Laboratory changes: Sustainability, Streamlining, and Satisfying ABET

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Abstract

Laboratory courses are an invaluable hands-on experience for students in all sorts of scientific disciplines. However, they can also be a significant strain on time and resources. In the junior and senior level mechanical engineering labs at Mercer University, student enrollment has been increasing, older equipment may not be replaceable, and the current spreading of faculty resources is not sustainable. In this paper, recommendations are made for changing and improving these lab courses. Changes are proposed to improve student outcomes, increase the number of simultaneous experiments that can be conducted in one laboratory, and replace experiments and projects which are no longer optimal for the current situation, while attempting to minimize costs. The change in wording in the ABET criteria for laboratory experiments is also considered. It is hoped that some or all recommended changes will be implemented in the next two semesters for the upcoming junior and senior lab courses.

Keywords

mechanical, laboratory, ABET

Introduction

At Mercer University, the mechanical engineering curriculum includes a junior and a senior level laboratory course, each with a focus on different aspects of experimentation. For a variety of reasons explained below, it is desirable to change some of the teaching and evaluation methods used in these courses, as well as to modify or replace some of the laboratory experiments which the students perform. In this paper, some recommendations are made regarding how to make changes, along with discussion of the reasoning behind the recommendations. As this is an ongoing process, it is expected that the recommendations herein presented may be modified as changes are implemented.

Background

Every spring semester, a junior level laboratory course with an associated lecture course is offered, hereafter referred to as junior lab and junior lecture. These comprise a subset of the prerequisites for the subsequent laboratory course, offered every fall, which shall be called the senior lab. The junior lab currently consists of six experiments. The first four have setup and procedure largely dictated to students, and students present their findings in a poster presentation format. For the last two experiments, students are given an experimental objective to achieve, and must generate a generally straightforward procedure to achieve the objective. They then run

their experiments and turn in a written lab report. In the senior lab, the semester is divided into two parts. In each part, the students are given a complex task to achieve. They turn in a written experimental plan, run a set of experiments and/or processes for several weeks, and turn in a written report at the end of the part. There are two tasks to be achieved, so halfway through the semester, students are switched from one task to the other, and the process is repeated.

Some aspects of the lab experiments could bear improvement. First, for some experiments, there is not enough equipment to serve all students at once. In particular, the last two experiments for the junior lab involve tensile testing in one case (one small and one large machine are available) and refrigeration cycle test benches in the other (two units available). This equipment is prohibitively expensive to replace or augment, and because of the legacy refrigerants currently in use, it is not certain that the refrigeration test benches could be repaired if they develop problems. The result of this problem is that students either work in two different laboratories (the tensile test equipment is not in the same space as the rest of the course), necessitating additional faculty workload to maintain proper oversight; or multiple student groups use the same equipment simultaneously, degrading the learning experience. Second, it is desired to change one of the projects for the senior lab for a variety of reasons. In this task, students are required to develop an experimental free convection correlation, while also determining all fluid properties experimentally. Because this involves, at a minimum, five experimental setup configurations, students often have great difficulty planning the whole task in advance for their experimental plan. Students are also required to do additional reading to learn necessary material which has not been covered in previous courses. The result is that experimental plans (and lab reports to a lesser degree) are not well organized or thought out and are very difficult to mark constructively. Faculty must also spend considerable time in the laboratory guiding students toward correct procedures and understanding of the theory behind the experiments, even though the work is nominally self-guided by the students.

In addition to changing some of the experiments, it is also desired to improve the focus on certain student outcomes. One aspect of student success that we would like to improve upon is the ability to write experimental plans in the senior lab. Students struggle with this, partly because they are writing extensive plans that cover work for half a semester, but also perhaps because they do not get much experience writing plans in the junior lab. Additionally, the wording of the ABET requirements for experimentation has changed slightly. While the old criterion 3b was “an ability to design and conduct experiments, as well as to analyze and interpret data”, the new criterion 3(6) is “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions”. The main difference seems to be the replacement of “design” with “develop”.

Goals

There are several goals of the proposed changes to the lab courses, which require a certain amount of balance and compromise. The first goal is to maintain or improve the student experience and learning outcomes in the lab course. Specifically, it is desired to improve the students' ability to develop experimental plans, and it is also desired to have each group of

students always working on a different experimental apparatus. Second, the proposed changes should not increase the average faculty workload, and should prevent the need for multiple faculty for parts of the semester (due to simultaneous experiments being in different laboratories). Adjustments should also agree with the current ABET evaluation criteria. These goals will be accomplished by making modifications to the teaching and evaluation methods, as well as by changing the experiments that are performed. Particularly, it is recommended that the refrigeration experiment in junior lab be augmented by other experiments and eventually replaced, and that the free convection correlation task in senior lab be replaced. All changes are also recommended with reasonable frugality in mind, particularly when replacing experiments.

Timeline

It is anticipated that some of these changes will be implemented during the spring 2019 semester for the junior lab. New experiments will be introduced without necessarily removing old ones, such that over the course of the semester, a few experiments may not be performed by all the students. Changes to the senior lab will depend on the amount of support received, but could potentially be totally implemented for the fall 2019 semester.

Junior lab changes

Some format change is recommended for the junior lab. Currently, the junior lab has poster presentation for the first four experiments, and experimental plans and full lab reports due for the last two experiments. While the posters generally improve over the course of the semester, the experimental plans and lab reports often seem weak in comparison. In an effort to provide more of a transition, it is proposed that a short "executive summary" report be written for the fourth experiment. This will force content to be condensed like it is on the posters, but will let students write more in the style of regular reports. Maximum page limits may also be added to reports in an effort to keep them succinct. An effort will also be made to provide clearer instruction in the junior lab and lecture as to what is expected for experimental plans and lab reports.

It is also proposed that the refrigeration experiment be replaced with an acoustic impedance experiment and a pump characterization experiment. The refrigeration cycle experiment requires students to correlate one state variable in the refrigeration cycle to the coefficient of performance, while keeping another state variable constant. The replacement experiment(s) will be performed by some groups, while other groups run the refrigeration experiment instead. To keep some parity between experiments, it is desired to have each experiment require calculations over a range of values. In the proposed acoustic experiment, a waveguide will be made of PVC pipe, with a foam plug added at one end, and a speaker at the other. Ports for two microphones will be added to the pipe. Using a signal generator to drive the speaker, and a computer to record the microphone inputs, students will be asked to characterize the acoustic impedance of the foam. Since the microphones and digital computer interface are available, as well as a signal generator, this experiment should incur minimal cost. If the experiment is duplicated, some additional equipment will need to be purchased, which is expected to be no more than a few hundred dollars if a spare computer can be requisitioned. The proposed pump characterization

experiment will involve a DC water pump which will accept variable voltage input. The pump will be submersed in a water tank, and a circuit built which includes a length of hose and a valve to restrict flow. Using a DC power supply, and the flow restriction valve, students will determine the efficiency of the pump versus flow rate, while keeping a constant system pressure.

Senior lab changes

A main objective of the senior lab course is for students to design experiments, which should perhaps be changed to "develop experiments" given the new ABET criteria. In the author's experience, most students, when asked to find some value or relationship experimentally, immediately perform an internet search to determine how to do it, rather than trying to develop a theory and experiment from first principles. This relatively recently developed tendency can make it challenging to develop design skills in students. Certainly for multi-week projects, students cannot be prevented from searching the web for answers; and even if the clever instructor thinks up an experiment for which the internet does not provide a ready answer, it will only be a matter of time before such an answer is posted. This may well be the reason that students are now expected to develop appropriate experiments rather than design experiments. The focus has moved from producing unique solutions (or solutions from first principles), to determining which already present/known solution is most suitable, and implementing it properly. To encourage critical thinking, then, it is important that the required task involve more than a single simple calculation, such that the student must determine which experiments are necessary, and how to carry them all out to determine whatever is required. Rather than finding all fluid properties required for a free convection correlation, it is proposed that this half semester of senior lab instead focus on two shorter tasks. This will doubly reinforce the process of determining, performing, and analyzing the results of the needed set of experiments, at the expense of some complexity in the process. In this author's opinion, it is a good trade. Like in the junior lab, some effort will also be expended to improve the quality of instructions that students are given as well.

The first proposed replacement experiment is a dynamics problem: find the center of mass of a flat plate of irregular shape, and for which the center of mass does not lie on the plate itself; and determine the moment of inertia about that point (for rotation in the plane of the plate). The goal is for this to be a short experiment, for which students can develop a clear plan, and the students can receive early feedback to help them in developing their second, more complex experimental plan. Additionally, enough equipment will be provided to allow the students to have several correct options available to determine the required values. This will be a good opportunity for the students to consider which method will provide the correct answer most easily or accurately. If time permits, one lab period may also be devoted to presentations and discussion of this first task. The cost for this experiment should be reasonable, as the required materials consist mainly of some small metal plates, a stand to allow for free rotation experiments, and measurement apparatus which are generally already available.

The details of the second replacement still require some refinement, but it is proposed that it be a fluid experiment to characterize flow through an orifice. Students will be tasked with generating

a curve fit, and determining the range of conditions for which the fit provides an uncertainty below a certain threshold. At a minimum, viscosity will need to be found experimentally to find the Reynolds number, and pressure and flow rate must be found in the orifice experiment. This task could be expanded to include making students build/assemble their own manometer for pressure readings, and possibly making students additionally analyze whole system performance. It is hoped that some support will be available to further develop this task over the coming spring and summer terms. A viscometer is already available for this task, but various other pieces of equipment will have to be purchased, including pumps, fittings, and hose and/or pipe; costs for this experiment have not yet been approximated.

The proposed changes to senior lab include replacing one task with two. While this does increase the faculty grading load, it is hoped that the decreased length of each assignment, coupled with the decreased complexity and hopefully better instructions, will improve the quality of the deliverables and mostly offset this extra burden. Additionally, if the fluids task can be replicated inexpensively enough, it may be possible to have four student groups per section rather than two; this could significantly decrease the number of faculty hours spent in the lab, even if it does not decrease the grading workload.

Evaluation

After implementation, each course will be evaluated to determine if the changes have made improvements in instructor effort and in student experience and outcomes. Conversations with the instructors will probably suffice to gain their opinions on both aspects. Additionally, a survey will be given to students in the junior lab regarding their opinions and experience with the experiment they are selected to perform, as well as their perceptions of how it compared to the other available experiments which they observe their peers completing. For the senior lab, a student survey can be given if two experiment options are given. However, if the old experiment is completely replaced as expected, then evaluations of ABET criteria for the new experiment can be compared to similar evaluations from previous years. Since this course is evaluated annually for criterion 3b (now 3(6)), the scores given by faculty reviewers could be a useful tool to evaluate these changes with respect to student outcomes.

Summary

Junior and senior level mechanical engineering lab courses required changes, and proposals have been made for how to make those changes. An acoustics experiment and a rigid body dynamics experiment are expected to be implemented for the spring and fall 2019 semesters, respectively, while a set of fluid experiments may be implemented for the spring and fall 2019 semesters, depending on the speed at which equipment can be procured, and availability of resources to work on lab development.

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