Student Designed Wear Tester in a Mechanical Engineering Lab to Better Understand Student Learning as it pertains to ABET EAC Student Outcome 6

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Abstract

ABET engineering accreditation commission has seven student outcomes that are assessed to ensure our program has met standards to produce engineers ready to contribute to the community. Outcome 6 focuses on experimentation and states: "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions". The mechanical engineering department at Mercer University School of Engineering has been assessing a singular experiment for many years in a senior lab with mixed result especially with the use of engineering judgement portion of the statement. A group of senior engineering students in the department used their capstone design project to build a prototype wear tester to run project-based experiments. The goal of this work is to provide experiments that are more complex in the junior year, that force the students to use their engineering judgment. So that the instructor of the course can provide immediate feedback to the students. What is written here are a summary of the design, the details of how to use the device in a project-based lab experiment, initial feedback on usage of the device, and how this will better prepare students for the senior lab.

Keywords

Mechanical Engineering, Material wear tester, Senior Design, Assessment, Lab Based Class

Introduction

The Accreditation Board for Engineering and Technology (ABET) requires that engineering programs have seven documented student outcomes specified in Criterion 3 that prepare graduates to attain their program educational objectives. The one that pertains to this study is as follows:

…an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

At Mercer University, the mechanical engineering laboratory sequence consists of two courses that addressed the following components of Criterion 3 outcome 6:

(i) the *analyze and interpret data* component was addressed in the student's junior year in MAE 301L (Mechanical Engineering Laboratory I), and

(ii) the *ability to develop and conduct appropriate experimentation,* component was addressed in the student's senior year in MAE 402L (Mechanical Engineering Laboratory II).

(iii) Both classes allow the students to *use engineering judgment to draw conclusions* based on the experiment.

The descriptions of these courses have been discussed elsewhere.[1,2,3] In short, 301L Mechanical Engineering Laboratory I is comprised of four laboratory exercises done on two week intervals on various topics that are used to introduce students to experimental measurement of quantities of interest to mechanical engineers. The lab consists of 0 lecture hours and 3 hours of laboratory per week, which results in 1 credit hours for the course (0-3-1). Topics include hardness testing, shear strength, beam bending, column buckling, thermal sensor response, and thermal sensor calibration. Each of these exercises results in a lab poster and presentation to the class[4]. This class is coupled with a lecture-based class that meets for 3-50 minutes sessions per week. The next series of experiments are two projects, which are intended to introduce the practical concept of developing experiments based on a problem statement. Typical laboratory objectives were:

(i) Use the MTS materials testing system to plot the stress-strain diagram using displacement data and determine elastic modulus, tensile and yield strengths, and ductility.

(ii) Determine the effect of condenser pressure on the coefficient of performance of a vapor compression refrigeration cycle;

The 402L Mechanical Engineering Laboratory II builds upon this experience where two project-based lab experiments are done. Students groups are presented with a problem statement such as "Develop a correlation for the heat transfer coefficient for natural convection for a flat plate" and the student teams are then required to determine the types and number of experiments to achieve the goal set by the instructor.

While the first project in the 301L class mentioned above has been useful in preparing students for the second course 402L, the other project has not been as useful. Therefore, it has been proposed to build a second project that may help student performance in 402L.

Capstone Design Project

A tribometer tests wear between two surfaces (pin and the sample under testing) by measuring the mass lost on each sample over a certain number of cycles. In industry, these machines can test various materials at various speeds, temperatures, and forces. They also have the option of adding lubrication. These devices generally exist in two forms: linear and rotational. Commercial "Tribometers" are quite expensive tools. The design of a low-cost alternative was proposed to the senior design class. A group of students was assigned the task of designing and constructing a low-cost material wear tester for polymers.

The goals of this project were:

- Successfully wear samples
- Create a mechanism to standardize wear testing process
- Cost less than $1,000
- Develop a simple user interface
- Provide polymer testing specification based on ASTM G133[5]

Design Summary

The frame of the wear tester was built from aluminum extrusion to be strong, modular, and easily reproducible. The motor to drive the device is a Trinamic TMC2208 stepper motor. It has smooth operation, impressive torque, and runs quietly when compared to other motors. Stepper motors were chosen due to their low cost and ease of operation in open-loop fashion while still being precise. ASTM G133 is the standardized version for metallic materials and the team followed the standard specifications as closely as possible. As such, the carriage which carried the sample was chosen to be belt-driven vs being driven by a lead screw or ball screw. A 10mm diameter steel ball normally used for hardness testing was utilized to apply force on the sample during testing. In order to hold the ball in place, a holder was designed that screwed onto the ball and allowed a portion of it to protrude in order to touch the sample shown in Figure 1.

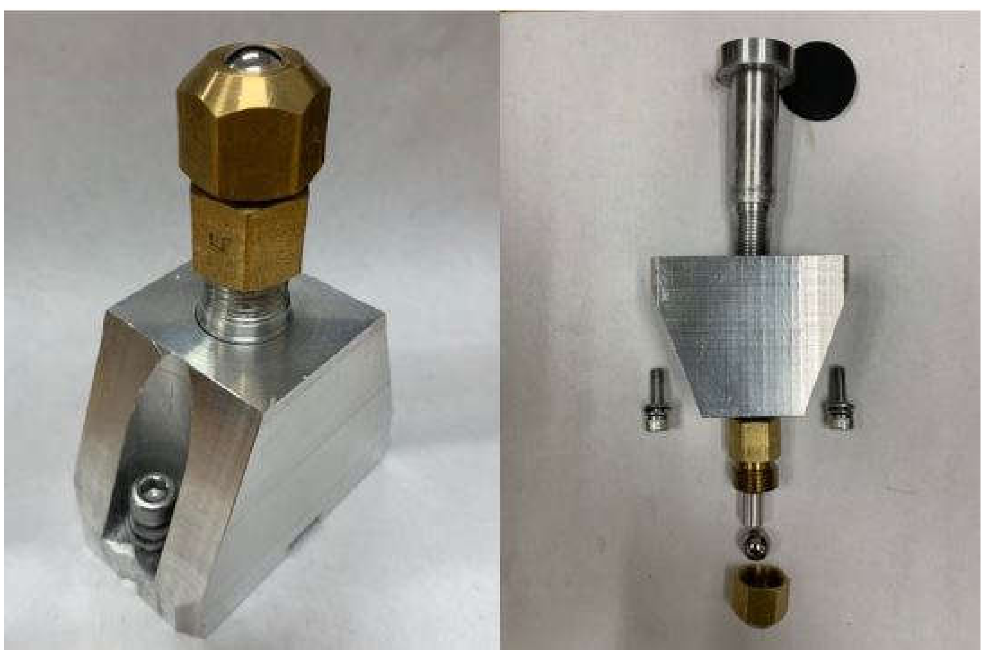

Figure 1. Pin Holder built by senior design team to hold ball

With this design, the ball could be rotated and reused as it wears over time, but still is held strongly enough to prevent the ball from rotating freely. The test sample was carried on a carriage via two linear rails and the carriage holds 4 captive nuts so that a sample can easily be screwed onto the carriage. A full picture of the device is shown in Figure 2.

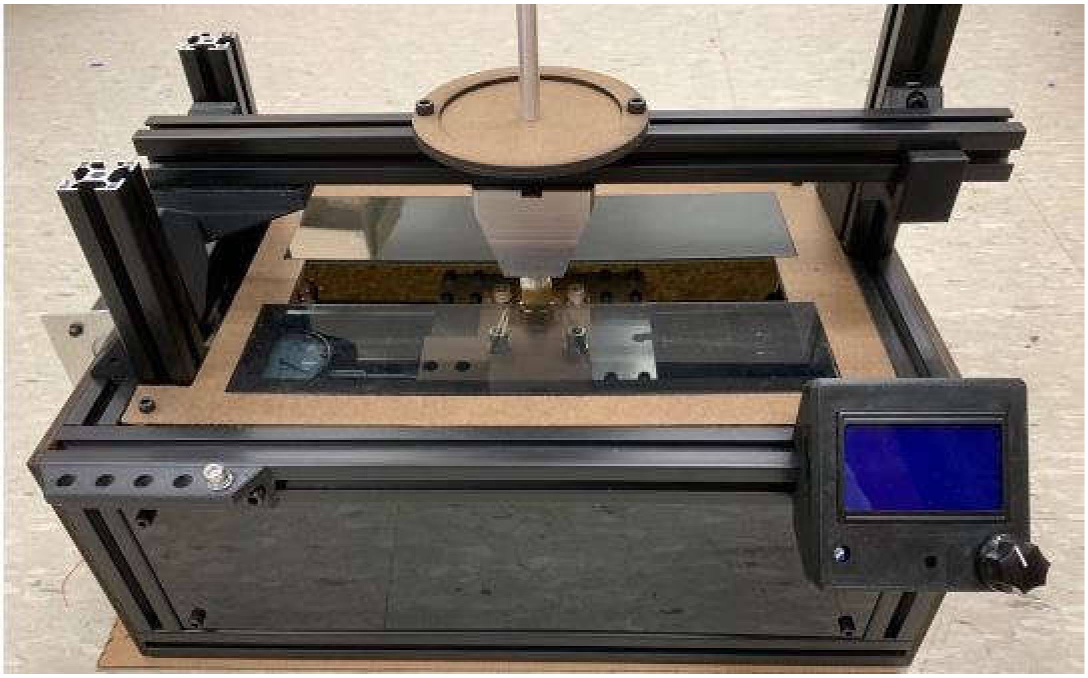

Figure 2. Reciprocated wear testing apparatus built by senior design team

As for the electronic components, the controlling processor was an Arduino Mega--chosen for its modularity, on-board voltage regulators, simple programming environment, and open-source libraries. A RAMPS board was attached to the Arduino Mega. The board is typically used for 3D printers but was suitable for this project since it had provisions to attach stepper motor drivers, stepper motors, and an LCD display with an encoder. A Reprap full graphic display with built-in encoder, another piece commonly found on 3D printers is used for input and display of all relevant parameters. Since all the parts are mass-produced and open-source, the cost of these components was affordable for the senior design project.

Once individual components had been tested, the entire machine was fully assembled to run tests on different materials. For the sample pieces, ABS plastic and epoxy was used as the testing material. The speed and the number of cycles was varied and multiple samples were run for each test configuration. From one of these sample tests, it was noted that between 5 samples, there was a ±8% deviation from the average values measured between samples.

Initial Feedback from Usage

After running a few tests on this device a few changes were recommended in order to improve the wear tester functionality. Firstly, the senior design team recommends a ball screw drive the carriage. These are used in CNC machines and have the benefits of smooth operation, accuracy, and nearly zero backlash. The reason this was recommended over the current belt-drive system is that even when the stepper motor is holding still, there is still enough flex in the belt for the carriage to be moved a millimeter in each direction. The next recommendation was for a load cell to be used to measure the force. A load cell, while expensive, would allow accurate, repeatable results, and would allow an emergency stop to be added into the code for a sudden lack of load mid-test. The final recommendation made by the team was to use an encoded three-phase motor in place of the current stepper motor. This was another modification that would typically be found on a CNC mill, and for a good reason. These motors are powerful, much faster than the stepper motors, and can operate in closed-loop fashion, allowing the controller to endure higher loads and speeds without the risk of "missing steps" the way a stepper would.

Usage of Device in Junior Mechanical Engineering Lab Class

Currently, the students use a tensile testing device to measure the tensile and yield strength of different materials. The plan would be to use the new equipment in conjunction with other experiments in the mechanical engineering materials lab during the junior year. An example of using this device would be the following. The problem statement would read something like this: “Determine an optimal polymeric/composite material to be used on an off road vehicle”. The student team could then test different sets of given materials in yield using a tensile testing device, flexure strength using a similar apparatus, hardness using the hardness tester, and then wear using this equipment or an impact jet erosion tester[6]. Then use the results of all the experiments and their ***engineering judgement*** to make a decision on the material for a given application with an explanation of why this is the best choice. The instructor of the course would provide feedback on the process and results.

Since this is a project based experiment where the student team must perform a set of experiments, interpret the results, and then draw conclusion, this should help the students with the “use engineering judgement to draw conclusion portion of Outcome 6” and prepare for the senior laboratory experience.

Indications from Past Assessment

At this time, student reports completed in the senior 402L lab are the sole basis used to assess whether Outcome 6 has been achieved for the Mechanical Specialization at Mercer University. A team of three faculty members, each of whom separately evaluates each of three tasks per laboratory group, conducts formal assessment:

(i) Develop and conduct of appropriate experimentation
(ii) Analysis and Interpretation of data
(iii) Using engineering judgement to draw conclusions

Each task listed above is associated with five sub-tasks, and each report is given a “point” for each sub-task that is deemed to have been accomplished. If, for example, any of the sub-tasks have been adequately presented, then a score of ‘3’ is recorded on the evaluation sheet for the appropriate task. These nine individual scores thus obtained (three per evaluator) are subsequently averaged, and the grand average is determined for each laboratory group. The outcome is judged to have been achieved if 70% or more of laboratory groups have a grand average of 3.0 or higher[2]. Tables 1, 2, and 3, show current rubrics used to rate the experiments used in the class.

Table 1. ABET Outcome 6, Develop and Conduct Appropriate Experimentation

		Outcome 6 Rubric (revised 3 January 2019)				
		Unsatisfactory 1	Developing 2	Meets Expectations 3	Exceeds Expectations 4	Greatly Exceeds Expectations 5
Performance Indicators	1. Develop and conduct appropriate experimentation					
	Identify experiment goals and describe an experimental process and procedures to achieve the goals	Does not identify goals nor determine appropriate data to collect. Does not identify or describe applicable experimental processes and/or viable procedures.	Identifies some goals and/or data, but may be inadequate for the intended experiment. Describes some applicable experimental processes or partial procedures.	Identifies necessary and sufficient goals and appropriate data to be collected. Describes one set of applicable and sufficient experimental processes and procedures.	Identifies the most preferable goals and data to be collected. Describes a preferable set of experimental processes and procedures.	Identifies goals and relevant data that extend the original scope of the experiment. Generates multiple applicable experimental processes and procedures.

Table 2. ABET Outcome 6, Analyze and Interpret Data

		Outcome 6 Rubric (revised 3 January 2019)				
		Unsatisfactory 1	Developing 2	Meets Expectations 3	Exceeds Expectations 4	Greatly Exceeds Expectations 5
Performance Indicators	2. Ability to analyze and interpret data					
	Acquire and present data in a meaningful way	No data presented. -or- No evidence of thought given to a clear presentation of data to help the reader understand the data.	Some data presented, but presentation is incomplete or unconvincing. Reader can grasp general idea, but may have some difficulty understanding the presentation details.	Sufficient data acquired. Applies relevant data reduction and presentation techniques. Reader can understand the data presentation with little to no difficulty.	Ample and preferred data acquired. Applies most effective data reduction and presentation. Reader can follow data presentation intuitively.	Invents new data reduction techniques or new data presentation and visualization techniques. Data presentation is exceptionally concise, yet clear and informative.

Table 3. ABET Outcome 6, Engineering Judgement to Draw Conclusion

		Outcome 6 Rubric (revised 3 January 2019)				
		Unsatisfactory 1	Developing 2	Meets Expectations 3	Exceeds Expectations 4	Greatly Exceeds Expectations 5
Performance Indicators	3. Use engineering judgement to draw conclusion					
	Summarize findings, compare actual to expected results, and extract conclusions from analysis	Findings neither summarized nor related to expected results. Cannot reach meaningful conclusions from analysis of experimental data. -or- Analysis performed incorrectly. -or- Makes wrong conclusions.	Summarizes findings in an incomplete way. Can make some sense of the data, but results not compared to expected outcomes. Extracts some valid conclusions for the experiment, but may miss some valid conclusions.	Summarizes findings in a complete way and compares them to expected results. Extracts all relevant and valid conclusions from the experiment.	Summarizes work and findings without any ambiguity and in relation to experiment objectives. Makes clever observations and deductions leading to substantiated conclusions.	Derives unique insight or conclusions from the experimental data. Uses conclusions to propose new questions and experiments.

Prior to the 2018, Outcome 6 was Outcome 3b[7], and has been assessed every other year, and the results are shown in Table 4. Between the years of 2014 – 2016, a poster presentation requirement was added as mentioned earlier in the document. This helped to better prepare the students as immediate feedback was provided versus waiting for a graded lab report.

Table 4. ABET Outcome 3b Assessment Summary

Year	2012	2014	2016
Interpretation of Data	2.86	2.44	3.3
Percentage of Groups with grand average of 3.0 (or higher)	50%	50%	75%

With the release of the new Criterion 3 and the school fully assessing the ability to use engineering judgement. Assessment data for 2018 is shown in Table 5. This data reflects the usage of the older experiments in the junior laboratory class.

Table 5. ABET Criterion 3, Outcome 6 Assessment Summary

Year	2018
Develop and Conduct Experiment	3.13
Analyze and Interpret Data	3.13
Use Engineering Judgement	2.8

Referring to Table 5, the use of engineering judgement is lower than the other two assessment items. With most of the comments from evaluators related to the students not making all of the relevant connections that should be making in their conclusions. With the addition of this new, project-based experiment, the student teams will be able to practice this feature in the junior MAE 301L lab which will better prepare the students for the senior laboratory experience.

Conclusions

In order for the school to stay compliant with Outcome 6 of the ABET engineering accreditation commission, the school must produce students who have the ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. By continually updating and improving the experiments used in both the junior and senior lab classes in the mechanical engineering department, the faculty aim to show through assessment data the ability of students to meet these objectives.

Within the mechanical engineering department, the goal is to use more project based experiments where students are exposed to experimental questions versus a list of procedures to follow given by the instructor of the course. The new experiment that was designed, built, and tested by senior engineering students will be used in conjunction with other equipment in the lab to improve compliance with this outcome. As in the past, data obtained during the assessment process will be used to continually improve the students experience in the lab setting.

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