

Design Projects in First-Year Physics



Boon Leong Lan

School of Science, Monash University, 46150 Bandar Sunway, Malaysia.

E-mail: lan.boon.leong@monash.edu

(Received 26 May 2011; accepted 18 September 2011)

Abstract

I use design projects, instead of the typical cookbook exercises, in my first-year physics labs for engineering students. These student-centered projects, which I have developed over the years, require each small group of students to cooperatively (i) design and build simple devices which satisfy constraints, and (ii) design and conduct experiments and analyze data. Examples of the engineering and experiment design projects are given. Student evaluations show that the design projects are significantly more useful than cookbook lab exercises as a resource for learning for engineering students. The evaluations also show that the projects are highly effective in helping students develop some of the generic attributes of an engineering graduate. The projects also helped students develop creative and innovative problem-solving skills, develop critical and logical thinking skills, develop leadership skill, manage time, and understand concepts.

Keywords: First-year physics lab, project-based learning, engineering design, experiment design.

Resumen

Yo uso los proyectos de diseño, en lugar de los ejercicios del libro de cocina típica, en mi primer año de laboratorio de Física para estudiantes de ingeniería. Estos proyectos centrados-estudiantes, los cuales he desarrollado a lo largo de los años, requiere que cada pequeño grupo de estudiantes coopere (i) diseñe y construya dispositivos simples que satisfagan las restricciones, y (ii) diseñen y realicen experimentos y analicen datos. Ejemplos de los proyectos de ingeniería de diseño y experimentación se dan. Evaluaciones de los estudiantes demuestran que los proyectos de diseño son mucho más útiles que los ejercicios de laboratorio de libros de cocina como un recurso para el aprendizaje de los estudiantes de ingeniería. Las evaluaciones también muestran que los proyectos son muy eficaces para ayudar a los estudiantes a desarrollar algunos de los atributos genéticos de un graduado de ingeniería. Los proyectos también ayudaron a los estudiantes a desarrollar creativas e innovadoras habilidades para resolver problemas, desarrollar habilidades de pensamiento crítico y lógico, desarrollar habilidades de liderazgo, manejo del tiempo y entender los conceptos.

Palabras clave: Primer-año laboratorio de Física, proyecto-basado en aprendizaje, diseño de ingeniería, diseño de experimento.

PACS: 01.50.Qb, 01.40.-d, 01.40.Fk

ISSN 1870-9095

I. INTRODUCTION

Typically [1, 2, 3], in the first-year physics labs for engineering students, students passively follow given recipes to perform experiments and analyze data. However, such cookbook lab exercises are not well suited for engineering students simply because they do not mirror the practice of engineering. Not only do engineering students need [4, 5] to learn how to design and build things but they also need to learn how to design experiments to make measurements.

In contrast, in my first-year physics labs for engineering students, students actively engage in design projects instead of 'cooking'. These projects, which I have developed over the years, require students to work independently in small groups (no more than three members per group) to (i) design and build simple devices which satisfy constraints, and (ii) design and conduct experiments and analyze data. I will refer to the former as engineering design projects and the

latter as experiment design projects. There are some first-year physics labs for engineering students which incorporate one of the two types of design projects, see [1, 2, 3, 6, 7, 8] for example, but I am not aware of any which incorporates both types of projects.

The aim of this paper is to report on the usefulness and effectiveness of the engineering and experiment design projects in my first-year physics labs for engineering students. In the same physics unit taught at another campus of the university, the engineering students are still just 'cooking' instead of doing design projects. This difference in approach to lab exercises gives us the unique opportunity of comparing the usefulness of the design projects and the cookbook exercises as a resource for learning for engineering students using the unit evaluation data for the two campuses. In addition to the presentation in this paper of the student evaluation data for such a comparison, I will also present student evaluation data which show how effective the design projects were in developing some of the

generic attributes which are expected of engineering graduates by Engineers Australia, ABET [9] and other engineering accreditation bodies. Students' written comments are also presented to illustrate how else the design projects were useful.

Examples and essential features of the engineering and experiment design projects are given next before the student evaluation data are presented and discussed. Conclusions on the usefulness and effectiveness of the design projects in my first-year physics labs for engineering students are summarized in the last section.

II. EXAMPLES

Our first-year physics for engineering students covers mostly mechanics, some waves and a little quantum physics. Typically, my students work on three engineering design and two experiment design projects which are related to these topics. Students are given two weeks to complete each project. Feedbacks are given on how they can improve after the completion of each project.

In contrast, students taking the same physics unit at another campus work in groups on cookbook experiments (six in total) and write brief reports.

In the first week of the semester, to help the students get started, I conduct a workshop where they learn how to learn independently from textbooks, learn how to work effectively in a team, and learn the fundamentals of engineering design.

The following are some of the engineering design projects the students have worked on:

- Design and build a protection for a raw egg that allows the egg to fall fastest from the top of a building and remain unbroken after hitting the ground [10, 11].
- Design and build a rubber band powered vehicle to ferry an egg the greatest horizontal displacement.
- Design and build the longest horizontal overhang relative to the edge of a table using a fixed number of identical blocks [12].
- Design and build a water rocket that will land within a target area.

The materials needed for the engineering design projects are no more than ordinary household items. Various design constraints are imposed to make the projects challenging. For example, in the egg-drop project, a maximum weight is imposed on the protection for the egg.

Marks are allocated for the performance of the design and for the oral report (everyone in a group has to present) which explains the physics principles employed to achieve the design goal. The performance mark for each group can be determined very easily, see [11] for example, using a simple formula which incorporates the result of the group and the best result of the class. This relative marking scheme naturally motivates the groups to do their best. The performance mark also implicitly captures the students' design process, which includes trouble shooting and solving engineering type problems. Penalties are imposed for violations of design constraints.

The following are some of the experiment design projects the students have worked on:

- Design and perform an experiment to determine whether a simple pendulum is a simple harmonic oscillator.
- Design and perform an experiment to determine the wavelengths of some lights emitted by a mercury source.
- Design and perform an experiment to determine the coefficient of static friction for a given material.

Marks for each experiment design project are based on the design of the experiment, data collection, analysis and interpretation, and a full written report. For the first experiment design project, before submitting the final report, each group submits a skeleton report, which contains only headings and a brief description of what information goes into each part, and receives feedbacks for improvements.

III. STUDENT EVALUATIONS

A. Usefulness as a Resource for Learning

In the unit evaluations, there is only one question pertaining to lab. In particular, students were asked to evaluate whether "the laboratory sessions were a useful resource for their learning". Table I below shows the evaluation results for this item from 2007 to 2009 for my unit and for the counterpart unit taught at another campus.

TABLE I. Evaluation results for "The laboratory sessions were a useful resource for my learning".

| Semester | Average for my unit | Average for counterpart unit |
|------------------|---------------------|------------------------------|
| Semester 1, 2007 | 4.04 | 3.29 |
| Semester 2, 2007 | 4.04 | 3.22 |
| Semester 1, 2008 | 4.17 | 3.71 |
| Semester 2, 2008 | 4.01 | 3.32 |
| Semester 1, 2009 | 4.01 | 3.97 |
| Semester 2, 2009 | 4.26 | 3.33 |

The evaluation scale is: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. For all six consecutive semesters, the average (greater than 4) for my unit is higher than the average (less than 4) for the counterpart unit. In fact, my averages are all significantly higher than the counterpart averages, except for one semester (Semester 1, 2009) where my average is just slightly higher. With the exception of this outlier, the evaluation results show that the engineering and experiment

design projects are *significantly* more useful than cookbook exercises as a resource for learning for engineering students.

B. Effectiveness in Developing Generic Attributes

For the same period from 2007 to 2009, my students also evaluated whether the design projects helped them to develop certain generic attributes which are expected of engineering graduates. Each evaluation result reported in Table II below is the mean of the six averages for the six semesters.

TABLE II. Evaluation results for effectiveness in developing generic attributes.

| Generic attribute | Mean |
|---|------|
| The <i>design projects</i> helped me to develop an ability to apply knowledge of physics. | 4.20 |
| The <i>design projects</i> helped me to develop an ability to function in a team. | 4.19 |
| The <i>design projects</i> helped me to recognize the need for independent learning and develop an ability to learn independently. | 4.23 |
| The <i>engineering design projects</i> helped me to develop an ability to design a system, component, or process to meet desired needs. | 4.27 |
| The <i>engineering design projects</i> helped me to develop an ability to identify, formulate, and solve engineering problems. | 4.03 |
| The <i>experiment design projects</i> helped me to develop an ability to design and conduct experiments, analyze and interpret data. | 4.04 |
| The <i>experiment design projects</i> helped me to develop an ability to communicate effectively via written reports. | 3.90 |

All the mean scores in Table II are above 4, except for the last one which is very close to 4. The maximum possible mean score is 5. The evaluation results show that the engineering and experiment design projects were highly effective in helping engineering students develop the generic attributes listed in Table II.

C. Other Usefulness

Below are some comments written by the students on the design projects which illustrate in what other ways they were useful:

- Stimulate creativity and innovation.
- Stimulate critical and logical thinking.
- Helped me to improve my thinking skill.
- Taught me leadership abilities.

- Time management is crucial as we have to finish the project on time.
- Helped me to understand the concepts.

IV. CONCLUSION

Student evaluations show that the engineering and experiment design projects were far more useful compared to cookbook exercises as a resource for learning for engineering students. The design projects were also highly effective in helping students acquire some of the generic attributes of an engineering graduate. In addition, the design projects helped students develop creative and innovative problem-solving skills, develop critical and logical thinking skills, develop leadership skill, manage time and understand concepts.

One student summed it up best: the design projects helped me “learn about being an engineer in a simple way”.

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