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Design a cost-effective Bending/Compression educational laboratory test apparatus

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Design of a Cost-effective Bending/Compression Educational Laboratory Test Apparatus – an Integrated Project Based Learning Activity

Abstract

This paper is focused on an undergraduate design project on the design and implementation of a dual-purpose, cost effective, educational laboratory test apparatus. Students have the task of designing an apparatus that can be used as a bending test apparatus to determine the Modulus of Rupture (MOR) and a compression test apparatus to determine the compressive strength of a material. The device should be able to easily convert between the two configurations. During this project, students will also satisfy the writing unit requirement of the General Education curriculum of the Institution.

This project aimed to facilitate student learning through self-learning team activity. Throughout the project execution period, students apply their knowledge in hands-on activity, develop their technical writing and documentation skills, and gain knowledge when addressing new challenges. This paper describes the project, how engineering report writing and documentation are addressed, the effectiveness of this project assignment over different offerings, and how students benefit from project-based learning. Course outcomes and assessment of the project are also discussed.

Introduction

Teaching design and communication skills to engineering students is always a challenging and evolving process. The goal of engineering design courses at Muskingum University, a traditional liberal arts institution, is to provide the students the education needed to solve complex engineering problems through hands-on experience that addresses different aspects of design.

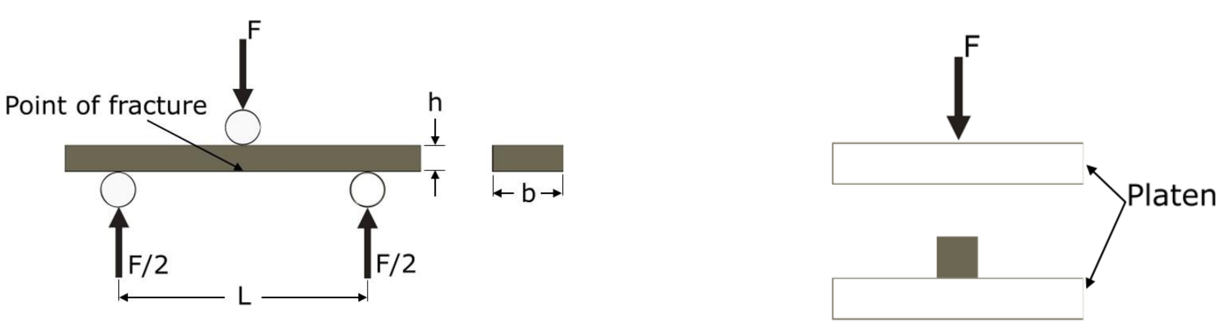
Hands-on experience in undergraduate engineering curriculum allows students to apply their knowledge to solve engineering problems and navigate through challenges in the process by acquiring new knowledge. At Muskingum University, two engineering courses were linked to provide the students with the hands-on design and writing experience necessary to solve engineering problems. We linked the Materials Science course with the Principles of Design course using a single design project to satisfy the requirements of both courses. The combination of both courses aims to provide students with a comprehensive overview of design procedures, educate students on design principles and practices to help them make informed design decisions, and solve complex problems. To accomplish that, project selection is very important to motivate and encourage creativity in students.

The Materials Science course includes theoretical explanations and details about materials, properties, usage, and material processing. The material processing part of the course consists of theoretical study and observation. When working on the design project, students must use some of these processes at the manufacturing stage. By doing this, they will gain first-hand experience, which allows them to have an educational experience both in the classroom and in the practical environment and to acquire theoretical knowledge and practical experience. The Principles of Design course is a junior-level writing course focused on improving students communication skills. It satisfies the upper level writing unit requirement of Muskingum University's general education curriculum. A writing unit is a course that utilizes formal writing as a substantial mode of learning. To fulfill this requirement, during the course students must document their design process, write a formal design project report, and present a poster describing their work at the end of the course.

The project described in this paper focuses on the design of a system intended to be used in an educational laboratory as a test apparatus to determine the Modulus of Rupture (MOR) and compressive strength of a material. The goal of this project is to design a cost-effective device that can be used for demonstrative educational purposes to facilitate student learning. A design project like this encourages them to work as a team, communicate, self-learn, gain experience in project management and enhance students' interest and enthusiasm [1], [2], [3]. Students are required to apply their knowledge acquired throughout the material science course and, at the same time, work in their communication and writing skill. This combination will lead to a better learning experience with thoughtful insight. The design project of these courses is used to address student outcomes 2, 3, 5, 6, 7 of ABET accreditation criteria [4].

Project Description

This project is focused on the design and implementation of a cost effective, dual-purpose test apparatus. The device can be used as both a bending test apparatus to determine the MOR and a compression test apparatus to determine the compressive strength of a material in an educational laboratory. The MOR is sometimes referred to as the flexural strength (F.S.) and is similar in magnitude to the tensile strength, as the failure mode in bending is tensile along the outermost edge of the sample. The apparatus should be able to easily convert between the two configurations. Figure 1 illustrates a bending test and a compression test diagram, respectively [5], [6].



(b)

Figure 1. Schematic representation of the two parts of the testing apparatus. (a) Configuration for the bending test. (b) Configuration for the compression test.

To determine the MOR, it is necessary to measure the applied force. For the compression test, it is required to measure both, the applied force and the length (height) of the specimen. The applied force for both tests can be measured by employing a load cell. An electric motor or simply a hand crank could be used to apply force and an encoder could be attached to estimate the displacement. The apparatus should consist of the main supporting structure, actuator system that applies force to the sample, including sensors for load and displacement measurements, and fixture design for the sample holder. Possibly, fixture design could enable interchangeability and facilitate the test configurations appropriately, allowing to employ same actuator system and sensor placement that leads to a multipurpose apparatus with minimum configuration changes.

Integrating writing into the design process

Muskingum University requires that students take two Writing Unit courses, with at least one upper-level course. To lighten the number of external courses that engineering majors have to take as part of their General Education requirements, the engineering department decided to make Principles of Design an upper level writing unit. The course is offered as a writing-intensive experience that benefits engineering majors and adequately prepares them to meet the needs of future industry employers or graduate studies.

Technical writing topics are discussed in lecture during the semester. Topics include graphical communication, oral and written reports, literature reviews, patent searches, and posters amongst others [7]. Writing activities in the course includes project updates or status reports, preliminary project report and oral presentation, and final project report and poster presentation. All the writing activities are connected to the design problem. Iterations and revisions of their work are required. The process of returning to the same core of information for each of the reports and presentations encouraged the students to reflect upon the feedback and evaluation given and address challenging issues in the current report or presentation they were working on. This allows students to build on learning at the same time they apply their engineering skills to solve the problem. At the end of the course, students were also required to present their projects to the campus community in a poster.

Assessment of the project

The assessment of the design project was divided in two categories: technical writing and design functionality. Both are done using direct assessment rubrics. For the technical writing category, we continue using a performance assessment rubric. This rubric was used previously for other design projects in the course [8]. The rubric uses a quality scale (0 =Unacceptable, 1=Marginal, 2=Acceptable, 3=Exceptional). To assess students' writing skills, the rubric evaluates report mechanics and content. For the report mechanics, we evaluate organization, aesthetics, format, spelling, grammar, and punctuation. For content, parts of a technical report were evaluated: abstract/summary, introduction, problem statement, requirements and constraints, technical requirements, results, conclusions, and future work or recommendations. Citation format and appropriate references are also part of the evaluation. The group had an average of 2.7 in the writing category. Functionality of the designed device is evaluated using a numeric scale (4=best to 1=bad design). The design is evaluated using the following categories: modification/testing, design knowledge, function, design criteria and constraints. The current design obtained an average of 3.8 in this category.

Students' feedback is important for understanding their view of the project-based learning experience and can be used to assess and improve the activity in subsequent course offerings. We survey the students to seek their feedback. The survey asked them if the course/project met the program outcomes and used a Likert 5-point scale (Definitely Yes = 5, Mostly Yes = 4, Somewhat = 3, Not Quite = 2, Not at All = l) to quantify. The design project should address the following student outcomes:

ABET outcome 2: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

ABET outcome 3: an ability to communicate effectively with a range of audiences.

ABET outcome 5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

ABET outcome 6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

ABET outcome 7: an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Results from the survey indicate that students agreed that the course/project met the program outcomes 2, 3, 5, 6, 7 while strongly agree on outcomes 5, 6, 7. Table 1 summarizes assessment results.

Table 1: Student feedback for ABET outcomes

ABET outcome #	**Assessment Avg.**
2	4.2
3	4.2
5	4.8
6	4.5
7	4.7

The survey also asked the students to assess the work of themselves and their colleagues and seek individual contribution towards team goal and function. A five-point scale was used: 5 = was a crucial component to group's success, 4 = contributed significantly to group, 3 = Sufficient effort; contributed adequately to group, 2 = Insufficient effort; met the minimal standards of group and 1 = Little or weak effort. Table 2 list average scale for each criterion assessed.

Overall, all students participated actively and were able to work toward the team goal. Based on students' comments, we can conclude that they enjoyed it and agreed they had a better learning experience.

Table 2: Peer assessment results

Assessment Criteria	**Assessment Avg.**
Participation in developing ideas and planning project	4.6
Willingness to discuss the ideas of others	4.8
Cooperation with other group members	4.7
Interest and enthusiasm in project	4.3
Participation in leading/facilitating discussion	4.4
Ease and familiarity with discussion material	4.5

An indirect assessment was done in the Materials Science course using the course evaluations at the end of the semester. From the course evaluations, we used the questions presented in Table 3 to additionally assess students' satisfaction in the course. Students answered using an agreement scale (5= strongly agree, 4= agree, 3=neutral, 2= disagree, 1= strongly disagree). It is clear from the assessment results that, overall, students have benefited from project-based learning experience.

Table 3: Indirect assessment results using mean scores of course evaluations

Assessment category/ question	**With a project**
Course Goals and Objectives	4.0
Students Interest/ Involvement in learning	4.0
In this course I felt challenged and motivated to learn	4.0

Discussion and future work

Third-year undergraduate engineering students at Muskingum University, a small liberal arts institution, had the opportunity to work on hands-on activity through this project to satisfy the requirements of two courses. They experienced different phases of a design process: identify the objectives and constraints of the project, selection of the best design, and implementation. They identified and finalized a list of material needed including control aspect, sensors and actuators for implementation where they applied their knowledge of mathematics, science, and engineering while acquiring and applying new knowledge as needed. Students involved in this project were also required to communicate their results by writing a report and oral presentations. Communication skills were assessed in terms of understanding and use of listening and writing skills in a professional environment, including correct grammar, punctuation, and spelling in both the report and oral presentation.

Based on course evaluations and students' feedback, students enjoyed having the opportunity to work as a team on this hands-on, multicourse project. The enthusiasm of the students throughout the project is evidence of the importance of hands-on learning in engineering. We expect that the multiple skills that they added to their resume during the development of this project will place them in a better position in the entry-level industrial job market or will better prepare them for graduate school.

For future semesters, we are planning to assign projects with similar complexity in these courses. Future projects are related to materials science and applications. Some possible projects are: a thermal conductivity measuring apparatus, a fatigue testing machine and a tensile test apparatus. In addition, possible improvements to this design have been considered and the same project could be reassigned in future semesters. It is our intention to evaluate the impact of this experience on the student's capstone project during their final year. Possible project ideas with an appropriate complexity level for first year and sophomore courses include control of an autonomous tractor-trailer robot [9], hysteresis simulation and visualization apparatus [10] and projectile launcher apparatus.

Project-based learning approach is distributed across different levels in the engineering curriculum at Muskingum University. This type of design project were students work on the design of a known laboratory equipment is very promising in engaging students.

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