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Revising Mechanical Engineering Laboratories for Improved Student Outcomes

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Introduction

"Scientists are men who dream about doing things. Engineers do them…You're an engineer, young fellow, and you're to be proud of it."
-James Michener, *Space* (1982).

Michener's words are as true today as they have ever been. Engineers do things. Mechanical engineers, in particular, apply the fundamentals of science and math to build mechanical devices that help solve problems. Laboratory experiences have practically always been used by mechanical engineering educators to instill those fundamentals in students;[1-3] and it is, presumably, in the laboratory that undergraduate students learn to fill in for themselves the gaps between theory and practice. However, a common problem in the undergraduate laboratory is ill- or under-defined learning objectives, which often lead to deficiencies in student performance.[4] Such a problem existed in mechanical engineering at the Mercer University School of Engineering. The overall goal of this paper is to examine the initial results of curriculum changes that were made in mechanical engineering to better align learning objectives with student performance.

Background

The Accreditation Board for Engineering and Technology (ABET) requires that engineering programs have eleven documented student outcomes that prepare graduates to attain the program educational objectives. The outcome that most specifically addresses laboratory courses is (b):[3]

…an ability to design and conduct experiments, as well as to analyze and interpret data.

At Mercer (prior to Spring 2011), the mechanical engineering laboratory sequence consisted of two courses that addressed the following components of criterion (b):

(i) the *analyze and interpret data* component was addressed in the student's junior year in MAE 302L (Mechanical Engineering Laboratory I), and

(ii) the *design and conduct experiments* component was addressed in the student's senior year in MAE 402L (Mechanical Engineering Laboratory II).

The descriptions of these courses have been discussed elsewhere.[5,6] In short, 302L Mechanical Engineering Laboratory I was comprised of six single-week laboratory exercises on various topics that were used to introduce students to experimental measurement of quantities of interest to mechanical engineers. The course consisted of 1 hour of lecture and 3 hours of laboratory per week which results in 2 credit hours for the course (1-3-2). Topics included: hardness testing, shear strength, beam bending, column buckling, thermal sensor response, and thermal sensor calibration. Each of these exercises resulted in a formal lab report, which was either individual or group-based, depending on the lab exercise. The series of experiments was followed by three two-week projects, which were intended to introduce the practical concept of experimental design to students. Typical laboratory objectives were:

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

(ii) Compare/contrast measured mass flow rates and meter coefficients determined by the venturi flow meter with mass flow rates and meter coefficients determined by using an orifice plate as a function of pressure tap location and orifice geometry, and

(iii) 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.

Indications from assessment

Student reports completed in both labs are the sole basis used to assess whether ABET Outcome (b) has been achieved for the Mechanical Specialization at Mercer. Formal assessment is conducted by a team of three faculty members, each of whom separately evaluates each of four tasks per laboratory group:

(i) Design of experiment

(ii) Conduct of experiment

(iii) Analysis of data

(iv) Interpretation of data

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 four of the sub-tasks have been adequately presented, then a score of ‘4’ is recorded on the evaluation sheet for the appropriate task. These twelve individual scores thus obtained (four 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[6].

An assessment was conducted in 2010 that provided the motivation for changing the content of the junior-level laboratory course (MAE 302L). The results of that assessment exercise indicated low performance in the ‘interpretation of data’ task (2.17/5.0). This result was consistent with results from earlier assessment cycles using a less refined assessment scheme. Additionally, only 4 of 6 laboratory groups (67%) had a grand average of 3.0 or higher. In the endeavor to address the results of that assessment, the series of laboratory exercises highlighted above remained unchanged and efforts focused on restructuring and expanding the lecture portion of the course to address perceived needs. The decision to alter only the lecture component of the course was made in order to more clearly differentiate the impact of changes. Modifications to the junior-level laboratory course MAE 302L were made in Spring 2011, in conjunction with other modifications to the mechanical engineering curriculum. The course was renamed MAE 302 Experimental Methods for Mechanical Engineers, and consisted of 3 hours of lecture and 3 hours of laboratory per week which results in 4 credit hours (3-3-4) to reflect the increased coverage of measurement, data interpretation, and writing.

The original lecture schedule provided for a total of fifteen 50-minute lecture periods, including in-class testing. An effort was made to organize lectures so that material significant to a laboratory assignment was discussed in class directly prior to that activity. Further, laboratory work began in the third week of lecture so that there was sufficient lead time on topics prior to the beginning of the laboratory tasks. In this arrangement, lecture topics included:

- uncertainty (2 periods);
- report format and data presentation (1 period);
- statistics (3 periods);
- curve fitting (1 period);
- temperature measurement (2 periods);
- pressure measurement (1 period);
- stress/strain measurement (1 period);
- flow measurement (1 period);
- tensile testing (1 period); and
- testing/mid-term exam (1 period).

The remaining period was reserved for emphasis on any particular topic that arose from observed laboratory practice, results of report grading, or lecture based assessment including in-class quizzes or testing.

The modified lecture scheme provides for a total of 42 lecture periods (50 minutes each), including in-class testing. The effort to organize lectures so that relevant material appears in lecture before lab continues. Laboratory activity still begins in the third week of the term. In this arrangement, lecture topics currently include:

- uncertainty (5 periods);
- report format and data presentation (2 periods);
- statistics (7 periods);
- curve fitting (2 periods);
- temperature measurement (6 periods);
- pressure measurement (3 periods);
- stress/strain measurement (3 periods);
- flow measurement (4 periods);
- tensile testing (1 period);
- vapor compression refrigeration cycles (1 period);
- engineering ethics (2 periods);
- writing reports (3 periods); and
- testing/exams (2 periods).

Again, the remaining period is reserved for use as needed in response to other topics that arise during the course of the term. In the following section, the following hypothesis will be tested:

Student performance in MAE 402L will improve if more time and effort is spent in MAE 302 addressing the ABET-related topics of analyzing and interpreting data, and designing and conducting experiments.

Basis for hypothesis

Since the assessment in 2010 indicated low performance in the 'interpretation of data' task, efforts focused on expanding the lecture portion of the course to address perceived needs. Hence the information is now presented thoroughly over a longer period of time. There is evidence to suggest that students learn more in low-density lectures.[7] In the context of a medical school, three groups of students were given lectures with 90% new material, 70% new material, and 50% new material and during the remaining time the lecturer reinforced the material's significance either by restating key ideas or providing examples. Students in low-density lectures scored higher on various assessment means.[8] In this case, both new topics were added and the breadth of the lectures increased.

Evaluation of student performance – Course grades

Grading is subjective and difficult, even under the best of circumstances with a well-defined, well-implemented rubric. The group nature of laboratory work complicates the issue even further, making it more difficult to evaluate individual contribution. Having mentioned but two of the caveats associated with relying on course grades to assess a curriculum change, Table 1 shows students' grades for the original MAE 302L/MAE 402L sequence before the lecture modification, and Table 2 shows grades for the sequence of courses after the modification.

Table 1. Student performance in the MAE 302L/402L sequence before lecture modification.

	Overall grade	
	Number	% of total
Improved	40	97.6
No Change	1	2.4
Worsened	0	0
	n = 41 students	

Table 2. Student performance in the MAE302/402L sequence after lecture modification.

	Overall grade	
	Number	% of total
Improved	34	91.9
No Change	0	0.0
Worsened	3	8.1
	n = 37 students	

Based on overall grades, there is no clear evidence that the change was beneficial. In both cases, the vast majority of students earned better final grades in MAE 402L than they earned in the junior-level course. These data were evaluated further using a paired t-test to assess differences between the students' mean grade change. The mean grade increase before the change to the lecture was 9.95% with a 95% confidence interval (CI) for the mean of (+8.4%, +20.4%) with a p-value <0.001, while the mean grade increased after the change to the lecture was 8.10% with a 95% CI for the mean of (+7.6%, +12.0%) with a p-value <0.001.

Evaluation of student performance – Written report grades

Since report writing was also seen as an area of concern, similar analyses were conducted on grades students earned on the reports written in both classes. Table 3 shows students' report grades for the MAE 302L/402L sequence (before the change) and Table 4 shows report grades after the change.

Table 3. Student performance on written reports in the MAE 302L/402L sequence before lecture modification.

	Reports grade	
	Number	% of total
Improved	33	80.5
No Change	6	14.6
Worsened	2	4.9
	n = 41 students	

Table 4. Student performance on written reports in the MAE 302/402L sequence after lecture modification.

	Reports grade	
	Number	% of total
Improved	19	51.4
No Change	4	10.8
Worsened	14	37.8
	n = 37 students	

Based only on written reports, there is evidence to suggest that changes have actually worsened the situation. Prior to implementation of the change to the lecture component of MAE 302L, the vast majority of students (approximately 95%) experienced no change or an improvement in their grades for written reports in MAE 402L compared to their report grades in MAE 302L. By contrast, that number dropped to 62% after the change. Paired t-tests confirm the result, the mean grade increase on the reports before the change in the lecture was 9.76% with 95% CI of (+5.7%, +23.3%) and a p-value <0.001and the mean grade increase on the reports after the change in the lecture was 0.62% with 95% CI of (-1.8%, +3.1%) and a p-value = 0.628. It must be noted that different instructors teach both lab courses from year to year, which likely introduces grading inconsistencies and statistical bias.

Evaluation of student performance – Subsequent assessment

So far, results of the change have proven discouraging. While the ‘interpretation of data’ task score rose from 2.17 to 2.86 and 2.44 for the 2012 and 2014 cohorts, respectively, the percentage of laboratory groups with a grand average of 3.0 or higher dropped from 67% to 50% in both cohorts. In short, although students continue to do well in the ‘design of experiment’ task, they are struggling more in the other three tasks (i.e., conduct of experiment, analysis of data, and interpretation of data). At this time, the desire is to collect more data (at least two additional years) under the current scheme before any additional changes are made.

Conclusions

In order to address perceived weaknesses in student performance, a significant change was made to a junior-level mechanical engineering laboratory course at Mercer University. The change expanded the lecture content to include more coverage of topics associated with instrumental measurement, data interpretation, and technical writing. Unfortunately, both metrics of evaluation (ABET assessment and student grades) have indicated lower performance. There could be a number of reasons for this indication. First, the sample size used here is relatively small and includes only one assessment after the change in lecture. Secondly, the student sample chosen is assumed to have a similar overall academic record; however, this may not be the case. Finally, the assessment technique may be flawed and may need some revision as this continues through the next ABET assessment term.

While discouraging, the mechanical engineering faculty at Mercer University will resist the temptation to make additional changes so soon, based on a relatively limited data set. Subsequent analysis will be conducted in two years, and if these preliminary results are confirmed, fundamental changes to both courses may be required to achieve a level of acceptability in the areas of conduct of experiment, analysis of data, and interpretation of data.

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References

1. Grayson, L.P., The Making of an Engineer, New York, N.Y.: John Wiley and Sons, 1993.

2. Reynolds, T.S., 75 Years of Progress: A History of the American Institute of Chemical Engineers, 1908–1983, New York, N.Y.: American Institute of Chemical Engineers, 1983.

3. “New Directions in Laboratory Instruction for Engineering Students,” Report of the Commission on Engineering Education, Journal of Engineering Education, Vol. 58, No. 3, Nov. 1967, pp. 191–195.

4. Feisel, L.D., and A.J. Rosa, “The Role of the Laboratory in Undergraduate Engineering Education,” Journal of Engineering Education, Jan. 2005, pp. 121-130.

5. Butler, A. J., and W. M. Moses, “Introducing Experimental Design in Mechanical Engineering Laboratories,” ASEE Annual Conference and Exposition, Portland, Oregon, June 12-15, 2005.

6. Butler, A. J., and W. M. Moses, “A Method of Assessment to Examine Experimental Design in Mechanical Engineering Laboratories,” Paper no. ASEE AC 2009-2209, ASEE Annual Conference and Exposition, Austin, Texas, June 14-17, 2009.

7. Russell, I.J., W.D. Hendricson, and R.J. Hervert. “Effects of lecture information density on medical student achievement”. Journal of Medical Education ,Vol. 59, No. 1l, 1984, pp. 881-89.

8. Bland, M. , Saunders, G. and Kreps, Frisch J, “ In defense of the Lecture,” J. Coll. Sci, Teach, Vol. 37, No. 2, 2007, pp. 10-13.