# Cover page for Ottilie Schillig Special Teaching Projects

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| Title of Proposed Project:<br>STUDENT-DESIGNED MECHANICAL TESTING MACHINES TO ENHANCE LEARNING BY FUTURE | | |
| Project Director (PD) Name:<br>Steve Elder | PD Phone Number:<br>325-9107 | PD Email:<br>selder@abe.msstat |
| PD Department:<br>Agricultural & Biological Engineering | PD College:<br>Engineering, College of | Estimated # of Students Impacted each Semester:<br>150 |
| Requested Amount from Schillig Funds ($ 3,000.00 maximum):<br>$ 3,000.00 | Cost Share Amount (optional): | Total Amount for Project:<br>$ 3,000.00 |
| PD Signature:<br>Steve Elder Digitally signed by Steve Elder Date: 2023.03.07 11:55:39 -06'00' | | Date:<br>03/07/2023 |
| Department Head Signature (if cost share included): | | Date: |
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# STUDENT-DESIGNED MECHANICAL TESTING MACHINES TO ENHANCE LEARNING BY FUTURE STUDENTS

Steve Elder
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## PROJECT DESCRIPTION

This project has two objectives:

1. To give a group of biomedical engineering students the opportunity to design and fabricate *two* low-cost universal mechanical testing machines that rival commercial testers.
2. To begin the process of introducing all biomedical engineering students to the operation of industrial-grade universal testing machines as they learn about material characterization.

Determining the mechanical properties of materials is an important aspect of engineering and materials science. Biomedical engineering projects frequently involve mechanical testing for purposes of material selection, manufacturing quality control, and characterization of tissue structure-function relationships. Mechanical properties are a central design consideration for many types of implants, including orthopaedic, dental, and cardiovascular. Thus, it is imperative that biomedical engineers have a good fundamental understanding of the meaning of mechanical properties and how they are derived from mechanical tests. In 2017, Dr. Elder received a Schillig award to purchase 3 handwheel-driven mechanical testing stations (Fig. 1) for use by biomedical and biosystems majors in a required course, ABE 3813 Biophysical Properties of Materials, and occasionally in the capstone design courses, ABE 4813 Principles of Engineering Design and ABE 4833 Practices of Engineering Design. That experiment was successful, and the ABE Department proceeded to purchase an additional 7 testing stations that are now used in four different ABE 3813 laboratory exercises (Fig. 1), as well as for project evaluation in ABE 1921 Introduction to Engineering Design (Fig. 1).

**Figure 1.** A - 250 lb test stand with force gauge and digital length scale. B – Students using mechanical testing stations in ABE 3813. C – Mechanical testing of 3D-printed bridge in ABE 1921.


*Although the testing stations generally serve their intended purpose, they do not expose students to the type of testing performed in research laboratories or in industrial settings.* Currently, a student must manually turn a wheel to deform the specimen in small increments. After each applied deformation, students must record the displayed displacement and force. The testing stations do not connect to the students' laptops. An industrial-grade universal testing machine is motor-driven and computer-controlled. It deforms specimens at a constant rate, displays the resulting force vs. deformation curve in real time, and permits saving the data for further analysis. As one might expect, commercial testers are expensive. Prices start at approximately $5,000 for a barebones system, and most of the appropriate size are $10,000 - $25,000. However, a custom universal testing machine with specifications approximating those of commercial testers can be fabricated for much less. In fact, one dubbed the Universal Mechanical Testing Kit (UMTK) was designed and constructed by students at the University of Toronto from low-cost, readily available parts for approximately $560 USD per unit, and it was presented at a 2020 virtual meeting of the American Society of Engineering Education (Fig. 2).[1]

[1] Liu X, Pajovic S, Kei CYL, Delaviz Y, Ramsay S. Use of a Low-Cost Open Source Universal Mechanical Testing Machine in an Introductory Materials Science Course. Paper ID #29934, ASEE Virtual Conference, June 22-26, 2020.

If funded, this project would support the design and fabrication of two identical testing machines similar to the UMTK. The testers are to have a graphical user interface, which the students can design using MATLAB, LabVIEW, or Processing (a free and open source graphical library). Students will draw upon foundational coursework that includes Physics I, Engineering Mechanics I & II, and Mechanics of Materials. They will also leverage the knowledge they acquired in ABE courses such as Introduction to Engineering Design, Transport in Biological Engineering, Biosystems Simulation, Physiological Systems in Biomedical Engineering, Bioinstrumentation I &II, and Biomechanics. Specifications for the testers will be on par with those of the UMTK:

- Maximum Load 1.5 kN
- Stroke Length 125 mm
- Crosshead Velocity 0.1 – 240 mm/min
- Load Measurement Accuracy ± 3.0 %
- Extension Measurement Accuracy ± 0.1 mm
- Data Acquisition Rate 50 – 200 Hz

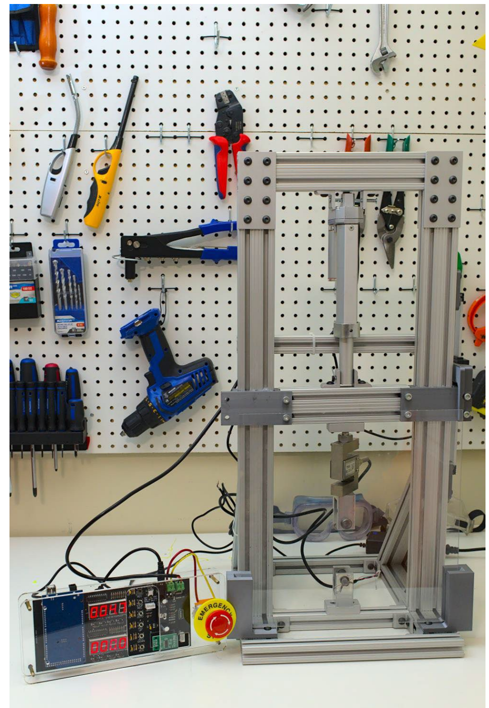

**Figure 2.** Low-cost universal mechanical testing kit (UMTK), designed by faculty and students at the University of Toronto.[1] It will serve as a model for the machine to be designed by MSU students under the guidance of MSU faculty members.

**The ASEE conference paper mentioned above included a comparison of the UMTK to a commercial tester that relies on the students turning a crank to perform the test, just as MSU BME students do in lab. The authors found that the UMTK, which is more representative of those used in industry, was the only one with a significant difference between the mean grades pre- and post-tutorial.**[1] They attributed the strong ability to enhance learning to several deliberate design choices, which we will also impose:

1. It should resemble universal testing machines used in industry, with a fixed supporting structure and translating crosshead.
2. It should support tensile, compression, and three-point flexural tests according to ASTM standards.
3. Its working parts (e.g. load cell, linear actuator, printed circuit board) should be fully exposed so that students can easily comprehend each part's function.
4. It should operate much like a commercial tester with standard jogging controls.

Dr. Elder will directly advise the design team. He has extensive knowledge and experience using universal testing machines, as well as some experience designing and building electro-mechanical devices. Other ABE faculty members, such as Dr. Filip To and Dr. Xin Zhang (instrumentation experts), will also be available for consultation. The design students will have access to 3D printers and to the ABE machine shop, which occupies the entire basement of the ABE Building. It is equipped for the fabrication of machines that are much larger and more sophisticated than the proposed testers.

<u>Timeline</u>

The project will start by selecting a team of four biomedical engineering majors to undertake the design of the testing machine during the F2023-S2024 academic year. The selection will be made by Dr. Elder based on interviews and consultation with other ABE instructors. The students will be expected to have all materials in hand and two frames fully assembled by the end of F2023, including motors and load cells. Electronic integration of all the components and creation of the computer control system will take place in S2024, with the delivery of two fully-functional machines by the end of the S2024 semester, including software and user manual. After a thorough evaluation by Dr. Elder during F2024, including any steps necessary to complete them, the machines will be placed into service in S2025.

IMPACT ON UNDERGRADUATE TEACHING

This project will have a profound impact on the students selected to design and construct the mechanical testing machines. It is somewhat more ambitious and comes with a much larger budget than most senior design projects. If not externally supported, the department provides $100 per project. The students will have the opportunity of a lifetime to apply their engineering knowledge and skills to the design of the testing machine, with the UMTK as inspiration.

Once built and confirmed to be working properly, the machines will greatly enhance our ability to teach students standard mechanical testing methods and how to analyze the data. The current stations support the collection of a very small number of data points per test, whereas the industrial-grade tester will generate smooth curves containing hundreds, or perhaps thousands, of data points per test. Students will be much more excited to see the force vs. displacement curves appear on the screen in real time as each specimen is deformed, rather than having to plot a handful of recorded values after the testing is completed. It will also permit students to perform tests that comply with ASTM standards, which is something they cannot do using the current mechanical testers.

Number of students impacted (4 in Year 1, ~150 per year thereafter)

The machines will be put to use by students in ABE 3813, which is taught every spring to approximately 50 students as a required course in the BME curriculum. Likely they will be utilized to complete 4 different laboratory exercises as they replace the handwheel-driven stations currently in use. The machines would also be available to subsequent classes of senior design students who often need to perform mechanical tests to develop and evaluate their projects. There are typically 40 students in a senior design cohort. Even freshmen in ABE 1922, another required course in which 80-100 students are typically enrolled, will be able to use them to evaluate the strength of 3D-printed projects. If the machines perform as well as the UMTK, then we would gradually upgrade all of the ABE Department's handwheel-driven stations to motor-driven, computer-controlled testing machines. Using ABE 1921 and ABE 3813 lab fees, supplemented by departmental funds, it should be feasible to construct 1-2 additional machines each year until we have 8-10 machines.

RATIONAL FOR REQUESTING FUNDS

As detailed above, the project will create two motor-driven, computer-controlled mechanical testers that resemble commercial testers. The project will first provide a tremendous learning opportunity for the team of four students selected to design and construct the testers. The completed machines will be used exclusively for teaching, as the ABE research laboratories are equipped with a wide range of commercial mechanical testing machines. The new testers will differ significantly from the handwheel-driven mechanical testing stations our students currently use, and there is evidence that industrial-grade machines with the desired design features will enhance student learning.

Budget

Prices have risen substantially in the last three years, and we estimate that each machine will cost approximately $1250 (a small fraction of the price of a commercial tester). The budget includes $500 to pay additional undergraduate students wages of $8/hr during F2024 to complete the testers if they are left unfinished by the students in capstone design (contingency). If no such costs are incurred, the excess budget would be used to fabricate grips for holding specimens firmly in the testers.

| **Category** | **Cost per machine** | **Total Cost** |
|---|---|---|
| Mechanical Components | $750 | $1500 |
| Fasteners | $200 | $400 |
| Electronics | $150 | $300 |
| Tools and Miscellaneous | $150 | $300 |
| Contingency fund | $250 | $500 |
| | | |
| **GRAND TOTAL** | **$1500** | **$3000** |