

# Quantifying the Efficiency of Project-Based Learning Experiences

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## ABSTRACT

This paper examines methods by which the efficiency of Project-Based Learning experiences can be quantified. One specific area of interest is the cost per student per project as a function of the number of learning outcomes for that project. The paper uses four Project-Based Learning experiences that have been offered to two different groups of students over the past two years as a test-bed for the investigation. Although quantitative results still need to be processed, instructor observations, project economics and student comments reveal that more significant learning outcomes are achieved when a project is both technically challenging and the technology is observable. For the projects examined in this investigation the more expensive projects were found to result in the more significant learning outcomes.

## INTRODUCTION

The use of active learning, and specifically Project-Based Learning (PjBL), has been shown to be an effective means of increasing the development of attributes that would otherwise be difficult to enhance in a traditional engineering curriculum [1]. Teamwork, interpersonal communication, engineering economics, and dispute resolution are all examples of attributes that can be developed and strengthened through the PjBL experience. The utility of these dual-impact learning experiences is that they help strengthen not only the hard-to-reach attributes but also reinforce technical understanding of the particular subject area that the PjBL experience relates to [2,3]. Although there are many positive aspects surrounding the PjBL experience, the fact remains that they can be expensive to implement given the requirements for non-traditional hardware and infrastructure, the additional expenses for the materials and supplies required for each project, and the additional instructor time required in preparing for the activity, running the activity, and in post-activity assessment.

Engineering educators and administrators need to have methods of assessing the tradeoff that exists between the enhanced value in the form of learning outcomes that result during a PjBL experience with the additional financial investment required to offer that experience. It is with this view that this paper examines different methods of quantifying the efficiency of PjBL experiences. Efficiency itself is a broadly-defined term that is traditionally dimensionless; however, in this paper several different indicators are developed that indicate the "efficiency" of a PjBL experience. With these indicators an engineering educator would then be better positioned when deciding which PjBL experience to offer in a course.

The paper will include analysis of PjBL experiences in Renewable Energy that were offered in a collaboration involving the University of Calgary and Shantou University (STU) during two

consecutive years [4], May 2010 and again in May 2011. During each program year a total of forty students were divided into eight groups of five students per group, and each group was given a one-week long PjBL experience that nominally required approximately 16 hours of laboratory time to complete. Teams were randomized from week to week in an attempt to remove biases that come from team unification through repeated group activities. During the May 2011 PjBL experience team members were asked to complete a survey that quantified the learning process, including the level of difficulty of each step of the exercise, the level of involvement (number of tasks per team member), the level of learning associated with non-technical attributes, and the level of learning associated with technical attributes. This information, combined with financial aspects associated with the cost of each project, provides input data with which the different efficiencies can be quantified.

Given that the 2011 program only concluded on 28 May 2011, it was not possible to process student survey results in time for this paper. This paper will instead discuss aspects of the survey design, the economics of the four PjBL experiences, and instructor observations that were made as a result of a small but significant changes between the May 2010 and May 2011 program that help interpret activities within the student teams.

## **BACKGROUND**

As discussed in the introduction, PjBL experiences offer dual impact learning experiences, helping to strengthen traditional engineering skills itemized in CDIO Syllabus Categories 1 *Technical Knowledge and Reasoning* and 4 *CDIO in the Enterprise and Social Context*, but also providing mechanisms by which CDIO Syllabus Categories 2 *Personal and Professional Skills and Attributes* and 3 *Interpersonal Skills: Teamwork and Communication* can also be strengthened.

Although there are obvious benefits associated with PjBL experiences, Prince [5] points out that it is important to determine if the benefit of the active-learning exercise is significant and that the benefit of the activity needs to be considered in terms of the extra effort or resources required to achieve this benefit. Roselli and Brophy [6] use classroom observations, student surveys and knowledge-based questions to show that active learning can help students to better understand more difficult concepts in a course.

On the topic of the effectiveness of laboratory learning, both Campbell et al. [7] and Abdulwahed and Nagy [8] found that improved learning results when students are exposed to simulation-based learning prior to coming to the physical laboratory. Both papers highlight the shortcomings of standard laboratory-based instruction and highlight the benefit of student-motivated learning for laboratory-based courses. Although this paper does not use simulation-based learning, it does involve a laboratory-based course entitled Renewable Energy Practicum where groups of students design, implement and operate their own experiments. This type of approach to learning is more expensive than the courses described in References [7, 8] that involve the use of simulation-based instruction, thereby prompting the desire to quantify the efficiency of the learning outcomes more accurately.

One major driver in determining the efficiency of a project is group size. Griffin et al. [9] examine the impact of group size on learning outcomes in a capstone design course. Too large a group size results in free-riding and social loafing while too small a group size can impede the ability to innovate by restricting the diversity of past experience. In the context of the current

investigation, too large of a group size can result in free riding however too small of a group size can result in unreasonable expectations with too large a workload. Group size also has implications on permanent infrastructure costs as well as materials and supplies costs. Griffin et al. [9] conclude that for a capstone design course group size should not exceed 6 students due to the presence of free riding in larger group sizes.

## METHODS

A one-week pilot project was performed in February 2009 involving 30 Schulich School of Engineering (SSE) students and 30 STU students working in teams of 7-8 students on a single implement-operate project. This model of student exchange proved very successful, providing a hybrid between an international project and an international field trip [10] and the 2009 exchange provided motivation for developing the Renewable Energy Practicum course [11].

The Renewable Energy Practicum course consisted of four implement-operate exercises and two field trips. All of the exercises included both a build phase and a testing phase. Students were put in teams of 5 students, and student teams were altered for each exercise. Teams consisted of a mix of SSE and STU students, and gender balance was ensured for all teams. The exercises consisted of: i) construction and testing a solar-photovoltaic cell [12]; ii) construction and testing a solar fan [13]; iii) construction and testing of a wind turbine [14]; and, iv) construction and testing of a solar-thermal water heater [15]. Each implement-operate exercise was taken from the project-sharing website Instructables ([www.instructables.com](http://www.instructables.com)) [12-15]. The Instructables website provides step-by-step instructions on how to build a wide array of devices, and consequently it proves to be a very useful resource when planning implement-operate exercises.

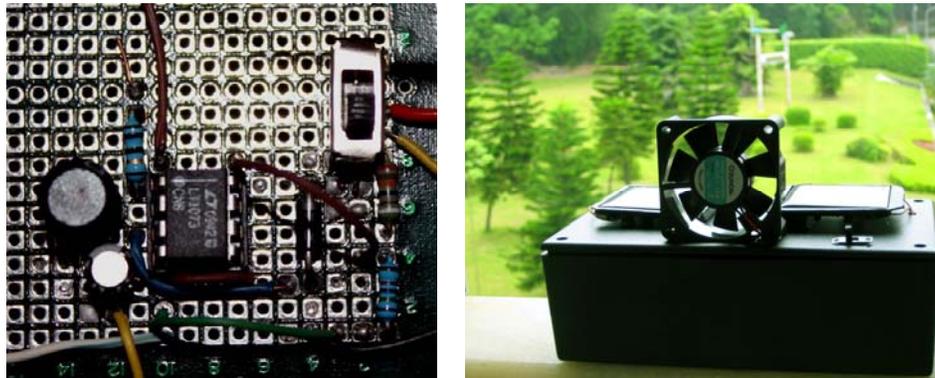
### Project Descriptions:

1. Solar Photovoltaic Cell: this project involved fabrication and testing of a copper-cuprous oxide photovoltaic cell. A copper plate heated on a hot plate resulted in the formation of a fine cuprous-oxide layer on the surface of the copper plate. The plate was then mounted in a case filled with a water / baking soda mixture. An electrical circuit was completed through the addition of a second copper plate, with the completed cell shown to the left in Fig. 1. This project was relatively simple and provided a gentle introduction for the students to both the workshop and the nature of the implement-operate projects. *Learning Outcomes:* mechanical design; photo-voltaic effect in a copper-cuprous oxide thin-film solar cell; simple soldering; efficiency estimation.



**Figure 1.** Solar Photovoltaic Cell (left) and Testing of the Cell (right)

2. Solar Fan: this project involved the use of two solar cells and two NiCd batteries (1.2V and 600 mAh) from commercial garden lights. The solar cells were used to charge the batteries during the day, and at night the charged batteries were used to power a 12 V (0.15A) computer fan. Use of two 1.2 V batteries to power a 12 V fan requires the use of a Linear Technologies micropower DC/DC converter (LT1073). The circuitry and fabrication in this project were more complex than the first project, requiring the students to be both organized and focused. An example of a final project is shown to the right in Fig. 2. *Learning Outcomes:* mechanical design; energy storage; power conditioning; soldering techniques; circuit assembly.



**Figure 2.** LT1073 DC/DC Converter circuit (left) and Solar Fan project (right)

3. Wind Turbine: this project involved the fabrication and testing of a vertical-axis wind turbine of the Savonius rotor design. The most complicated aspect of this project involved the fabrication of the electrical generator. Eight rare-earth permanent magnets (NdFeB) were mounted to the rotating Savonius turbine, and twelve generator coils were fabricated by winding aluminum bobbins using either 32 AWG or 36 AWG magnet wire. This project proved to be the most challenging given the complexity of the generator section. Placing it during the third week was optimum as students had honed both their mechanical and electrical skills in the two previous projects. Testing was performed at speeds up to 10 m/s in the Shantou University wind tunnel laboratory (3 m X 2 m test section; 45 m/s max velocity), as shown in Fig. 3. *Learning Outcomes:* mechanical design, wind turbine power curve; AC generator design; rectification of an AC voltage to a DC voltage; power estimation; designing an experimentation test plan.



**Figure 3.** Operating wind turbine (left) and students in the STU Wind Tunnel (right)

4. Solar-Thermal Water Heater: this project involved the fabrication and testing of solar-thermal water heater that mimicked the performance of an evacuated tube collector. Students fabricated the water heater using nested plastic bottles. Reflective tape was used to increase the concentration ratio of the collector. A simple child thermometer was used to measure the temperature of the water within the heating section, as shown to the right in Fig. 4. This was the simplest project and it was placed at the end of the course during the week with the least amount of time for the Practicum course. The students were skilled in the workshop by the final week and consequently the building phase of the project was completed in the first day. *Learning Outcomes:* mechanical design; solar-thermal energy systems; efficiency estimation.



**Figure 4.** Solar-thermal water heater designs (left) system testing (right)

#### *Instruments and Measures:*

As mentioned earlier, due to the fact that the May 2011 course ended on 28 May 2011, it was not possible to review the student surveys prior to writing this paper. Instead of performing detailed analysis of the student survey results, this paper will provide a summary of the instruments and measures used and offer some limited insight based on the data and information available at the time of writing. A future CDIO paper will offer more concrete data analysis.

##### *1) Team Project Review Survey*

In order to quantify the PjBL learning process, a short (8 question) survey was developed. As noted previously, this survey was completed by students at the end of each one-week long PjBL experience, and was intended to report on the level of difficulty of each step of the exercise, the level of involvement (number of tasks per team member), the level of learning associated with non-technical attributes, and the level of learning associated with technical attributes.

The survey was developed to be general enough so that it could be used for a wide range of projects, yet specific enough to allow PjBL experiences to be quantified. As well, we felt that it was important to use the same survey questions for each project for consistency: i.e., both in terms of making the questions familiar to students, as well as allowing for consistent analysis of the results.

To accomplish this, the survey, shown in Fig. 5, involved very general questions that could be linked back to each specific project. For example, Questions 1 and 7 focus on the level of difficulty of each step of the exercise. These questions do not assess the level of difficulty

directly, but instead ask students to quantify their level of activity on the project. “Level of difficulty” is very subjective and would vary from student to student based on their background as well as on how project tasks were shared among team members (e.g., some team members may be assigned less or more difficult tasks than others). However, by linking back to the number of steps involved in project, a relative level of activity per step can be translated into a level of difficulty for the project. This, in combination with student feedback on team size (Q 7), provides insights into the level of difficulty of each project (e.g., more difficult projects require more students).

Questions 2 and 3 tackle the level of involvement of students in a team setting. Rather than asking students to quantify the “number of tasks per team member”, we chose to quantify a more general “level of involvement”: i.e., asking students to quantify the number of tasks completed would have overly complicated the survey and would have likely proved to be unreliable (e.g., difficult for students to identify what constitutes a task). The more general questions on each student’s contribution to the team, in combination with the instructor’s knowledge of the number of steps for the project, result in a more reliable estimate to the level of involvement for individual students.

Team project review:					
<i>For each statement, select a number from 0% to 100% to indicate your degree of agreement with the following statements (please check one response for each statement).</i>					
	Disagree			Agree	
How strongly do you agree with the following statements:	0%	25%	50%	75%	100%
1 My level of activity on this project was high.	<input type="checkbox"/>				
2 I made important contributions to my team.	<input type="checkbox"/>				
3 My team's project would <u>not</u> have been completed on schedule if I was absent.	<input type="checkbox"/>				
4 I learned new non-technical skills (e.g., communication, team work, etc.)	<input type="checkbox"/>				
5 I learned new technical skills in the specific project area.	<input type="checkbox"/>				
6 This project helped me understand the technical area more than if I had only relied on lecture notes and a textbook.	<input type="checkbox"/>				
7 Our team had the right number of students for the scope and allotted time.	<input type="checkbox"/>				
<i>Based on your answer to statement 7, please indicate how many more or less team members you feel your team needed (please only answer 8a or 8b).</i>					
	1	2	3	4	5
8a My team needed ## <u>more</u> members.	<input type="checkbox"/>				
8b My team needed ## <u>less</u> members.	<input type="checkbox"/>				

**Figure 5.** Team Project Review Survey

The level of learning associated with technical and non-technical attributes is addressed by Questions 4-6: Questions 4-5 focus on new skills, while Q 6 focuses on the mode of learning (i.e., PjBL vs. traditional lecture notes and textbook). For this aspect of the survey, Questions 4-5 are linked directly to the intended learning outcomes for each project. For example, the Wind Turbine project performed by the University of Calgary / Shantou University students involved electric generators and full-wave rectifier circuits. Although the basic theory should not have been new to the students, the PjBL exercise led some students to new insights into power losses in practical electrical circuits. When viewing the survey results in the context of the project learning outcomes and the classroom assessments (e.g., team presentations and answers to questions), it becomes clear when and where new technical and non-technical attributes are gained for the project.

## 2) Project Budgets, Learning Outcomes and Quality of Learning Outcomes

The budgets for each of the projects included one-time equipment costs as well as materials costs required each time a project was performed. The costs will be reported on a per team basis assuming 8 teams. The cost of a Dremel high speed hand tool is included as a one-time cost for each project. The number of learning outcomes are estimated based on the nature of the exercise. The quality of the learning outcome is assessed by the instructor after giving consideration to the complexity and challenge of the project, the time taken to complete the project, and the nature of student comments made in relation to the project. The Wind Turbine Project often resulted in students stating that it was the best experiment that they have encountered in their undergraduate careers, consequently it received a *High* rating in the Quality of Learning Outcome column. It should be pointed out that the costs of testing in the Shantou University wind tunnel laboratory were not included in the project economics.

Table 1  
Project Budgets, Number and Quality of Learning Outcomes

Project	One-Time Cost (\$ / team)	Materials Cost (\$ / team)	Learning Outcomes	Quality of Learning Outcomes	Hours to Complete Project
Solar Cell	\$122.50	\$0.81	4	Low	4
Solar Fan	\$87.50	\$42.87	5	Medium	8
Wind Turbine	\$87.50	\$108.40	6	High	8-10
Solar Thermal	\$22.50	\$2.17	3	Low	2-4

### OBSERVATIONS AND DISCUSSION

Until the survey data has been processed and analyzed it is difficult to make specific conclusions about the relative efficiency of the projects. Based on instructor observations, however, it was noted that the more complex and involved a project, the more interested the students became. This was noted most for the Wind Turbine project where the complexity of the build operation was such that most team members needed to be involved. Although the Wind Turbine took a similar amount of time to complete as the Solar Fan, the Solar Fan involved the use of an Integrated Circuit (DC/DC Power Converter) and the students found the abstractness of the Integrated Circuit less appealing than the exposed and explicit nature of the AC generator in the Wind Turbine.

Although teams of 5 were prescribed, it is presumed that smaller teams may result in more significant learning outcomes. This comment can be supported by considering that in May 2010 students were not required to write a report documenting the build and test procedures, while in May 2011 such a report was required. It was observed that during the May 2011 course offering teams would assign one of the 5 members as the "note taker," a person who would type the build and test procedures on a laptop while the lab activity was taking place. Given that all projects were completed on time with one of the five members not engaged in the build-test cycle, it is possible to conclude that the group sizes could have been reduced from 5 to 4 students per team and still reach the goal of building and testing the device. Discussion with one of the students in the course supported this observation.

A third observation is that although the Solar Cell and Solar Thermal project were the most cost effective, they were characterized by lower student interest. The number of Learning Outcomes for both projects were also lower, and consequently the Quality of the Learning Outcomes was assessed as Low for both projects.

One other modification made during the 2011 course offering was to add two new dimensions to the grading rubric for the project report. The new dimensions assigned points for Innovation in both the Design and Testing process. The Design dimension states "The development makes 2 or more innovations beyond what was originally described that assist in system performance" while the Testing dimension states "The testing quantifies the performance of the system by exploring two or more variables." The addition of these two dimensions encouraged the students to think beyond the instructions provided by the Instructables website and helped keep them more engaged.

## CONCLUSIONS

This paper has made a first attempt to quantify the efficiency of four project-based learning experiences. A survey instrument has been developed to help assess student involvement and learning outcomes for the PjBL experiences. Although the study is still in the early stages and no quantitative results have yet been obtained, qualitative results indicate that the more involved the project the more interested the students become. According to the results found by other researchers, it is speculated that this will result in stronger learning outcomes. This does not mean that the projects with lower learning outcomes should be removed from the course as these projects help serve an important purpose by gradually introducing students to more general topics including workshop safety and lab conduct.

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