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Learning Design in Lab

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Abstract

Laboratory curricula in two core undergraduate-level engineering courses, Fluid Mechanics and Materials Science, have been enhanced through implementation of laboratory design experiences. In addition to performing established experiments, students work in teams to develop a laboratory experiment investigating a course-related topic which they are required to research and formally report on prior to pursuing development of the experiment. Students indicate their preferences from a general list of suggested topic areas or develop a topic in consultation with the course instructor. Over the course of the semester, each team researches, designs, develops, tests, and reports on the laboratory experiment developed for the selected topic. In addition to gaining hands-on experience in solving an open-ended problem and resolving design, development, and implementation issues, students develop their communication, teamwork, and management skills. Following team formation, each team begins by researching the topic and developing a formal project plan which includes a timeline. Laboratory experiment ideas are then proposed and discussed with the instructor. Once approved, the students proceed to preparing a complete laboratory experiment write-up (handout), data collection sheet, data analysis spreadsheet, and complete lab report. Additionally, each team demonstrates the laboratory experiment and presents the theory, hypotheses, results, findings, and conclusions to the class in an oral presentation. These laboratory projects fulfill several learning objectives for each of these two undergraduate courses including providing students with experience in design, development of students' abilities to perform and design experiments, and development of their communication and teamwork skills. Different learning styles are accommodated by the use of such open-ended and innovative educational experiences.

Introduction

Several educational goals [1] may be met in engineering laboratory courses [2; 3] including development of experimental skills, learning use of modern engineering tools and techniques, and development of teamwork and communication skills. Not incidentally, an important role of laboratory courses is exposure to real-world application of theory which can enhance students' learning and enthusiasm through the discovery process.

The level of structure in a laboratory course may vary depending on learning objectives of the course or curriculum and on the academic level of students enrolled in the course, i.e., lower-division vs. upper-division [2]. For example, a highly structured laboratory may be used to introduce students to laboratory analysis techniques and use of laboratory equipment. At the other extreme is the unstructured laboratory which may be used at the senior level, requiring students to apply analysis and synthesis skills to design and test a large-scale or multi-component system.

For students at the sophomore or junior level, a combination of these laboratory structures may be appropriate. Use of laboratory equipment and investigation of fundamental concepts may be addressed in structured experiments, while an open-ended project may be introduced to require design, development, and testing of an experiment once students are familiar with the laboratory and have gained the appropriate laboratory and analysis skills.

Incorporating design projects in laboratory courses meets several criteria defined by the Accreditation Board for Engineering and Technology for engineering programs [1]. By completing such projects, students enhance their abilities to apply knowledge of mathematics, science, and engineering (3a); analyze and interpret data (3b); design a system, component, or process to meet desired needs (3c); function on multi-disciplinary teams (3d); identify, formulate, and solve engineering problems (3e); communicate effectively (3g); and use the techniques, skills, and modern engineering tools necessary for engineering practice (3k).

Incorporating Design Experiences in Lab

At the University of the Pacific, laboratory curricula in two core undergraduate-level engineering courses, Fluid Mechanics and Materials Science, have been enhanced through implementation of open-ended laboratory design experiences. In addition to performing established experiments, students work in teams to develop and implement a laboratory experiment investigating a course-related topic which they are required to research and report on prior to pursuing development of an experiment.

Project and Team Selection

In these two courses, students are provided with a list of suggested topics or they may develop a topic in consultation with the course instructor. Topics are general and are not otherwise used as experiments in lab. For example, the list of potential Fluid Mechanics lab projects includes the following topics and broad descriptions:

- **Local Losses** - Local losses are energy losses associated with an obstruction to flow, change in pipe cross-section, change in pipe characteristics, or change in flow direction.
- **Drag on an Object** - Friction along the surface of an object produces drag forces opposite to the direction of flow. The drag force is a function of flow characteristics and physical characteristics of the object.
- **Weirs** - Weirs are over-flow devices used to measure flow in open channels. Weirs must be calibrated to account for losses associated with flow over the weir.

Similar descriptions are given to students in the Materials Science Laboratory for topics including "Cold Working", "Quenching", and Fatigue". Students may suggest topics or variations related to a particular area of interest, and the topic must be discussed with and approved by the course instructor. For example, students enrolled in Fluid Mechanics and working on the American Society of Mechanical Engineers' Human Powered Vehicle or Mini-Baja projects may develop an experiment to measure drag forces acting on models of different body designs. The unstructured nature of such projects is well-suited to capturing a range of students' interests and accommodating different learning styles. Students' mastery of the subject is enhanced with such creative and cooperative learning experiences [4].

Each topic may only be used by one team in a laboratory section. Students are assigned to two- to four-person teams, depending on the class size and project scope. In general, instructors attempt to form teams that balance students' abilities. Student teams perform preliminary research on a potential topic, then discuss the topic with the course instructor. Key to the project success is ensuring that the project and team members' responsibilities are well-defined, hypotheses are appropriate and thought-out, the project is within the scope of material taught in the course and is achievable within the allotted time. Instructors are responsible for guiding, but not leading, teams in these areas. In many instances, students have been requested to refine a proposed experiment, narrow or broaden a project scope, or revise plans to ensure that the project can be completed successfully and on time.

The laboratory experiment design projects are assigned in approximately the fourth to eighth week of the semester, depending on the course and specific requirements of the project component of each course. Four lab meetings are scheduled for project work and distributed throughout the semester, while additional structured experiments are performed during the remaining lab meetings. Final oral presentations and demonstrations are performed during the last week of the semester; either during the class or lab periods. A major benefit of holding presentations and demonstrations during class periods is that all students learn about others' projects.

Project Design, Development, and Testing

Each team designs an experiment for the selected topic and develops the set-up required to run the experiment. However, prior to development, each team submits a project plan which includes experiment objectives, theory, hypothesis, draft experiment set up, proposed procedure, and conditions used to run the experiment, together with a timeline (or project schedule and management plan). Project plans are evaluated by the instructor and discussed with each team during lab. In the Fluid Mechanics course, students also give a preliminary oral presentation approximately four weeks after the project is assigned. Each team presents the experiment to the class, discussing objectives, set-up, theory, and presenting progress to date. Questions, comments, and constructive peer critiques are highly encouraged; students often help their peers to better define the project and provide suggestions for overcoming obstacles. In

Materials Science, a written progress report is submitted during approximately week 11; the instructor reviews, evaluates, and discusses the project with each group.

Students gain hands-on experience by developing the experiment set-up and determining how to implement it using existing lab equipment. Before running the experiment, each team prepares data collection sheets, which requires an in-depth plan for running the experiment systematically and thought regarding all parameters to be measured. Lab scheduling problems can be averted by posting a lab and equipment availability sign-up sheet, thus allowing teams to reserve time to work in the lab outside of scheduled lab hours, if necessary. As teams run the experiments and gather data, it becomes evident that careful thought, preparation, development, and implementation are critical for project success. For instructors, working with students in the lab to resolve design, development, and implementation issues is probably the most rewarding, but also the most time-intensive, component of this exercise.

Developing Communication and Teamwork Skills

In addition to gaining hands-on experience in solving an open-ended problem and resolving design, development, and implementation issues, students develop their communication and management skills. Each team submits a project plan with a timeline before starting the project. In conjunction with experiment design and development, each team prepares a laboratory write-up or handout. The write-up must include the experiment purpose, theory, setup, procedure for running the experiment, detailed instructions for calculating and presenting results (including graphs), and a set of questions that must be answered based on theory, experiment observations, and graphical results.

Teams develop a data collection sheet together with a data analysis spreadsheet template which is used to analyze experiment data and present tabular and graphical results in a professional manner. For the Materials Science course, teams also submit a completed lab report which includes an appropriate background section and requires presentation and discussion of results and conclusions. For the Fluid Mechanics course, teams submit a set of "Instructor's Notes" which includes a detailed description of how to set up the experiment, special instructions for equipment use, full derivation of all equations, and discussion of expected results together with a completed spreadsheet using the test results.

Finally, during the last week of the semester, every team demonstrates the laboratory experiment and makes an oral presentation to the class. The presentation includes experiment objectives, set-up, theory, results, analysis, and conclusions, together with a set of suggested improvements. The projects are peer-evaluated; students are given a score sheet to evaluate other teams on the following criteria using a scale of 1 (Poor) to 5 (Excellent):

- Quality of the Experiment Developed
- Quality of the Analysis and Findings of the Experiment
- Quality of the Presentation

- Complexity/Effort-Put-Forth/Completeness of the Project
- Overall Assessment of the Project

Each team's overall project grade includes peer evaluation results together with the instructor's evaluation of the overall project, reports, spreadsheets, and presentation.

Assessment

At the start of the Spring 2003 semester, a preliminary survey was distributed to eighteen students who had taken both courses at the University of the Pacific and completed the experiment design projects in each course. Students rated the degree to which the course and project learning objectives were met using a scale of 1 (did not meet this objective at all) to 5 (successfully met this objective). Survey questions and results are presented in Table 1.

Table 1. Students' Assessment of Project Effectiveness in Meeting Learning Objectives

	Materials Science		Fluid Mechanics	
Learning Objective	Average	Std. Dev.	Average	Std. Dev.
Improved Knowledge of the Subject	4.1	0.6	3.8	0.8
Developed Teamwork Skills	4.5	0.7	4.4	0.6
Developed Oral and Written Communication Skills	4.3	0.7	4.3	0.7
Improved Ability to Use Lab Equipment and/or Machine Shop	3.6	0.8	3.7	1.2
Developed Ability to Plan and Execute a Complete Experiment / Project	4.3	0.7	4.3	0.5
Developed Ability to Resolve Fabrication or Implementation Issues	3.9	0.8	3.8	0.9
Developed Data Gathering, Organization, and Analysis Skills	3.8	0.9	4.0	0.7

Analysis of survey results indicates that the use of such a project as part of the course was successful in developing students' knowledge of the subject and for improving their teamwork and communication skills. Additionally, students perceived improvement of their analysis and synthesis skills by developing and executing a complete project. To a lesser extent, students perceived development of their ability to develop and implement a design, to use lab equipment, and to analyze results. These initial findings may indicate that additional time needs to be devoted to the development and implementation components in the future. In future semesters, student feedback will be solicited at the end of each course using a slightly modified version of the survey shown in Table 1.

Incorporating such design experiences as part of a laboratory requires students to function at all levels of the cognitive domain [5], namely, knowledge, comprehension, application, analysis, synthesis, and evaluation. Students are required to research their selected topic in the context of course material, requiring familiarity with and comprehension of the material and its application. Students then apply this knowledge towards developing the experiment, considering the laboratory equipment and appropriate techniques that must be used or developed to meet the desired experiment objectives. Critical analysis and synthesis skills are developed as students determine the appropriate theory and approach and apply creative problem-solving skills to develop, implement, and if necessary, troubleshoot, the actual experiment. Evaluation and analysis skills are enhanced by development of spreadsheets, analysis of experimental results, and overall assessment of the experiment.

Conclusions

Laboratory design experiences were incorporated into two core undergraduate-level engineering courses, Fluid Mechanics and Materials Science, at the University of the Pacific. Students work in teams to design, develop, implement, and report on a laboratory experiment focused on a course-related topic. These laboratory projects fulfill several learning objectives for each of these two undergraduate courses including providing students with experience in design, development of students' abilities to perform and design experiments, and development of their communication and teamwork skills.

The unstructured nature of such projects is well-suited to capturing a range of students' interests and accommodating different learning styles. Students become more involved in, and responsible for, their own learning. Through close interaction with teammates, with other students working on different projects, and with the instructor, they work towards understanding and applying the theory, techniques and skills necessary to complete the project; hopefully successfully.

References

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