2006-1346: A PROGRESSIVELY OPEN ENDED LABORATORY TO PROMOTE ACTIVE LEARNING

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Abstract

The mechanical engineering laboratory sequence at Central Michigan University consists of two courses in the junior year and one in the first semester of the senior year. One of the goals of this sequence is to prepare students for testing senior design prototypes in the second semester of their final year. The first course in the sequence, solid mechanics laboratory, is described in this paper. This course is structured so that students progress from "cookbook" experiences to somewhat more open ended labs and finally to a significant experimental design process. In the first series of six straightforward "cookbook" labs, students have one week in which to perform pre-lab work, do the experiment, and write a short technical report documenting their results. Next, there are two somewhat more open ended "two week labs" where students extend the knowledge and skills obtained earlier in the course to answering slightly more difficult experimental questions, with slightly increased reporting requirements. Finally, the last quarter of the semester is devoted to a four week experimental design laboratory, requiring students to formulate a question, select equipment, construct or modify an apparatus, carry out the experiment, write a formal report and give an oral presentation.

This paper provides a detailed description of the course, including examples of experiments, and discusses how it promotes active learning, introduces lifelong learning concepts, fosters teamwork, increases communication skills, and prepares students for further laboratory courses or experimental activities. It is found that by providing increasingly open ended experiences, students become actively engaged in the laboratory experience, and exhibit a high level of satisfaction with the course.

Introduction

The EC 2000 accreditation criteria require that an institution have in place a comprehensive outcomes assessment program to ensure the quality and continuous improvement of the educational process[1]. Program outcomes are in essence statements of the skills, knowledge, and behaviors that are attained by the time students graduate from a program. Although all of the eleven "a-k" program outcomes specified in the criteria are important in laboratory courses, at least three have particular bearing:

b. an ability to design and conduct experiments, as well as to analyze and interpret data.
d. an ability to function in multidisciplinary teams.
g. an ability to communicate effectively.

In the newly developed mechanical engineering program at Central Michigan University, these program outcomes are integrated throughout the required laboratory courses.

Laboratory Sequence

After their initial exposure in the freshman and sophomore years to experimental techniques in introductory chemistry and physics courses, students are prepared for engineering laboratory experiences. The mechanical engineering laboratory sequence at

Central Michigan University consists of three semester long courses intended to be taken in the junior and senior years. The brief catalog description for each of the three courses is given below:

EGR 360 Solid Mechanics Laboratory
Experimental skills and techniques with applications to material behavior, static and dynamic stress and strain analysis.

EGR 458 - Measurement and Instrumentation Laboratory
Theory and application of mechanical measurements, instrumentation, and computer-based data acquisition.

EGR 460 - Thermal Fluids Laboratory
Experimental skills and techniques including design, analysis, and reporting. Applications in fluid flow, thermodynamics, and heat transfer using modern sensors, instrumentation, and data acquisition systems.

Each of these courses is taught as a three credit course, with between one and two lecture hours and between two and four laboratory hours per week. The three courses are designed to be taken sequentially and build upon each other by developing in students increasingly advanced experimental abilities. Other general goals for this sequence include opportunities to enhance written and oral communication skills, and to participate in a team environment. Further, this laboratory sequence is intended to prepare students for testing senior design prototypes in the second semester of their final year.

Course Objectives for Solid Mechanics Laboratory

In developing course objectives, a study of current literature and practice was undertaken. The recent work by Feisel and Rosa[2] investigates most of the current publications in the area and distills them to a comprehensive set of thirteen fundamental objectives for engineering laboratories. These objectives have been used as a framework for all laboratories in the mechanical engineering program at Central Michigan University.

The focus of the present paper is the first course in the mechanical engineering laboratory sequence, EGR 360 Solid Mechanics Laboratory. Thus it serves both as a transition from basic science laboratories to engineering laboratories, as well as a foundation for more advanced engineering laboratories and the senior design sequence. Therefore, the objectives suggested by Feisel and Rosa, with appropriate modifications and additional specificity have been used as the basis for the EGR 360 course objectives, which are stated below.

Upon successful completion of this course, the student will have the ability to:

1. Select and use appropriate sensors, instrumentation, and/or software tools to make measurements of various solid mechanics quantities including force, displacement, stress, and strain.

2. Identify the strengths and limitations of theoretical models for stress and strain as predictors of real world behaviors in engineering structures.

3. Design an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data.

4. Collect, analyze, and interpret data, and to form and support conclusions.

5. Recognize unsuccessful outcomes due to faulty equipment, parts, software, etc., and then re-engineer effective solutions.

6. Recognize health, safety, and environmental issues related to laboratory processes and activities, and deal with them responsibly.

7. Communicate effectively about laboratory work, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.

8. Work effectively in teams, including individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.

Concomitant with these objectives is the knowledge that in their first engineering lab experience students may not be prepared at the outset for some of the higher level activities. Therefore, the course is designed to progressively guide students from basic to more advanced, open ended, experiments.

Laboratory Structure

At the beginning of the course, it is not realistic to expect students to learn how to use new equipment and make measurements while simultaneously designing the experimental procedure. Thus, the course is structured so that students progress from prescribed experiments to somewhat more open ended laboratories and finally to a significant experimental design process. Further, although students have previously been exposed to some of the theoretical concepts upon which the course is based, new concepts, additional background material, and various laboratory procedures must be presented. This is accomplished each week prior to the experimental components in a lecture portion of the course.

One Week Labs

Roughly the first half of the course involves rather straightforward, "cookbook" experiences designed to allow the students to acclimate to the lab, form and work within teams, and become acquainted with some of the testing equipment. Further, the students learn report writing expectations and develop and practice notebook skills. In the first series of labs, students have one week in which to perform pre-lab work, do the experiment, and write a short technical report documenting their results. Thus, they have been assigned by students the descriptor "one week lab."

Each student is required to use a laboratory notebook, and all work done during the experiment must be recorded, in ink, in the notebook. A detailed description of the purpose and use of the notebook in this and other courses is discussed in class. The signed notebook originals are handed in at the conclusion of each laboratory period, and the student retains the carbon copies. The notebook counts for 20 percent of each lab grade, with students receiving no credit if the notebook is not handed in before leaving lab. The requirement that students hand the notebook pages at the end of each period forces them each to record data during the lab period, rather than reconstructing it from partner's notebooks.

Before each laboratory, students complete a pre-lab report consisting of a set of questions, estimates to make, and problems that must be solved before beginning the experiment. These are designed to insure that students come to lab well prepared and do not waste lab time. Pre-lab calculations must be done in the laboratory notebook, with the originals handed in before each lab starts, and count for 20 percent of the lab grade, with late pre-labs receiving no credit. When students hand in the pre-lab at the beginning of the lab period, it is checked and must be approved before being allowed to begin the lab.

A short quiz on material similar to problems worked on pre-labs, material covered in lecture, or results from previous labs is also given prior to each lab. The quiz is given during the first ten minutes of the lab period, and students arriving after that time will receive a grade of zero on the quiz. The quiz grade counts for 10 percent of each lab grade. This quiz has the dual purpose of preparing students for the lab and motivating them to arrive on time. For example, prior to a lab involving torsional deformation, students might be asked to list and define the variables upon which this deformation depends. Or, they might be asked to briefly define terms such as accuracy, precision, and resolution. The quizzes are designed to be quite straightforward for prepared students.

Students perform the experiments working with one or more partners, but all one week lab reports must be done individually. Students are encouraged to discuss the experiment and their interpretation of the results with their partner or other students. On the other hand, they are expected to do your own numerical solutions, derivations, error analysis, graphing, writing, etc. Students are informed that handing in the data of another student or the modification of data constitutes cheating, and will result in a grade of zero for the lab.

Laboratory reports are due at the beginning of the laboratory period, one week from the day the lab was performed, and lab reports turned in after the period begins are considered late. Laboratory reports are worth 50 percent of the lab grade, and to get the most credit, laboratory reports must be technically correct, and must follow the report format guidelines presented in class (see Appendix A). Late labs are penalized at the rate of 10% per day, up to one week, and reports turned in past one week late receive a grade of zero.

Reports are graded according to a rubric (see Appendix B), allowing for uniformity in grading and assessment. The rubric allows 0-5 scoring for ten evaluation parameters, listed in Table 1. Students self evaluate their reports according to this rubric prior to handing them in. Although only the instructor grade is counted, students find value in this exercise both through the process of self evaluation, but also when the reports are returned and the student views the correlation between their own and the instructor's scores. As the course progresses, the lab scores increase and correlation between student and instructor scores is enhanced. Students are also encouraged (but not required) to have a peer review their report prior to handing it in.

Form
References
Objectives
Procedure
Data
Analysis
Discussion
Conclusion
Appendices
General

Table 1: Rubric Evaluation Parameters

Intermediate Design Lab

During the second half of the course, lab teams will complete a series of two intermediate design labs. Due to the increased scope of these labs, students are allowed two weeks for completion. In these "two week labs," students extend the knowledge and skills obtained earlier in the course to answering slightly more difficult experimental questions, with slightly increased reporting requirements. These labs are much more open-ended than the one-week labs and are designed to provide an experience similar to that of an engineer working on a project in industry. For the "two-week labs", students are provided with a general statement of the objective and the test equipment and are expected to develop a procedure and complete the lab on their own. The results of the lab are written up in a formal lab report.

The intermediate design labs fall into one of two general project areas:

1. Improve any existing EGR 360 experiment.
2. Research and design a new experiment.

Improvements to existing experiments can include any of the following: fabricating a new experiment set-up, developing new measurement techniques, using new instrumentation, and so on. Either type of project requires each team to do some research to determine existing techniques and data.

In the initial offering of this course, typical intermediate design labs include:

- Effect of Various Heat Treatments on Hardness of Steels
- Fatigue Life Under Tensile and Alternating Loads
- Static and Dynamic Balancing of a Rotating System

Final Design Lab

The Final Design Laboratory is an extensive, open ended laboratory experience requiring independent research and experimentation. This lab is intended to be the culminating experience of this course, and encompasses approximately the last four weeks of the semester. The final laboratory design project entails research, design, and execution of an experiment in the broad areas of solid mechanics, dynamics, and materials. Experiments may include fabricating a new experiment set-up, developing new measurement techniques, or using new instrumentation, depending upon what is required to meet the stated project objectives.

For this lab, each lab team writes a proposal for designing and conducting a lab experiment, along with a budget and timeline for completing this experiment. If approved, students are given four weeks to complete this experiment. These projects require students to formulate a research question, select equipment, construct or modify an apparatus, and carry out the experiment.

Each team must submit a single, well written, formal report in appropriate format, following all applicable standards and guidelines. Laboratory reports must include (at least) the following items:

- background material from your research
- drawings of the experimental apparatus (CAD)
- procedure developed for experiment
- design calculations for the experiment
- reference material, including at least two library sources
- results from the experiment.

Further, a poster presentation containing a summary of the design lab is turned in at the end of the course, and finally the results are presented orally in a powerpoint presentation. Excellent posters are eligible to be submitted to the annual campus wide undergraduate research exhibit.

In the initial offering of this course, typical final design labs include:

- Investigation of Bending and Shear Stress Distribution in a Beam
- Impact Resistance vs. Temperature for Two Polymers
- Effect of Holes and Slots on Vibrating Beam Natural Frequency

Summary

Student feedback for the first offering of the course was in general positive, with students enjoying the ability to choose topics of interest. The only negative comments reflected the somewhat unstructured operation of the last part of the course, where the lab resembled a research project, rather than teaching lab. On the whole, students exhibited a high level of satisfaction with the course, and in several cases devoted much more time than would normally be expected in similar traditional courses.

The open ended activities promoted within this course force the students to become actively involved in each lab, facilitate a dialog with the instructor and each other, and encourage working together as a team. Progressively increasing the amount of independent work expected throughout the semester enables the students to accomplish a significant design lab experience without being overwhelmed. By requiring research into open ended questions, the course introduces lifelong learning concepts and prepares students for further laboratory courses or other experimental activities.

Bibliography

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Appendix A: Technical Memo Report Guidelines

A Technical Memo is meant to be a brief communication tool. Due to limited space you will have to be selective when deciding what to include. There are two general questions to consider when writing a report: what information should be communicated and how should that information be presented. These topics are independent of each other and of nearly equal significance. For example, meaningful information can be presented poorly, or meaningless information can be presented well. A truly excellent report will communicate necessary and relevant material in a clear, easy-to-understand manner. Each of these topics will be heavily weighted when grading technical reports.

Required Format

There are three general sections of a technical memo: the header, the body, and the appendix. The header contains the name of the person to whom the memo is addressed, the name(s) of the person (people) submitting the memo (printed and signed), the date the memo is handed in, and a brief description of the memo subject. An example of a memo header is shown in Figure 1.

Technical Memorandum

To:	Professor
From:	John Smith, {*signature*}
	Susan Jones {*signature*}
Date:	January 18, 2001
Subject:	Lab # 3 Dynamic Response

Figure 1. Example of a Technical Memo Header

The header and body of the memo must fit on two pages or less, using font size 10, 11, or 12 with 1 inch margins – No exceptions. Memos that are longer than two pages (not including the appendix) will not be accepted.

At least one appendix should be included in every memo. Include information relevant to the lab but that was not included in the body of the report. A copy of the lab manual should not be included in the appendix.

Items to Include in the Body

You should generally first consider what to include in the body of a technical memo report. The reader may not read the appendices, so the body must be self-contained. The following list is a general guideline and not meant to be exhaustive. The body should have multiple paragraphs separated by headings.

- Objectives – You might ask the following questions when considering what to say in an introduction:
  - Why is this report being written?
  - What sort of information do you want to communicate?
  - What useful information should someone obtain from reading the report?
- Procedure - By understanding how an experiment was conducted it is often easier to understand the meaning of the results. Also, a description of experimental methods provides guidance for others wanting to duplicate your results. The apparatus used should also be included.
- Data – Always present the results of your study or experiment. “Results” can mean a single number, a plot, a table of data, or an equation.
- Analysis – You must describe how the data was used to reach a conclusion. What equations were used? What data was used in these equations?
- Discussion – You should always give your interpretation of the results. If the results found were expected, say so. If you get confusing or unexpected results, suggest possible reasons. Talk about sources of error and their significance. You should

clearly demonstrate your understanding of the experiment with a meaningful discussion.

- Conclusions – Anything that can be concluded from the results of the study should be stated. Summarize what was done or found. No new information should appear in this section. Also, you may recommend actions that should be taken, based on your conclusions.
- Appendices – Any information that was used to write the report, but doesn't have direct applicability to the main portion of the report should be placed in an appendix. An example may be a listing of the raw data, or sample calculations. Note, however, that raw data might be included in the main section of the report if its inclusion is deemed useful and pertinent.

Presentation Considerations

After you have determined what you want to include in your report, you should consider some of the following presentation guidelines.

- Use a Computer – Use a computer to generate everything that appears in a report. A report containing hand-written material will not be accepted. There is one exception to this rule: the contents of appendices may be generated by hand.
- Graphs, Plots, and Pictures – A graph or plot is generally more useful than a table of numbers. A picture will usually be more effective than a paragraph of text. When including a graph, plot, or picture, label it with a number and a descriptive title appearing below it. In all instances, use the label "Figure # 1", not "Graph" or "Plot", and refer to it that way in the text of the report. If a figure appears in a report, then it should always be referred to (by number) in the text. Place the figure as close to the text describing it as possible, or in the appendix. Clearly describe what is being shown and why it is being included in the report. Label all axes with a brief description and appropriate engineering units.
- Tables – Present a set of numbers or a list of information in a table. Place the label "Table", a table number, and a brief description above the table. If a table appears in a report, then it should always be referred to (by number) in the text. Place the table as close to the text describing it as possible, or in the appendix. Clearly describe what is being shown and why it is being included in the report. Label all rows and columns. Include the engineering units where applicable. Report a meaningful number of significant figures.
- Language – Use proper grammar, correct spelling, and organized sentence structure. Above all, make sure that the text flows well. Remember, this report represents work that you have done, therefore it should be written in the past tense. Here are a few tips to ensure that your writing is readable:
  - Proofread your work one or more days after you have written it.
  - Read it out loud to yourself.
  - Have a friend read through it with a red pen in hand.
  - Use a spell checker.
- Get to the Point – A clear, concise document is much better than a lengthy, verbose one. It is also generally more difficult to write. Reports are not graded by the pound.

Appendix B: Technical Memo Evaluation Rubric

Author:__________________Lab Partner:______________Professor:________________

Each Evaluator Should Score Each Parameter From 0 to 5

Evaluation Parameter	Evaluator		
	Self	Peer	Prof
1. Form: Is the report in memo form? Does the memo use language and vocabulary appropriate for technical writing?			
2. References: Are all statements that are not common knowledge adequately referenced?			
3. Objectives: Is the objective statement obvious and clearly stated?			
4. Procedure: Is this organized and clearly written so that the scope of the experiment is defined and the issues are clear?			
5. Data: Is raw data included or referenced to an appendix? Is it complete and correct?			
6. Analysis: Is this well organized and logical? Do graphs and tables contain enough information to support the discussion and conclusion? Are they clearly defined?			
7. Discussion: Does it accurately apply and relate to the information in the introduction?			
8. Conclusion: Does this support the objective statement?			
9. Appendices: Is the appendix well organized? Are sample calculations clearly done? Is all raw data included?			
10. General: Is the error in the experiment clearly and realistically defined?			
Comments			