ACTIVATING A SECOND YEAR MEASUREMENT LAB SEQUENCE

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ABSTRACT

MECH 215 is a core measurement course in Mechanical and Materials Engineering at Queen's University with a lab component intended to maintain active learning skills fostered in the common first year program. In contrast to cookbook labs it is more process focused and drives student engagement through several active learning techniques. The learning objectives of a typical undergraduate lab experience are often undermined by the conflicting objectives of completing the task as quickly as possible while producing a good mark. The MECH 215 sequence intentionally reduces the complexity of the lab content in order to focus on the process and require active engagement in the measurement activity through several simple techniques.

- Incomplete information is provided in the lab material. Students are required to discover necessary characteristics of the available equipment and make independent decisions in order to meet the objectives.
- Just in time delivery of knowledge is provided in several ways. The students work in small groups within a larger lab plaza, so discovered information travels peer to peer. TAs and a faculty member monitor progress and deliver assistance only when students have hit a roadblock.
- Planned failure is incorporated into the activities with the expectation that some (or all) students will not get high quality data or flawless instrument performance. Overcoming these problems exercises critical thinking and engineering decision making skills in the lab environment.
- Multiple paths to a successful outcome exist for the activities. Students have choices to make in how they use the available resources.

The paper outlines the sequence of activities with specific examples of the application of these principles in practice and illustration of the flow of measurement concepts. This approach to giving labs provides some efficiencies of scale from having many groups active on the same activities at the same time, but also requires more faculty engagement in the delivery. A cost comparison between delivery methods in the same environment is made, showing that substantial advancement of CDIO syllabus objectives can be reached for little or no incremental cost.

KEYWORDS

Measurement, Laboratory, Cost, Active Learning

INTRODUCTION

For the past generation lab activities included in a typical North American Mechanical Engineering curriculum have involved only slightly more active learning than the typical lecture / assignment / exam courses they accompanied. These “traditional labs” generally focus on the demonstration of some physical principles developed in a lecture course by making measurements as reliably as possible on a mechanical system such as an IC engine, then completing some analysis and comparing the results to the idealized models derived in class. Characteristics of these labs include:

- A well integrated test system, with good quality instrumentation installed professionally to provide reliable data.
- Data display and recording systems pre-programmed and pre-wired for efficient and consistent performance.
- Lab documentation with detailed specifications of the hardware, instrumentation, and software involved.
- Step by step operating instructions to guide the students through the measurement process, and often the analysis phase.

These characteristics succeed in providing all students with a similar experience, exposing them to operation of a real system while collecting enough good quality data to analyze, producing predictable results that support classroom instruction. The well integrated package and detailed instructions allow the students to complete the lab activity in as little time as possible with minimal additional instruction or supervision and a very limited chance of failure at the task. Productivity is high by typical measures that focus on what content is taught, rather than on learning outcomes as in the CDIO approach [1].

Unfortunately, these seemingly positive characteristics also lead to some negative results with regard to learning outcomes:

- There is a significant amount of effort and expense involved in creating the integrated lab package, so they tend to be the same from year to year even as they become outdated.
- Running the same lab each year allows the students to pass down their lab reports as aids to the next year’s students, or for outright copying, which the predictable lab outcomes make difficult to detect.
- Labs in support of lectures are generally aimed at linear, steady or periodic operations that can be adequately described analytically in class and easily measured. Ignoring the non-linear, transient performance that is often important.
- Cookbook instructions do not require any engineering skills or knowledge to follow during the lab session, and provide no decision making options, limiting student engagement and thus reducing student learning.
- Learning objectives are further undermined by the conflicting objectives shared by both the students and the TAs delivering the lab. Both would like to complete the task as quickly as possible to move on to something else, and both would like the result to produce a good mark for the undergraduates. The result is even more streamlining of the lab process so that the undergraduates move through it as quickly and smoothly as possible, leaving with all the data required for the analysis, but little understanding of the how the results were achieved, or why.

The first two can only be thoroughly addressed by changes in resources and rewards associated with the lab activities. Resources alone are not enough without motivated faculty to make new activities part of the program. This paper addresses the approach to and experiences with reducing the last three by creating a linked sequence of labs with variable outcomes, engaging students through incomplete specifications, decision making as part of a team, and active assembly of the test equipment.

LAB SEQUENCE

The sequence of labs in the course is designed to flow in conjunction with topics addressed in the lecture portion of the course, however the labs also build on each other, carrying tools and concepts from one lab to the next.

Lab Zero: Labview was added to the sequence to provide students an opportunity to get familiar with simple Labview programming and operation for data acquisition and is a TA guided implementation of a simple virtual instrument (VI) that they will use throughout the sequence to record transient voltage data.

Lab One: General Instrumentation has the students work with and compare the features of simple bench instruments like a digital multi-meter, analog oscilloscope, and computer data acquisition (using the VI developed in lab zero) by using them to measure the output of a signal generator, battery voltage and resistance of ¼ watt resistors. Emphasis is on uncertainty, sources of error, and sampling rate requirements.

Lab Two: Temperature Measurement uses the instruments from labs zero and one to measure the behaviour of thermometers, thermocouples and resistance temperature detectors (RTDs), and introduces the wheatstone bridge for measuring small resistance changes. Emphasis is on transient response and developing a first order model.

Lab Three: Stress and Strain uses a cantilever beam load cell to develop the idea of calibration for the characteristics and accuracy of a measurement system. Strain gauges in a wheatstone bridge give a near instantaneous response while the physical system mass and stiffness determine the second order dynamic response of the complete system.

Lab Four: Position Measurement repeats the calibration process with a rotary potentiometer then introduces the effects of noise in extracting measurements of angular velocity and acceleration from the raw position data. An additional segment has students determine the measurement capabilities of a complex system by examination of the output. GPS units and an optical position tracker have been used.

Lab Five: Pressure and Flow has students using a water manometer and solid state pressure transducers to measure steady and transient pressures, and then to measure the static pressure from taps on a small piping system driven by a vacuum cleaner. Pressure drop in the pipe is measured, as well as start up and shut down transients.

This sequence provides an opportunity for students to learn some important concepts in measurement and testing as well as the physics of the system behaviour. They encounter physical phenomena from previous or current curriculum which they can analyze, as well as elements like heat transfer they do not yet have the theoretical tools for. It can be carried out with inexpensive, uncomplicated equipment. It can be implemented in just about any facility, although a purpose built facility like the lab plazas in the Integrated Learning Centre at Queen’s [2] provides an ideal venue. Unfortunately, it can also be streamlined to allow students to complete all the necessary measurements for each segment and be out of the lab in half an hour, having learned little or nothing while actually *in the lab*. That streamlining is eliminated by actively engaging students in the process through the structure of the activity.

PREPARATION

Lab Zero prepares the students for the idea that they will actually be thinking and acting during the lab periods, while working in a group of three or four. A clear set of step-by-step instructions is provided to create a VI and test its functioning. This segment was only split off from the general instrumentation lab when we realized just how many sub-functional outcomes were possible from those instructions. As a separate segment there is time for each student group to debug their own VI to produce a tool they will use in all of the other labs. Students introduce personal elements as simple as names that give them ownership of the tool.

ACTIVATION

Labs one through five are distinctly different in being more open ended and lacking step-by-step instructions. Students must make their own decisions on how to achieve the measurement objectives and how to determine when those objectives are met. That includes completing all instrument connections themselves, and fabricating some of the test equipment. These elements allow students to take multiple different approaches to the measurement task, and because multiple groups are working alongside each other in the same space they learn from interactions between groups taking different approaches. This can be best illustrated by examples.

In lab one students move around the room with DMMs measuring the results achieved by other students. The result is student motivation to maintain quality in comparison to their peers and a unique data matrix to analyze for overall uncertainty in the process. They identify connections to make from device spec sheets and experience errors with poor or reversed connections after stripping insulation from the wires to make those connections.

In lab two each student starts with a short length of thermocouple wire that must be welded to make a junction and then connected in various configurations of measurement and reference junctions. They experience recoverable failure in their welds, with highly variable results. Groups that rush to complete the measurements see that their circuits of twisted wire connections cause them reliability problems even in the short term compared to those who solder the joints or use terminal blocks. Their constant reference temperature is provided by placing the reference junctions between two bricks with liquid crystal temperature strip, resulting in a different, uncontrolled reference temperature on different days (Figure 1).

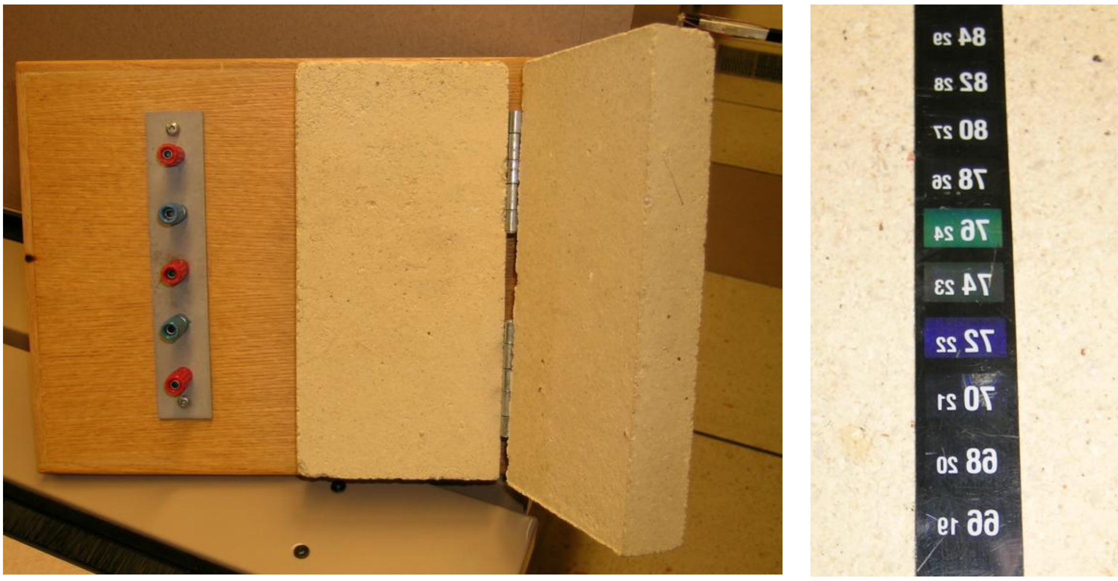

Figure 1. A simple system for connecting thermocouples and providing a reference temperature between two bricks. The LCD strip provides an imprecise reference in the uncertainty analysis. The burn mark on the left is evidence of student soldering in the lab.

In lab three each group glues strain gauges to a cantilever beam, then solders leads to the gauges, with an eventual success rate of about 95% – we keep a beam in reserve for those few groups who just can't get it to work in the time. Before even they starting they must first decide where to put the gauges on the beam and in which orientation.

Calibration of the load cell is performed by applying various weights held in a bucket, or otherwise (Figure 2). The students are not provided with reference weights but must use text books, lumps of scrap steel or anything else available and weigh their materials on a digital scale. They obtain irregularly spaced calibration points and must make their own decisions about how many are enough.

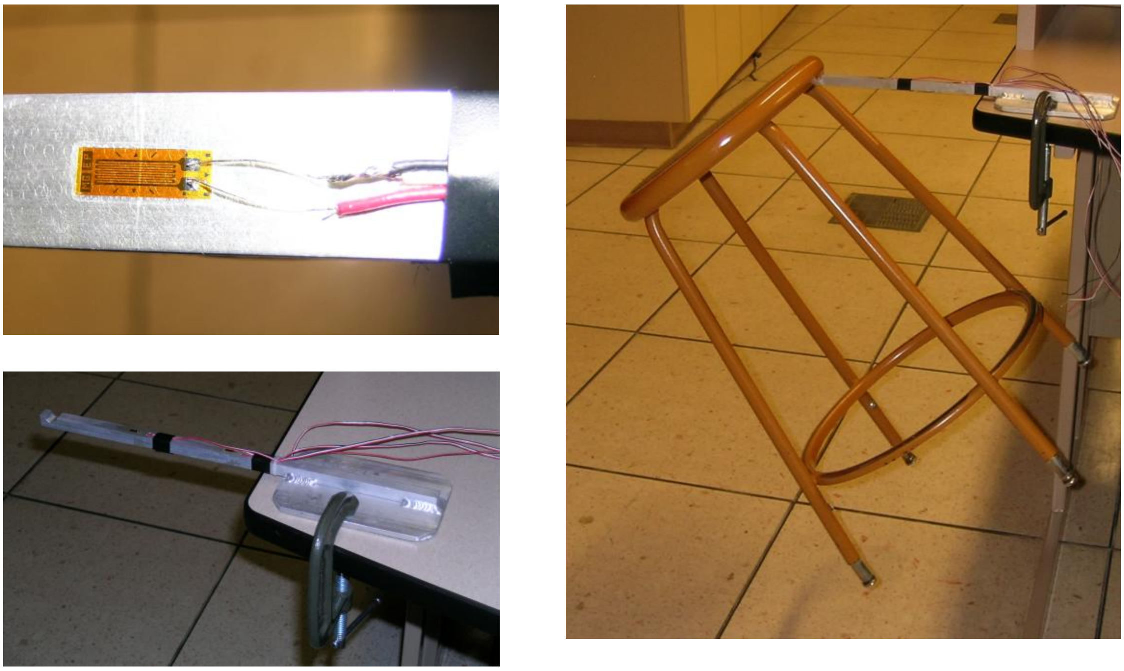

Figure 2. In the strain measurement lab students first glue a strain gauge to the aluminum cantilever beam, then solder leads to the gauge. This is made somewhat easier by the larger pads on Intertechnology student gauges. The beam construction allows easy clamping to a bench and the notch in the end of the beam allows suspension of a bucket or other objects.

In lab four students are challenged to measure which among them can turn the potentiometer knob at a most nearly constant angular velocity. In converting voltage to angular velocity they must first find a suitable circuit and then find a way to numerically differentiate the results without amplifying the noise too much. They discover some scheme (usually a moving average) to low pass filter their data.

In lab five they see a slow transient response from a manometer responding to a balloon popping step function (Caution: some students have a bad reaction to popping balloons so a warning and accommodations may be necessary) and a slow transient response from a solid state pressure transducer monitoring a vacuum cleaner running down and need to establish instrument response as distinct from system response.

In lab two students are simply asked to measure the time response of a thermometer suddenly dunked in hot water. They must decide how to measure time, how often to take readings, how long to take readings, and how to accomplish this as a group – it is difficult to manage timing, reading and recording alone.

Throughout the sequence they are measuring voltages or resistances that they must convert to other units through calibration factors they have determined themselves. There are many ways to assemble circuits of these low voltage components, most of which are harmless and offer learning opportunities in the debugging. We have explicit checkpoints where damage might result and have added small resistors to the wipers of the potentiometers to prevent outright shorts, but generally encourage students to test their ideas and learn from the experience.

GUIDANCE AND CONTROL

All of these uncertainties produce different responses in different students and each group and situation needs a different response from instructors. Active learning requires active guidance and control to recognize differences and respond appropriately, in ways that are usually beyond the capacity of a typical graduate student TA. The lab sessions must have supervision from somebody like a faculty member, adjunct, or senior technical staff member to keep things on track.

Some groups are all business, have read the materials in advance, come in and complete each task quickly and fully, and probably didn't need the lab experience because they have already achieved the learning outcome goals somewhere else.

Some groups are ill prepared but ready to try anything. They will complete some sequence that comes close to meeting the objectives, but may not recognize that their data are inadequate until long after the lab session when they go to write up.

Other groups are hesitant to try anything for fear that it may be wrong and would prefer to wait for an instructor to do it for them.

Those three descriptions are almost caricatures in their generalization, however they represent a large portion of the class. When things are going well the instructors will checkpoint the first type of group to make sure they are on the right track and compliment them on their preparation. The second group will notice that things are going well for the first group and will probably incorporate some of those techniques when their own first attempts don't work out so well. The third group may start their own efforts once they notice that nothing really bad has happened to groups one and two. If the population in the lab section is fairly balanced then this process will take little instructor intervention, but if there's a shortage of well prepared and competent groups, then the instructor needs to initiate and guide the process.

The eager, but ill prepared groups need to be redirected to recognize what they are missing and think a little more before acting, while the hesitant groups need to be encouraged to try out a few well considered actions to test what works, and if there is time, the businesslike groups need to be encouraged to try some other possibilities beyond the specified objectives to see what else they can learn from the situation. The result is rather like herding cats, however 2 TAs and a faculty member can guide a section of 10 to 15 student groups through these activities in two to three hours per lab segment.

COSTS

Our typical classes are on the order of 150 to 180 students. In a traditional lab offering a faculty member would be responsible for reviewing the lab equipment preparations, briefing and supervising TAs and delivering an introductory lecture for that lab to place it in context. Two TAs would then supervise the class as they completed the lab (typically 1 TA to 3 groups at a time) and mark the lab reports. The sequence of six labs would be spread over 6 faculty to distribute the load. The result, in addition to preparing the labs, would be 12 to 18 faculty contact hours and 12 TA term contracts at 60 hours each for supervision and marking.

In this active learning model a single faculty member would be responsible for all six labs to maintain continuity, and would attend all lab sessions, typically with 8 to 12 student groups per 2 to 3 hour session and 5 or 6 sessions per lab. TAs would each support all six labs through the term to spread their load. The result, in addition to preparing the labs, would be 60 to 90 faculty contact hours and 6 TA term contracts at 60 hours each.

The active learning approach requires less total personnel time, but requires considerably more time from a faculty member or similarly qualified individual. The six additional TA contracts translate to about $15,000 in our environment, which is similar to the cost of hiring and adjunct faculty member to teach the lab portion of the course, but somewhat cheaper than the cost of assigning it as core teaching load to a tenure stream faculty member. TA budget is often seen partially as graduate student support and comes from a different funding stream, making it more attractive to use TAs. Additionally, in tight economic times the tendency is to eliminate as many flexible costs as possible, including adjunct teaching positions. Finally, splitting the task between 6 faculty only adds a minor load to each faculty member which may not show up in accounting resource requirements. The result can be a bias towards delivering labs in a traditional cookbook format with limited student engagement.

The simplicity and intentional crudeness of some of the measurement devices allows assembly of many sets of equipment at minimal cost. Although a purpose built lab plaza provides a wonderful venue for this and other activities, this approach was first developed in large empty room with simple plywood benches and it worked very well there.

CONCLUSION

A sequence of labs can be delivered in a more activated form with more faculty involvement if the institutional will is there. The actual cost is similar, especially if the faculty member involved is an adjunct or other teaching focussed instructor. Student engagement is increased by adding obstacles to simple measurement tasks, however timely intervention is necessary to keep challenge from spilling over into frustration. Further assessment is required to determine formally if this active approach produces the better learning outcomes we observe anecdotally.

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Biographical Information

Rick Sellens is an Associate Professor in the Department of Mechanical and Materials Engineering at Queen's University. His research background is in Fluid Mechanics and more recently in Biomechanics and he has been actively involved in facilities development to support active learning, including the recently completed Integrated Learning Centre at

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