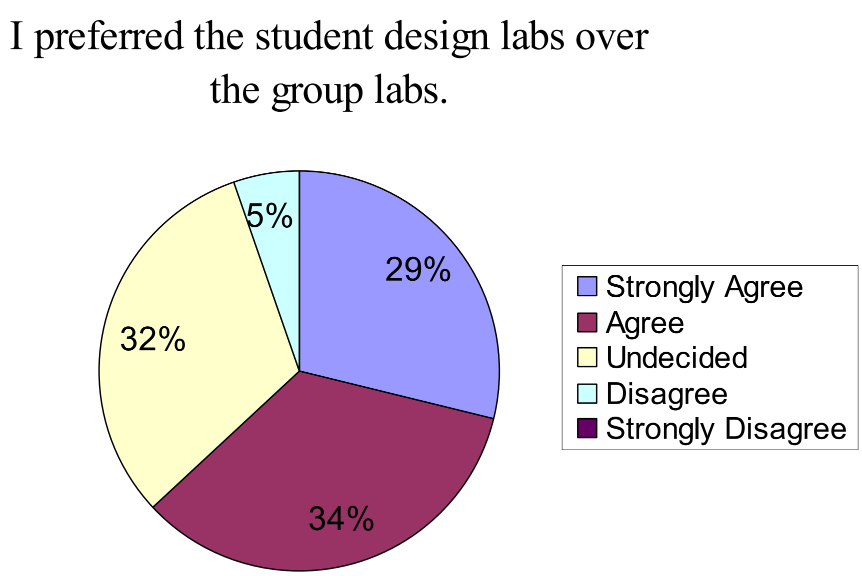

Figure 4. Graph of the student preference as determined by an anonymous survey.

Additional Formal Report to Include Experimental Design for Actual Product

Even with the experimental shift from professor designed laboratory experiments to student designed laboratory experiments as described in the previous section, students and future engineers still miss a key element of the design process. Many products specified by structural engineers are pre-engineered and are approved for use as products that are in accordance with the governing building code in association with the International Code Council Evaluation Service (ICC-ES). The typical process follows:

- A product is invented for use as a structural system
- The inventor hires an engineer to work with ICC-ES to develop a report of calculations and experimental testing results to prove that the product meets the minimum standards in the governing building code
- ICC-ES evaluates the report and either requests more information or approves the product by issuing a report stating that the product appears to meet the intent of the relevant building code
- The product inventor markets his or her product using the ICBO-ES evaluation report issued after product approval

As part of the CIVL 307 course, students are required to design experiments necessary to approve a specific product. The following is an excerpt from a typical assignment.

Sample Student Assignment

As a young engineer, you have been informed about a newly invented product (special screw with locking mechanism) that easily connects plywood to wooden window openings to help protect homes during hurricanes. Your professor has informed you that you must prove to the ICC Evaluation Service that this product works so that they can approve it for use in accordance with the governing building code in South Carolina. All students are required to author a report on the ICBO Evaluation Service and approval process by first perusing the website http://www.icbo.org/ICBO_ES/ and then summarizing the steps that are required for approval of the new product by analyzing similar products that are marketed and approved for use today. A major focus of the report should include a determination of proposed experimental testing requirements contrasted with limit states that require only hand calculations.

Summary and Conclusions

Through the help of a benefactor, the Department of Civil & Environmental Engineering at The Citadel has attempted to address the lack of design in its Mechanics of Materials Laboratory (CIVL 307) course by replacing over fifty percent of the experiments. An active learning environment is now in place where students can design their own experiments with various pieces of equipment that attach to a large structural frame. The students consistently agree that the new student designed experiments provide a very effective tool for learning the material covered in a standard mechanics of materials laboratory course.

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