

The Challenges of an Integrated Laboratory Course Sequence

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INTRODUCTION

The engineering program at The College of New Jersey (TCNJ) offers undergraduate degrees in engineering science with specialties in one of the areas of Mechanical, Electrical, or Computer Engineering and Engineering Management. The main goal of the department is to well prepare the graduates for entry-level positions in industry and/or to continue graduate studies. The mission statement of the department reflects on all necessary ingredients for achieving this goal.

One of the eight cylinders of the engine required for supplying the means to arrive at the department's main goal is: "develop the student's ability to design and conduct experiments, analyze and interpret data, and communicate the results effectively." In 1998, the faculty in the mechanical specialty of the program decided to separate the laboratory components of the specialty courses from the lecture content. Prior to this most experiments were conducted as part of normal lecture courses. There were several contributing factors to the making of this decision. The final objective is to improve on and better execute the laboratory component of the program.

Among the considered factors, the injection of elements to enhance "the ability to design experiments" was both most appealing and challenging. This would seem "structurally" more probable to create and execute in a stand-alone course(s) rather than an added factor in a mixed lecture-lab course. Increased chances of obtaining both more advanced hardware and software through institutional and outside national resources seemed to serve as another incentive. Last, but certainly not the least was the influence of ABET Criteria 2000. Higher visibility and better means of demonstrating "where the beef is" for satisfying the experimentation requirements of the criteria seemed more probable in the separated mode.

The authors/coordinators of the four newly born "1-credit" laboratory courses, will discuss the logistical problems they have faced in this process. They will also share "the first order" solutions they have generated to address most (but not all) of these difficulties.

THE COURSE SEQUENCE

Traditionally, laboratories are employed in such a manner that the students conduct the corresponding experiments of certain theories one or two semesters after they have had exposure to them. In this way, experiments related to several subjects may be "packaged" in a single laboratory course. The major advantages in this approach are presumably the elimination of many synchronizing activities required in a mixed lecture-lab course and greater development of measurement theory. However, the main disadvantage is the loss of "the two-way street" through which theory and experimentation simultaneously enrich understanding by supporting each other. *Recognizing this dilemma, we have tried to bring the best of the two worlds together and minimize the loss in the previous model.*

To achieve such an idealized environment, the following four major questions/difficulties had to be addressed:

1. What material should be covered in each of the courses in the sequence?
2. How much time should be allocated on a weekly basis?
3. Where should these courses be placed in the body of the 8-semester?
4. How many lab courses are necessary?
5. How many credits should be allocated for each course?

As one may easily realize, these are the main parameters that form the equation of the problem. In our first iteration for calibrating the equation of the new model, the following decisions were made.

It was highly desirable to maintain the integrity of “the two-way street” approach. Therefore, every effort has been made to maintain the close proximity of lecture-laboratory material. The number of courses (four) was decided based on the need for synchronization with the lecture materials of the courses. The courses would meet weekly for a 2 ½ hour session during the 14-week semesters. After several brainstorming sessions and iterations, a promising sequence of material coverage and placement emerged.

The following table displays the order in which the mechanical laboratory courses are placed in the program along with their relations to other supporting courses.

<i>COURSE</i>	<i>YEAR TAKEN</i>	<i>TERM TAKEN</i>	<i>SUPPORTING COURSES</i>	
			<i>TAKEN PRIOR</i>	<i>TAKEN CONCURRENTLY</i>
<i>MECH. LAB. I</i>	2	2	<ul style="list-style-type: none"> • <i>PHYSICS I & II</i> • <i>TECH. WRITING</i> • <i>STATICS</i> • <i>COMPUTER PROGRAMMING</i> • <i>DIFF. EQS.</i> 	<ul style="list-style-type: none"> • <i>MECHANICS OF MATERIALS</i> • <i>MATERIAL SCIENCE</i> • <i>PROBABILITY</i> • <i>DYNAMICS</i>
<i>MECH. LAB. II</i>	3	2	<ul style="list-style-type: none"> • <i>THERMO. I</i> • <i>NUMERICAL ANALYSIS</i> • <i>ADVANCED MATH. I</i> 	<ul style="list-style-type: none"> • <i>THERMO. II</i> • <i>FLUID MECHANICS</i> • <i>ADVANCED MATH. II</i>
<i>MECH. LAB. III</i>	4	1	<ul style="list-style-type: none"> • <i>MECHANICAL ENGINEERING ELECTIVE I</i> 	<ul style="list-style-type: none"> • <i>HEAT TRANSFER</i> • <i>CONTROL SYSTEMS</i>
<i>MECH. LAB. IV</i>	4	2	<ul style="list-style-type: none"> • <i>MECHANICAL DESIGN ANALYSIS</i> • <i>MECHANICAL ENGINEERING ELECTIVE II</i> 	<ul style="list-style-type: none"> • <i>COMPUTER AIDED DESIGN</i> • <i>DIGITAL CIRCUITS AND MICROPROCESSORS</i> • <i>MECHANICAL ENGINEERING ELECTIVE III</i>

Table 1: Sequence of the four laboratory courses and their relationship with lecture courses

Mechanical Engineering Laboratory I

Students take the first course in the sequence in their sophomore, second semester. The bulk of the experiments are related to the theories of mechanics of materials. They must sign up for the mechanics of materials course as the co-requisite of this course. More importantly, this lab course serves as the “co-requisite” of the mechanics of materials course. In other words, the lectures in one course and the experiments in the other fully complement each other.

In the first three weeks, the students are exposed to general measurement systems, experimental test plans and metrology. A complete and customized review of statistics including regression analysis and goodness of fit is provided. Uncertainty analysis is covered at an introductory level. Heavy emphasis is placed on the quality of technical reports and group dynamics.

In conjunction with their first experiment (metrology) students are given a project through which they must apply all their up to date knowledge of data analysis. Use of Mathematica is required as part of this exercise. In the process of another experiment (uni-axial deformation of non-prismatic bars), details are provided on how they may observe the simple and yet effective means through which this experiment was created and utilize similar approaches for designing their first experiment in the sequence of the four courses. They must present their design in the last session of the course.

Ten additional experiments are conducted during the course. These are all related to theories of mechanics of materials with heavy emphasis on the strain gauge use and applications. Commercially available software ($c^2 b^2$) is applied in conjunction with two of the experiments. Advantages and limitations of this software are examined.

Mechanical Engineering Laboratory II

The second course in the laboratory series is offered during the junior second semester. It is intended to reinforce the Thermodynamics and Fluid Mechanics material. Thermodynamics II and Fluid Mechanics are taken concurrently. Experiments within this laboratory cover such topics as viscosity, friction loss in pipes, equations of state, and saturation properties. More advanced thermodynamics topics are also involved, including coefficients of performance, calorimetry, and emissions analysis. On the measurements side students are introduced to basic temperature and pressure measurement devices, including fluid velocity and flowrate measurement. Extra emphasis is placed on thermocouples and manometers as they are used in several of the experiments. Considerable time is spent introducing and using the concept of uncertainty and learning to identify sources of error. This allows the students to refresh and build upon their knowledge of statistics covered in the first laboratory course. There is continued attention in this course on group report writing.

The design content of the course deals mainly with the selection and specification of experimental components (such as thermocouples, RTDs, etc.) to achieve a desired result. A driving factor in the design aspect is the inclusion of uncertainty in the part selection with goals placed on the accuracy of the measured variable.

Mechanical Engineering Laboratory III

The third course in the sequence occurs during the student’s senior year, first semester. This time corresponds with the students’ coverage of Heat Transfer in lecture. Topics within this laboratory course cover advanced fluid mechanics and all topics within heat transfer. This includes lift and drag, heat transfer by conduction, convection, and radiation, as well as the use

and verification of analytical fluid mechanic and heat transfer equations (such as the lumped capacitance method). The measurement of temperature, pressure, and velocity is expanded by using new apparatus (7-hole probe, inclined tube manometer, hot wire anemometer) and by further covering measurement techniques (thermocouple reference junctions and voltage to temperature equations). However, the major addition to the student's measurement knowledge in this course is computerized data acquisition. Students are exposed to the concepts of analog to digital conversion, discrete binary values, resolution, and sampling rate. This material is facilitated by an introduction to and use of the LabVIEW data acquisition software. The brief coverage of LabVIEW will be reinforced by use of the software in a separate controls laboratory. The use of data acquisition in this course includes a review of the uncertainty material covered in the second laboratory course and allows the introduction of dynamic measurement systems; including an experiment dealing with time constants for first order systems.

The design content for this semester is expanded to encompass the complete specification of the experimental procedure. The design problem also involves a data acquisition system that must be configured and programmed by the students.

Mechanical Engineering Laboratory IV

The last course in the sequence is offered in the second semester of the fourth year. A vibration or an advanced stress related course is usually offered during the same semester (Mech. Elective III). The experiments cover introductory to advanced topics in vibrations, advanced stress related phenomena such as combined stresses in pressure vessels and structural members. During this course the dynamic aspects of measurement systems, which were introduced one semester earlier, are expanded to higher order examples.

Use of Working Model and LabVIEW is heavily pronounced in the course. Working Model is used for simulating experiments which would be physically impossible to generate in the small lab environment (system of large lumped-masses). The momentum gained in the use of LabVIEW both in the previous laboratory course and the Control Systems courses is also maintained throughout the semester. In addition, the final design project (design of an experiment) must be fully interfaced with the software.

CHALLENGES OF THE FORMAT

1-Credit limitation

The 1-credit limitation was a compromised solution and was made based on the following criteria. While all other programs on the campus of TCNJ require approximately 120 credits for graduation, the engineering program has managed to maintain a 135 credit requirement. Although it was desirable to have four 2-credit courses, the already higher cap of 135 credits prevented such an arrangement. Based on the collected data (course evaluations), students express that the magnitude of the work involved currently goes far beyond only a 1-credit reward. This seems to be an epidemic in all of the four laboratory courses. One justification is to think of it as a 2-credit course while you pay for 1-credit only!

Synchronizing Laboratories and Courses

The greatest challenge of this format is properly synchronizing the laboratory experiments with the lecture classes. While some topics, such as lift and drag, are covered in lab the semester after they are covered in lecture the vast majority of experiments are performed the same semester these topics are being introduced to the students. Based on experience to date

this results in two possible courses of action; 1) ensure that the experiments are performed after the lecture material is covered or 2) perform modified experiments which do not require previous student knowledge.

Either option can be used effectively if time is spent ensuring that the experiments are “configured” properly. Traditional experiments generally have the student take several measurements and then process this data through a number of theoretical equations to derive a certain result. An example would be to have students take pressure readings across a series of pipes and then use these values and the one-dimensional flow equations to compute values for friction factors. These types of experiments serve to reinforce theory by having students review it, apply it, and reflect upon the results. However, due to scheduling difficulties some experiments must be performed before the co-requisite lecture material has been covered. In these cases the “traditional” experiment cannot be used as it creates undue stress and confusion on the students’ part; which in turn limits the instructional usefulness. In these special cases the experiments must be modified to a demonstration or introductory mode. The intent is to give the students a better feel for the physical phenomena in the hope that this will aid understanding when the associated lecture material is covered.

Limited Apparatus

Another challenge of this, and any, laboratory course or sequence is availability of apparatus. This goes beyond just having the equipment, but having enough equipment to facilitate laboratory groups. Under the constraints of the 1-credit courses this has also been a major challenge. When there is limited equipment available some format must be developed which allows all of the students to have access to the one piece of equipment. The simplest solution is to use the equipment in a demonstrative fashion. All students can then be provided common data for analysis. The drawback to this is that students do not get individual hands-on experience with the equipment. While this format may be preferable in certain situations, where safety or complexity is concerned, an effort is made to keep all laboratories as “hands-on” as possible.

A second solution to the equipment problem is to have lab groups use the equipment during different times outside of class but within a set time period, so that everyone is working on the same experiment at the same time. The organization of the laboratory sequence inhibits this method. Since each lab course is only worth 1-credit there is little room in the student’s schedules to arrange for different meeting times. Additionally, there are students who live off campus and in some cases quite some distance away. These considerations limit the potential of this format.

The third solution is to use group rotation. Each week a different group has access to the equipment in a rotational basis. This solves the equipment problem nicely but creates a number of laboratory scheduling problems. The prime restriction being the synchronization with lecture classes. For instance, if there are five lab groups in a weekly rotation students will be working on this experiment for five weeks. If the topic being explored is covered in a concurrent course this makes it extremely difficult to ensure that all students have covered the necessary material prior to performing the experiment.

SOFTWARE INTEGRATION

One aspect worth mention in the development and organization of this laboratory sequence has been the integration or use of engineering software. The major piece of software

used is LabVIEW. As with other topics the use of LabVIEW is evolutionary. Students are exposed to LabVIEW programs during the first and second courses. During these courses they do not have to do any LabVIEW programming or understand data acquisition principles. However, they become familiar with the LabVIEW environment and the use of LabVIEW programs. During the third course, which covers data acquisition, they are instructed on the actual programming of LabVIEW. Their understanding is then reinforced by continued use in the fourth sequence course and the separate controls laboratory.

Other software packages are also used throughout the sequence. Mathematica and $c^2 b^2$ are used in the first course to provide comparison data for experiments. Working Model is used in the fourth course and ANSYS can be used in the second, third, and fourth laboratory courses. By integrating this software into the laboratory courses use of the programs is spread more thoroughly throughout the curriculum.

GROUP DYNAMICS

The elements of group dynamics are introduced early in the current curriculum and are continuously emphasized from the first laboratory course to the last one. An integral part of each group report is an evaluation sheet for assessing the performance and contribution of each of the group members (in a confidential manner). How group membership is defined differs from course to course in the sequence. In the first laboratory course group size and composition varies from experiment to experiment. In latter courses, groups are specified at the beginning of the semester and remain unchanged, due to equipment limitations and experiment rotations. While students have some choice in the group membership our preference is to assign students to groups. This tendency is based on the fact that in industry, individuals usually do not have the luxury of choosing whom they work with. It is our intent that students develop the interpersonal skills necessary to work in this environment.

CONCLUSIONS

A laboratory sequence has been developed and implemented which reinforces the mechanical engineering curriculum and provides evolutionary development of measurement techniques. The major limitations of the format are the 1-credit per course and properly synchronizing the experiments with related lectures. We have found that flexibility in format is essential. It is accepted that there will never be enough equipment or time to perform the experiments in an ideal manner. Therefore, it is necessary to form some compromise between the needs of lecture synchronization, limited equipment, and the 1-credit per course limitation. There are benefits in terms of active “hands-on” learning and topic repetition, especially for measurement theory. While this sequence has been developed at The College of New Jersey for mechanical engineering the format is applicable to other institutions and engineering specialties.

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