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Designing the Laboratory Experience from the Ground Up: Custom Laboratory Equipment and Writing-Intensive Pedagogy

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Abstract

This work details two dimensions involved in designing the educational experience in an undergraduate engineering mechanics laboratory course, centered around the course goals. The two main goals in the course were: 1) to provide students with hands-on learning experiences in materials testing to enable them to connect these experiences with theoretical concepts taught in the related lecture course, and 2) to teach undergraduate engineering students how to prepare a formal engineering laboratory report. Custom equipment for materials testing was designed and constructed in order to meet the first goal in an economically reasonable manner. Writing-intensive pedagogy was used to meet the second goal, with weekly individual writing assignments and one-on-one feedback meetings with every student to promote learning and writing skills improvement. This publication provides some details regarding how the development of custom materials testing laboratory equipment and workbenches shaped the laboratory experience, and also outlines the writing-intensive course structure used to support the development of students' writing skills.

1 Background

1.1 The Need for Hands-on Laboratory Experiences

Laboratory work in engineering typically involves the physical demonstration of scientific principles through carefully designed experiments or similar educational project activities. Two underlying concepts are core to the reason we use experimentation in education: 1) the scientific method, and 2) individual knowledge construction.

The basis of the scientific method is that of experimentation. Gower [1] traces the foundations of the scientific method through Gallileo, Bacon, Newton, the Bernoullis, Bayes, and more. Despite uncertainty and the probabilistic nature of experimental results, scientific knowledge is based on certain methods, logic, and experiments. If we are to understand this scientific knowledge, then we must become students of this history, these methods, and these experiments. This is the first major course goal: to personally involve students in experimentation.

As students become involved personally in experimentation, they construct an internal understanding of observed phenomena. Jean Piaget [2] proposed a thoery of cognitive development in which an individual, as learning and maturation proceed, progressively moves through four stages of mental maturation. These stages include the sensorimotor stage, the preoperational stage, the concrete operational stage, and the formal operational stage. He also posited that two processes are vital to learning, which he termed assimilation and accommodation. These processes are used to describe the events that occur in the creation or construction of internal mental models that Piaget terms schemas. The process of assimilation involves relating new information to old schemas, and the process of accommodation involves the creation of new schemas when necessary.

One of the primary purposes of a teacher is to guide and direct learning, and to increase the rate at which students learn. Lev Vygotsky is credited with describing the role of support in learning through what is known as the zone of proximal development (see, e.g., [3, 4]). The idea is that students can learn more when supported in learning, and when learning experiences are specifically designed to suit where particular students are in the learning process. This learning does involve social interaction, but also involves careful instructional design. Jerome Bruner was a strong proponent of careful instructional design [5, 6].

Although constructivism as embodied through the theories of Piaget and Vygotsky are often placed at odds with behaviorist thoeries, especially of B.F. Skinner, Skinner himself believed that to learn, students must engage in behavior, rather than just passively receiving information. The idea that information should be carefully sequenced and presented is evident from the teaching machines developed through his research efforts, which could be adapted to the rate of learning for a particular individual.

In any case, it is clear that there should be careful and intentional design of laboratory experiences, which will serve to help students both build an understanding of underlying physical concepts, but also of the scientific method and experiments used to validate them. These were used as guiding principles in the design of this course.

1.2 Writing-Intensive Pedagogy

There are two major movements related to the inclusion of writing in courses that we draw upon: writing across the crurriculum, and writing in the disciplines. A more complete history is given in [7], but a brief summary is provided here. The initial impetus for the changes promoted by writing across the curriculum was a late 1920s study conducted at the University of Minnesota, which revealed that students showed no improvement in writing essays before and after completing a freshman English composition course. The recommendation from this research was to have English teachers, and those in other fields to collaboratively develop writing assignments for students. This and other similar studies eventually led to the development of the writing across the curriculum (WAC) movement, although this didn't develop much steam until much later. WAC would likely be seen as relatively new in the 1970s. The first writing across the curriculum conference was held in 1993, the first journal in 1994. Eventually the first two journals merged into the WAC Clearinghouse (http://wac.colostate.edu). Writing in the Disciplines (WID) focuses on discipline-specific writing practices and training. The focus here isn't so much which particulary theory is more relevant, but to the intentional design of this course as writing-intensive in nature. We include these as a nod to the massive past and ongoing efforts to bring focus and improvement to writing across the curriculum.

Writing-intensive courses are courses in which multiple iterations of writing and feedback play a major role [8]. Sometimes, and institution will adopt a writing-intensive label to describe a course, and if so, then to earn this label, courses have to meet certain requirements. While the specific requirements vary from one institution to another, the main characteristics include: class size requirements, teaching requirements, required number of papers or words, revision guidelines, grade impact, types of writing assignments, assignment-related instruction and evaluation of papers, and support services. Such labels are not used at our institution, but we will list the specifics for each of these to promote a clear understanding of the course.

2 Course Structure

The general structure for the course is given in Table 1, which shows the 14 weekly lab activities, including writing assignments, feedback meetings, and laboratory equipment used.

2.1 Experimentation and Custom Laboratory Equipment

2.1.1 Universal Testing Machine

This is an engineering mechanics laboratory course, and focuses on principles of the mechanics of solid materials. As such, physical testing of the materials plays an important role in this course. Perhaps the most important single piece of equipment used in this, and many other engineering mechanics lab courses, is the universal testing machine. As noted in Table 1, 12 of the 14 labs involved physical experimentation, and of these, 6 involved the use of a universal testing machine. The custom universal testing machine is shown in Figure 1, and was designed much like conventional universal testing machines. It has dual lead screws with a crosshead that moves with

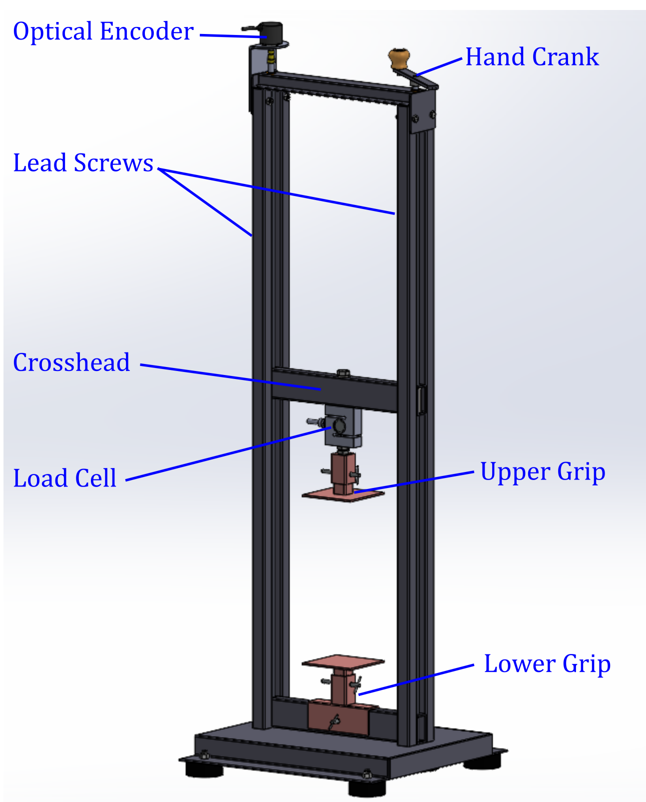

Figure 1: Custom Universal Testing Machine

the rotation of the two screws. The crosshead supports a 500 kg (1100 lb) s-type load cell, and

Table 1: Weekly Laboratory Activities, Feedback Writing Assignments, and Equipment for Strength of Materials Lab

Week	Lab Activity	Writing Assignment	Writing Feedback	Equipment
1	-	Report Formatting	-	Laptops
2	-	Citations and Referencing	Report Formatting	Laptops
3	Tensile Testing	Figures	Citations & Referencing	UTM
4	Tensile Parameters	Tables, Results Section	Figures	UTM
5	Statistical Variation	Discussion Section	Results Section	ASTM Standards
6	Modulus of Elasticity	Introduction Section	Discussion Section	UTM
7	Column Buckling	Theory Section	Introduction Section	UTM
8	Torsion Testing	Method Section	Theory Section	TTM
9	Three-point Bending I	Introduction, Theory, Method	Method Section	UTM
10	Three-point Bending II	Results, Discussion, Conclusion	Introduction, Theory, Method	UTM
11	Stress Visualization	Abstract, Title Page, Laboratory Notebook	Results, Discussion, Conclusion	Stress Polariscopes
12	Ductile and Brittle Failure	Laboratory Notebook	Abstract, Title Page, Overall	Pretzel Rods, Taffy Sticks
13	Ductile to Brittle Transition	Laboratory Notebook	Complete Report Feedback	Freezer, Taffy Sticks
14	Student-designed Experiment	Laboratory Notebook	-	Varies

Note: UTM = Universal Testing Machine, TTM = Torsion Testing Machine

distance information is measured with an optical roatry encoder. A hand crank is used to control crosshead motion, and grips are provided for various types of testing: wedge-style grips for tensile testing, flat plate grips for compression testing, and hook grips for spring testing. Fixtures for three-point bending, and both fixed and rotating (pinned) column support grips for column buckling are also used. Force and distance data is acquired by a small data acquisition unit. Inernally, the data acquisition unit has an Arduino Uno and a custom add-on board with pullup resistors for the encoder and two HX711 load cell amplifiers (one for the load cell and another for the extensometer). Students interact with this system by connecting their own laptops to the USB port data acquisition box, and using a serial terminal reader program (e.g., coolTerm) to save the comma-delimited data to file for later analysis. More information regarding the testing machine used can be found in [9], although substantial improvements have been made since that initial prototype.

2.1.2 Torsion Testing Machine

In addition to the custom universal testing machine, a custom torsion-testing machine was also used for one lab. This device is shown in Figure 2, and includes a fixed end support, rotating end support, and torque wrench with weights for applying a constant torsional load. The fixed-end

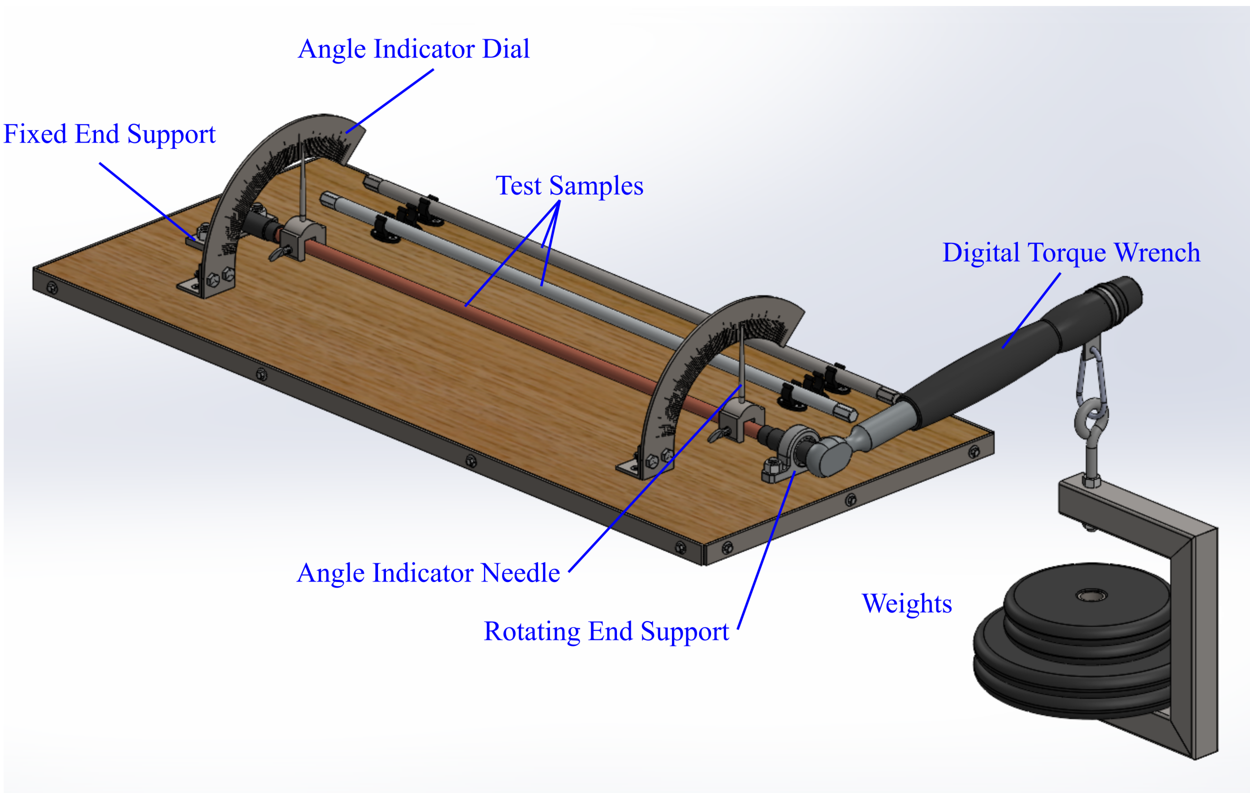

Figure 2: Custom Torsion-testing Machine

support consists of a 7/16 deep socket welded to a custom steel bracket, which is in turn bolted to the machine platform. The rotating-end support consists of a teflon-coated journal bearing that also accepts a 7/16 deep socket, which is free to move linearly and also rotationally. The angle indicator dials are made of 1/4 in thick aluminum and have degree angle numbers and tick marks machined on the face. The angle indicator needles attach to the test sample with thumb screws, and the weights are manually hung from the handle of the digital torque wrench. No tools such as wrenches or hex keys are required to carry out testing. More details can be found in [10].

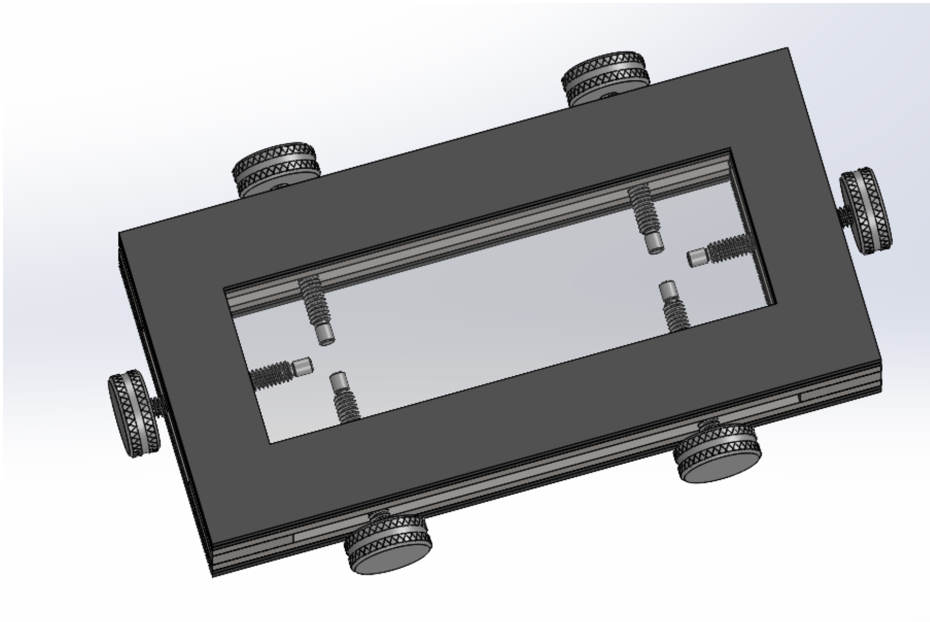

Figure 3: Stress Polariscope

2.1.3 Stress Polariscopes

The topic for week 11, as indicated in Table 1, was stress concentrations, and polariscopes were used to visualize the stress in transparent samples of material. The polariscopes were modeled after a model called the Stress-Opticon by Vishay Research & Education. According to the user's manual found with a device at the university, these were made in the 1970s, but attempts to contact the company to order more were not successful as it was no longer manufactured. The design was modified so that the polarizers were mounted between two layers of laser-cut acrylic, and attached to the frame with small neodymium magnets. This was an improvement over the original design, which used an aluminum strip with a slot for the polarizer film, which led to the film getting scratched when samples were removed. The cantilever support was also removed, and an additional screw for loading along the long axis was added. The modified model is shown in Figure 3.

2.1.4 Laboratory Workbenches

In order to meet the needs of the class, a better workbench was needed, which would have a location for mounting the universal testing machines, and also provide space to store materials to conduct experiments. This was designed and several were built for use in the space. A model of the custom lab workbench is shown in Figure 4. The workbench has two sides, one for each group of students, and an LED strip light, as well as a 4-ft power strip on each side. A single universal testing machine is placed on a cantilever shelf at the end of the workbench, so that students on both sides of the workbench share a single universal testing machine.

Figure 4: Custom Workbench

2.2 Writing and Feedback

As previously discussed, institutions who use the writing-intensive label for courses do so on the basis of several criteria, including class size requirements, teaching requirements, required number of papers or words, revision guidelines, grade impact, types of writing assignments, assignment-related instruction and evaluation of papers, and support services. These criteria are used as the organizational structure for this section.

2.2.1 Class size

The class size for this lab is limited to 18 students.

2.2.2 Teaching Requirements

The course is taught by a full-time faculty member, as opposed to a graduate or undergraduate teaching assistant.

2.2.3 Required Number of Papers or Words

As indicated in Table 1, writing and feedback is a part of the lab work every week. The first two weeks are dedicated entirely to writing and report preparation-related activities. Because students often struggle with report formatting-related work, such as creating appropriate headings and subheadings, equation formatting, figure preparation, and citation using a reference manager, the first two weeks are spent on these tasks. This allows students to focus more intently on writing content for other weeks, as formatting has already been formally addressed. Writing assignments for weeks two through eight are focused on a specific section or sections of an engineering lab report. The focus is on the content itself, and conciseness is valued, so there is not a specific number of words required. That said, weekly writing assignments typically consist of one to three pages, which includes figures, tables, equations, and single-spaced text. Weeks nine through thirteen are focused primarily on the writing and revision of a complete lab report, but students are also required to keep a laboratory notebook. The final week, students are required only to complete the laboratory notebook entry. Lab notebook entries are typically one to three pages, and the complete lab report is usually approximately ten pages long.

2.2.4 Revision Guidelines

Weekly writing feedback is provided either by the instructor or by an undergraduate writing fellow. The writing fellows are selected among the top undergraduate students who previously completed the class and lab. These students are hired by the university writing center, and are trained collaboratively both by the writing center, and by the laboratory course instructor. They are also required to register for a writing seminar course in which they learn techniques for being a tutor.

2.2.5 Grade Impact

Weekly writing feedback meetings are scored based on the level of preparation for the student attending the writing feedback meeting. Students who are prepared with the writing assignment completed as instructed receive full credit for those assignments. This is intended to provide an environment in which students are allowed to make mistakes, but still get feedback to improve their writing. The combination of lab activity and writing feedback meeting completion constitutes half the lab grade. The other half of the lab grade is based on the writeup of a complete lab report for the three-point bending lab. Before the final grading of this assignment, students have four feedback meetings on their report and so have plenty of opportunity to make revisions so the final product is of the highest quality. The second half of the lab grade is based only on the quality of the final report draft, not on previous versions.

2.2.6 Types of Writing Assignments

As explained previously in section 2.2.3, there are four different types of writing assignments a) report formatting assignments (2 assignments), b) report sections (6 assignments), c) full engineering lab report (1 assignment spanning 4 weeks), and d) laboratory notebook entries (4 assignments).

2.2.7 Assignment-related Instruction and Evaluation of Papers

Each lab is scheduled for 150 minutes (2.5 hours). The first portion of lab is used for instruction, both writing-related and also related to safety and completion of experimental activities. The first two lab periods are filled almost entirely with guided writing-related instruction (students work on formatting while instructor guides through various sections [i.e., section headings, tables, figures, equations, etc.]). Other weeks, writing instruction takes approximately 30 minutes of the allotted time. Paper evaluation was discussed previously in section 2.2.5.

2.2.8 Support Services

Several resources are available to students. First, students can set an appointment with the instructor or with writing fellows to get feedback on their work. This can be in addition to the required feedback meetings if desired. The writing center is also available for students who want drop-in writing support, but the help students get in the writing center is not as specialized as from the instructor or writing fellows. Students are also allowed to work collaboratively in the sense that although each student must complete every writing assignment individually (reports are individual, not group submissions), they may ask each other for help. For example, students often have questions regarding aspects of data visualization such as modifying axis labels.

3 Discussion

There have been several benefits observed from taking this approach to lab development. First, intentional design of the laboratory space and equipment by faculty is noticed by students. The act of faculty themselves modelling what it means to be an engineer through developing solutions to the educational problems is of value. Second, since the lab activities were all re-designed, there is a much better connection between class topics and lab activities. Students measuring material properties themselves helps de-mystify the meaning of values they use from tables in the textbook for completing homework problems. Lab materials were organized using carefully labelled plastic totes, which are stored under each workbench. This makes preparing and finding materials needed for a particular lab experiment simple. Because small testing machines are used for tensile testing, for example, sample preparation is as simple as cutting a section of wire from a reel. This is much less labor-intensive than milling or machining dogbone samples, which was necessary before these changes were implemented. In terms of lab equipment, the number of students per machine was reduced to four (less for some experiments). The more students there are per machine, the less time students can each spend with the equipment. In addition, improving the connection between the class and lab, and the experiment and the concepts was beneficial.

In general, our experience is that engineering students are not overly enthusiastic about writing. This course is the first in which they are expected to prepare a complete, formal engineering lab report. Nevertheless, the structured approach for this class with weekly feedback meetings allows students room to learn and make mistakes without harsh punishment during the process. Overall, providing individualized oral feedback to students regarding their writing is a significant amount of work, but close collaboration with the university writing center makes it possible, and scalable to more students. Although the class size in this case is limited to 18 students, the 5 workbenches and 10 sets of lab supplies can support up to 20 students. This could likely be scaled up for universities with more students, but an increased number of workstations, lab assistants, and writing fellows would be necessary. Based on our experience, with writing fellows working 5 to 10 hours per week, we recommend one writing fellow per 10 to 12 students.

References

[1] B. Gower, *Scientific Method: An Historical and Philosophical Introduction*. Routledge, 1997.

[2] J. Piaget, *Six psychological studies*. New York, NY: Random House, 1967.

[3] L. S. Vygotsky, *Mind and society: The development of higher mental processes*. Cambridge, MA: Harvard University Press, 1978.

[4] P. Doolittle, "Understanding cooperative learning through Vygotsky," *Lily National Conference on Excellence in College Teaching*, June 2-4 1995.

[5] J. S. Bruner, "Learning and thinking.," *Harvard Educational Review*, vol. 29, pp. 184–192, 1959.

[6] J. S. Bruner, "The act of discovery.," *Harvard Educational Review*, vol. 31, pp. 21–32, 1961.

[7] C. Bazerman, J. Little, L. Bethel, T. Chavkin, D. Fouquette, and J. Garufis, *Reference guide to writing across the curriculum*. Parlor Press LLC, 2005.

[8] S. H. McLeod, E. Miraglia, M. Soven, and C. Thaiss, *WAC for the New Millennium: Strategies for Continuing Writing-Across-the-Curriculum Programs.* ERIC, 2001.

[9] J. Bishop, "BYOE: A low-cost material testing machine to increase engagement in a materials science lab course," in *2017 ASEE Annual Conference & Exposition*, no. 10.18260/1-2–27993, (Columbus, Ohio), ASEE Conferences, June 2017. https://Peer.asee.org/27993.

[10] J. Bishop, "BYOE: Engineering mechanics with a twist: Design and implementation of a custom torsion-testing apparatus," in *2023 ASEE Annual Conference & Exposition*, (Baltimore, Maryland), ASEE Conferences, June 2023.