

AC 2007-1800: SELF-PACED LABORATORY MODULES FOR ENGINEERING MATERIALS AND MANUFACTURING PROCESSES LABORATORY COURSE

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Self-Paced Laboratory Modules for Engineering Materials and Manufacturing Processes Laboratory Course

Abstract

Recently, the number of mechanical engineering majors in our department has risen sharply. While growth is exciting, it has stretched the capacity of our teaching laboratory facilities. One of the greatest challenges is keeping a larger group of students engaged in learning activities during a laboratory exercise that requires students to take turns using a single, major piece of equipment. Another challenge is to the instructor's ability to grade the greater number of laboratory reports with the same degree of rigor.

In preparation for the Spring 2006 course offering, I solicited and discussed ideas for improvements and changes to the laboratory format with faculty, staff, and students who had previously taken the class. Because of its small size, our machine shop is too small to allow extensive student training on the equipment; however, the students strongly recommended that more hands-on experience with manufacturing methods was needed. They suggested components of laboratory exercises that could be deleted from the formal exercise and converted into self-paced, independent student activities. Our department's machinist is heavily involved in working with students in the capstone design courses in the second half of each semester; therefore, the assistance of the staff machinist was incorporated into additional self-paced manufacturing exercises during the first half of the semester.

This report describes the steps that were taken to maintain the quality of the hands-on experiences of a greater number of students in a laboratory course with limited laboratory space, a description of the modifications and innovations that were attempted, and a review of which modifications were successful and which require future modification or replacement.

Introduction

In the second semester of their junior year, our mechanical engineering students take EGR3322 – Mechanical Engineering Materials and Manufacturing Processes (hereafter referred to as Materials), a 3-credit course (i.e., 2 credits lecture / 1 credit laboratory) that is their first upper-division, hands-on laboratory course. ABET outcomes that are specifically addressed in this course include:

- **a:** *an ability to apply knowledge of mathematics, science, and engineering;*
- **b:** *an ability to design and conduct experiments, as well as to analyze and interpret data;*
- **c:** *an ability to design a system, component, or process to meet desired needs;*
- **e:** *an ability to identify, formulate, and solve engineering problems;*
- **g:** *an ability to communicate effectively;*
- **j:** *a knowledge of contemporary issues;*
- **k:** *an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.*

Our mechanical engineering program has been historically small, and the laboratory's physical space is well-suited for small sections (i.e., under 10-12). Students are grouped in teams of two to three and required to write formal memo-style laboratory reports to hone their technical writing and graphical communication skills. There are 11-12 laboratory exercises over the course of the semester with grammar, vocabulary, formatting, and presentation weighted at 10% of the laboratory report grade.

Prior to May 2004, only bachelors' degrees in mechanical, electrical and computer, and general engineering were offered in our school. In May 2004, masters degrees in mechanical, electrical and computer, and biomedical engineering were added. Recently, the number of incoming freshman declaring their major in mechanical engineering has risen sharply. The number of juniors enrolling in Materials has doubled in the last three years and is projected to see an additional 30% or more increase in enrollment in Spring 2008. While growth is exciting, it has stretched the capacity of our teaching laboratory facilities and the capacity of the instructor to grade the increased volume of laboratory reports with the same degree of rigor. However, the recent addition of a masters program made teaching assistants available to assist during laboratory sessions.

Keeping a larger group of students engaged in active learning activities during a laboratory exercise that requires students to take turns using a single, major piece of equipment (e.g., the single electromechanical testing system used for compression and tension testing of materials) can be challenging. I sought guidance from a variety of sources, including students who had previously taken Materials, other faculty, the department's machinist, and presentations I had attended at a previous ASEE conference. The process that I went through to improve the laboratory experience for a larger class of students without sacrificing the quality of the hands-on learning experience is presented in this report.

Feedback from Past Students

Previously, student feedback in end-of-the-semester teaching evaluations indicated that the laboratory report format and the high expectations with regard to writing skills were quite unpopular with the students. This was expected; although, the importance of sound technical writing skills in the engineering profession outweighed student discomfort in my mind. My intent at the beginning of this inquiry process was to simplify the laboratory report format on most laboratory exercises and to require perhaps one or two full laboratory reports.

First, I invited students who had previously taken my course and who were still students at the university to sit down with me in a local coffee shop for a discussion of their opinions of the course and their suggestions for improving the laboratory experience for future students. Two undergraduate students who had taken the course in the previous year, one undergraduate student who had taken the course 2 years before, and three masters students who had taken the course 3 years before agreed to provide feedback. Based on comments in past teacher evaluations and from students during the semester, I expected that the students who had previously taken this course would recommend a lighter load with respect to the technical writing of lab reports. It was a gratifying revelation to hear the students universally state that they did not recommend simplifying the laboratory report requirements or lowering my expectations with regard to grammar and presentation. One student in particular stated that he did not fully appreciate the

benefit he gained because of the improvement in his technical writing skills until he enrolled in the fluids-thermodynamics lab course and the capstone senior design course in his senior year. The graduate students suggested parts of the laboratory exercises that could be stripped out and converted into self-paced, individual exercises, such as learning to use the Rockwell and Brinnell hardness testers under teaching assistant supervision or learning the proper use of a variety of measurement tools. They felt that this would facilitate additional laboratory exercises.

Because of the small size of our department's machine shop, most students' first opportunity to work in the machine shop in previous semesters was the welding laboratory exercise in which the students welded two steel specimens together, milled a tensile dogbone with the weld in the gage length, tested the strength of their weld in tension, and compared their results to the tensile strength of the bulk steel. Most of the students stated that this was their favorite lab and requested more exercises that would teach them machining skills. Several of the students requested more exposure to manufacturing processes, such as sand casting. One of the students suggested adding an exercise involving fasteners, particularly focusing on the information available in the Machinery's Handbook and vendor catalogs.

Feedback from the Machinist

Our machinist, previously employed in the aerospace industry, is eager to work with students. He suggested that students needed more exposure to the proper use of a variety of measuring tools, including inner diameter micrometers, outer diameter micrometers, depth micrometers, dial calipers, and fastener sizing tools. The translation of measurements into properly drawn and dimensioned technical drawings was a topic needing attention. Previously, Materials students had learned the proper use of a dial caliper and outer diameter micrometer during the course of a laboratory experiment via the instructor's or teaching assistant's demonstration.

The machinist also suggested that the students practice technical drawing skills by hand so that they could communicate better with him when they were discussing their component designs in senior design and to better prepare them for future interaction with machinists in industry. When I mentioned the student feedback regarding machine shop skills, the machinist suggested demonstrating the CNC mill and teaching the students to drill and tap a hole for a threaded fastener. In the second half of the semester, his time is dedicated to work in support of the junior- and senior-level design courses; however, he was available during the first half of the semester.

Feedback from Faculty

Feedback from other mechanical engineering faculty with expertise in materials and mechanics ran along similar lines to student and machinist suggestions. One recommended additional exposure to manufacturing methods. One recommended a metallography lab in which the students would mount, polish, and etch a specimen and study its microstructure using a metallographic microscope. All suggested adding a laboratory exercise related to new technologies, such as smart materials, rapid prototyping, or nanomaterials. The department chair approved the use of the machinist's time during the first half of the semester.

Assessing the Existing Laboratory Exercises

Armed with a plethora of ideas and suggestions, the first step was to assess the previous year's laboratory exercises in order to strip out those activities that could be converted into self-paced, individual exercises, dubbed Mini Labs. The existing laboratory exercises, the first three of which were Strength of Materials labs, included:

- Lab 1 - Static Strain Measurement – Students determined the elastic modulus of 6 cantilevered, strain-gaged beams.
- Lab 2 – Dynamic Strain Measurement – Students used the same 6 beams to study vibrational characteristics of the materials.
- Lab 3 – Pressure Vessel Measurement – Students mounted strain gages to soft drink cans to estimate the pressure inside the can.
- Lab 4 – Tensile Test – Students tested steel and aluminum specimens according to ASTM E8 standards and estimated a variety of material properties.
- Lab 5 – Statistical Analysis / Tensile Testing of Manufactured Components – Students tested a large number of bolts according to ASTM standards.
- Lab 6 – Fatigue – Students generated S-N curves for both aluminum and steel specimens that were tested on a rotating-bending apparatus.
- Lab 7 – Composites – Students compared the compressive strength of an aluminum pipe, a plaster of paris cylinder, and a composite of the two materials.
- Lab 8 – Heat Treatment and Hardness Testing – Students performed heat treatments on aluminum and steel.
- Lab 9 – Welding – Students welded steel pieces together, milled their specimen into a tensile specimen, and compared their weld strength to that of the bulk material.
- Lab 10 – CES 2006 Software Tutorial (<http://www.grantadesign.com/>, Granta Design Limited 2006) – Instruction in the use of materials selection software package.
- Lab 11 – Metallography- Students examined previously polished and etched specimens from a lawnmower engine.

New Labs and Mini Labs

The CES Software demonstration in Lab 10 was converted to a self-paced Mini Lab. The hardness testing instruction in Lab 8 was stripped out of the lab and converted to a Mini-Lab. Lab 2 was retired in favor of adding more materials and manufacturing lab exercises. The new Mini Labs included:

- Mini Lab 1 – Grammar Review for Technical Writing.
- Mini Lab 2 – Measurements – Instruction in the proper use of a dial caliper, vernier caliper, outer diameter micrometer, inner diameter micrometer, and depth micrometer.
- Mini Lab 3 – Fasteners – Instruction in sizing and identifying a variety of bolts, screws, and nuts.
- Mini Lab 4 – Hardness Testing – Instruction in operation of Brinnell and Rockwell hardness testers under a teaching assistant's supervision.
- Mini Lab 5 – Drilling and Tapping – Instruction in drilling and tapping a threaded hole using a mill.
- Mini Labs 6-8 – Graphical Communication – Instruction in hand drawing and dimensioning of engineering components.

- Mini Lab 9 – CES Software tutorial.

All Mini Labs were to be completed during laboratory periods only. An electrical engineering flex lab, next door to the Materials lab, was utilized as an overflow room to prevent overcrowding in the lab. With the exception of Mini Labs 1 and 4, which had specific due dates, the Mini Labs could be performed in any order and were due by the end of the semester. For example, on dates when the main laboratory exercise required use of the electromechanical mechanical testing system, teams would sign up for testing slots. Those who had to wait for the machine worked on Mini Labs in the flex lab while waiting their turn to test their specimens for the assigned lab for that period.

Labs 1 and 3-9 were kept without major modification in the syllabus (i.e., except for renumbering Labs 3-9 to 2-8). Modifications included:

- Lab 9 – Student-Designed Lab – Students researched an assigned ASTM test standard, designed a test jig for mounting on the mechanical testing system, presented their designs, chose a winning design, and performed the test to ASTM standards. In this semester, the assignment was for the design of a three-point-bend jig that could be used to test wood specimens.
- Lab 10 – Sand Casting Demonstration – A professor of sculpture in the Art Department was recruited to perform a demonstration of the process of constructing a pattern, forming a sand mold around the pattern, and providing a demonstration of sand casting of a bronze sculpture.
- Lab 11 – Metallography – This lab was expanded to a two-week lab in order to utilize newly acquired grinding and polishing equipment. Students learned to mount specimens, grind and polish them, and observe their specimen’s microstructure using a metallographic microscope.

Lessons Learned, Current Progress, and Future Plans

At the beginning of the semester, I carefully explained to the students that the Mini Labs were not meant to pile extra work on them but rather were intended to provide them with useful skills that could be learned in a self-paced manner while they were waiting for their turn to use the equipment for the assigned laboratory exercise. Students were allowed to work on the Mini Labs only during laboratory periods, which meant that there was no addition to out-of-class workload. I also explained that the addition of the Mini Labs was an attempt to alleviate crowded conditions in the laboratory and to prevent student boredom while waiting for their turn to use single pieces of equipment. When students were not performing their assigned laboratory exercise, they could move to the flex lab or to the machine shop to work on Mini Labs. The students’ ability to spread out into several locations meant that there were no crowding problems in the lab. The students quickly developed their own system for signing up for time slots for performing their labs. Then they would rotate through the lab with the group that was completing the laboratory exercise tasked with telling the next group on the list that it was their turn to use the lab equipment. This worked much better than expected, and the students were appreciative of the extra space to work in.

Students were asked at the end of the semester to provide written critiques of the Mini Labs and to provide constructive feedback with regard to improving the Mini Labs. Students were also

given the opportunity during one of the last lectures of the semester to discuss the Mini Labs and to provide suggestions for the future. Although the written reviews were helpful, the best feedback was obtained from the in-class discussion. The students were willing to take full advantage of the opportunity to suggest improvements that could make the Mini Lab exercises more relevant and less tedious for future students. When asked to consider these exercises as a way to keep students engaged in active learning activities in the face of increased enrollments and limited space and equipment, the students were willing to provide constructive criticism and excellent suggestions for future improvements for this course. The students' least favorite Mini Labs were the ones on fasteners and graphical communication. They felt that these exercises were too long and complicated, and I agreed with them after watching the large blocks of time that were required to complete these exercises over the course of the semester.

In one part of the Fasteners Mini Lab, the students were asked to learn a great deal of material on the subject of hex bolts and hex cap screws. They were provided with seven fasteners of varying sizes and grades and asked to size them, to identify them as bolts vs. screws, and to learn to identify their grade in order to look up specifications for a fastener of a particular grade and size. They were provided with a table to fill in with data, such as proof strength, lead angle, and tensile stress area, for each of the seven fasteners. The students suggested ways to reduce the tedium of this exercise while still providing them with a quality learning experience. Their suggestion for simplification was to require identification of each of the seven fasteners with regard to type, size, thread pitch, and grade; however, the more detailed specifications would be limited to only one of the seven fasteners. They also suggested that this component of the exercise could stand on its own as an individual Mini Lab. In the second part of the exercise, the students were provided with an additional collection of 15 different types of fasteners (e.g., socket head cap screw, elevator bolt, thread-cutting machine screw) and 4 types of hexagonal nuts. They learned to identify each of the fasteners or nuts and to learn their intended purpose by using a vendor's catalog and the Machinery's Handbook. While the students enjoyed being exposed to a collection of different fasteners, they suggested that this part of the exercise be split up into its own Mini Lab. Two students, upon returning to campus this fall after their summer internships, surprised me by telling me they had used the information learned in the Fasteners Mini Lab on the job.

For the Spring 2007 semester currently underway, all of the 2006 students' suggestions were implemented, and the current students worked much more quickly through the two modified Fasteners Mini Labs with a reduction in volume of general grumbling about the exercises compared to the Spring 2006 semester. The Fasteners Part 1 Mini Lab contains streamlined exercises on the hex bolts and hex cap screws. The students are no longer asked to fill in one large table with redundant information. The students indicate the head style, units system, grade specification, and material treatment by circling the correct answer in a multiple-choice table. The students are asked to provide the proof strength, tensile strength, and yield strength for each grade specification rather than for each of the 7 fasteners. A second multiple-choice table is provided to streamline the fastener sizing process. The students are asked to write the formal designations and to look up the lead angle and pitch diameter on one fastener only. The Fasteners Part 2 Mini Lab contains the unmodified exercises on the additional types of fasteners and hexagonal nuts. Some of this semester's students, who are also enrolled in the Junior Design course, have commented that they now feel more comfortable in hardware stores when searching for fasteners for their design project.

The students most enjoyed the Drilling and Tapping Mini Lab and the opportunity to work in the machine shop under the tutelage of our machinist. They strongly recommended that addition of additional exercises, such as learning to face off or to turn a simple component on the lathe. This suggestion has also been implemented for the Spring 2007 semester and added to Mini Lab 5.

The students also disliked the Graphical Communication Mini Labs; they preferred the use of CAD packages to draw and dimension a component. During the discussion, I asked what they felt they would need to learn if they had the occasional necessity to discuss a component they were designing with a machinist in trying to optimize the design. They made constructive suggestions for paring down the required drawing and dimensioning exercises while still providing practice in drawing and dimensioning a machine component by hand. These suggestions were also implemented for Spring 2007. The three-part Mini Lab series was edited down to two Mini Labs. The number of components that the students must measure and draw has been cut to one assembly. The students must draw and provide dimensions and tolerances for each of the components separately. They must then draw an isometric assembly drawing for the two components. These modified exercises seem to be less tedious for the students this semester.

The development and deployment of the self-paced Mini Labs combined with the ability to utilize flexible laboratory space allowed me to teach labs with larger enrollments without causing the students to feel overcrowded or bored. While some fine-tuning is required for the future, the use of self-paced Mini Labs worked well as an active learning tool. With continued future growth in our program, the issue of maintaining rigor in grading lab reports with increasing enrollment remains. This may be addressed through the use of online tools, such as LabWrite¹, in future semesters in order to aid students in improving their writing and critical analysis skills.

Future laboratory or Mini Lab modules in development include:

- The incorporation of a new drop tower impact testing system (Fall 2006 senior design project) into the heat treatment lab.
- Demonstration or use of the department's new rapid prototyping printer.
- Use of our department's new, more accurately controllable heat treating furnace to allow development of a shape memory alloy exercise².

Bibliography

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