Project-based learning in engineering education: Evaluation of the PBL implementation, students' perception and grade attainment

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1. ABSTRACT – Project-based learning (PBL) is usually adopted in engineering education to make learning more engaging than the traditional teaching style. In this paper, the PBL implementation in the engineering subject is presented. Students' perception of the implementation of the subject is investigated through a survey. The final score is analysed to see the correlation between the individual assessment in the test concerning the group mark from the project-based assessment. In addition, the effect of gender differences on the final score is also evaluated. The findings show that the final score is not affected by gender or the test. According to the survey, the assessment weightage and items have to be revised. Each group-based work has to be peer-rated and converted to the individual mark.

1. INTRODUCTION

Project-based learning (PBL) in pedagogy is a well-known methodology (Palmer & Hall, 2011) and significant to produce graduates with critical thinking skills and simultaneously challenging students' knowledge, attitudes, and competencies (Naviri et al., 2021). The project-based approach can stimulate students' interest in the subject and making learning more meaningful, relevant, and engaging (Allison et al., 2015).

Manufacturing Engineering is a branch of engineering that requires knowledge, practical skills, and experience to fully grasp, exploit and control all the engineering techniques in the manufacturing process and production methods. It also requires an attitude to plan for manufacturing methods, research and develop tools, processes, and machines, and combine facilities and systems to produce cost-effective products more feasibly (FKP Academic Handbook, 2020).

This paper discusses an evaluation of the PBL implementation, students' perception, and grade attainment for the Product Design and Manufacturing subject. The subject is designed to achieve some of the university's objectives, like producing graduates with technical competencies relevant to the industry's needs and equipping graduates with leadership, teamwork, critical thinking and problem-solving skills.

The first objective of this study was to gather students' perceptions of the implementation of this subject through a survey. Second, the author would like to evaluate the effect of gender differences on the final score. Thirdly, the impact of individual assessment on the final grade was analysed to determine whether the test weightage is sufficient or if the assessment items and weightage should be adjusted. Some recommendations to improve the PBL method in the following semester are proposed based on the feedback obtained from the survey.

2. METHODOLOGY

Product Design and Manufacturing is a compulsory subject offered during the third year of the four-year Degree of Manufacturing Engineering. The subject is a pre-requisite subject before the student takes the Integrated Product Design (IDP) subject in the subsequent semester. Therefore, this semester, the student will establish the fundamental and theoretical analysis of their product through the guidance of some assignments. The fabrication of their product will only be made in the following semester, during the IDP subject.

PBL incorporates requiring the student to work in a team and accomplish the given tasks according to mapping the course learning outcomes (CLO) and the programme outcomes (PO). In this subject, four lecturers are assigned as a team through shared teaching. Shared teaching in this study refers to the conduction of the subject according to the assigned topic for the whole semester. Before the beginning of the semester, a meeting was held to discuss the assessment and the weekly planning to establish a mutual understanding among all lecturers. Then, the tasks for the following 14 weeks were shared equally according to the expertise.

In this study, the assessment score of students from Semester 1, Session 2020/2021, was taken for the analysis. A total of 178 students enrolled in this course, conducted 100% online due to the COVID-19 pandemic, consisting of 57 female students and 121 male students.

2.1 Course Learning Outcomes (CLO)

Table 1 shows the CLO which are designed for this subject. Some elements are embedded, covering the fundamental knowledge of product design and the environmental consideration in product design. The teamwork effort is also measured by collaborating between team members in the oral presentation and report writing.

Program Outcomes (PO) are statements describing what students are expected to know and perform or attain by the time of graduation. These relate to skills, knowledge, and behaviours that students acquire through the program of study. Table 2 exhibits the PO which is mapped to this subject.

Table 1 Course learning outcomes (CLO).

CLO	Description
CLO1	Apply the methodologies for product design as a means to develop an idea from concept through to production to satisfy customer needs.
CLO2	Apply environmental concerns in creating sustainable products.
CLO3	Recommend suitable manufacturing processes associated with functional and product development requirements.
CLO4	Demonstrate the ability to collaborate efficiently among team members.
CLO5	Demonstrate the ability to communicate effectively both orally and writing project.

Table 2 Program outcomes (PO) of the subject.

PO	Description
PO1	Able to apply knowledge of mathematics, science, engineering fundamentals and manufacturing engineering to the solution of complex engineering problems.
PO4	Able to conduct investigation into complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
PO8	Ably to apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
PO9	Able to communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
P10	Able to demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

Table 3 shows the CLO-PO mapping of the assessment method. The Key Performance Index (KPI) achievement of the CLO-PO is calculated by looking at the individual mark of a student who passes 60% of the assessment mark set for each CLO-PO mapping. In general, four different assignments are created to guide the student in their project. Assignments 1-4 are designed to support this course's main project, documented in the technical report at the end of the semester. A guest lecturer from the industry was also invited to give a talk. Following are details of the assignment topics:

- Assignment 1: Quality Function Deployment
- Assignment 2: Concept Generation and Selection
- Assignment 3: Life Cycle Assessment
- Assignment 4: Product Analysis

Table 3 CLO-PO mapping of the assessment method.

CLO	PO	Assessment method	Percentage
1	4	Assignment 1	10%
		Test	15%
2	8	Assignment 2	10%
		Assignment 3	10%
		Test	15%
3	1	Assignment 4	10%
		Technical Report	15%
4	10	Peer Rating	5%
5	9	Presentation	10%

2.2 PBL Process Flow

In this subject, the students were allowed to form their group, consisting of 4-5 team members. The reason behind this is to allow the student to enjoy the collaborative work throughout the course, especially during the COVID-19 pandemic outbreak, where all of them are required to work online. A feedback form concerning this was first administered among the students, and 97.1% agreed if there are allowed to select their team members, and only 2.9% preferred of the team was selected by the lecturers. Before the group formation, a few guidelines were given to the student, including a mix of lower CGPA and higher CGPA students. A study by Hamid and Nordin (2019) has shown that lower CGPA students had achieved good grades in the subject. Therefore, this should eliminate the fear of a higher CGPA student collaborating with the lower achiever and promote a better combination of team members.

In this subject, the student has to select one product to be visually developed and conduct the analysis of their design in terms of QFD analysis, concept screening and scoring analysis, life cycle analysis, and useability analysis. For this semester, the theme was set to 'Innovative Solution for Community Application.' The scope of their project could be for disabled people, school children, SME industry, equipment/machine design, or older adults. Each group has to select their project supervisor among the engineering lecturers at the department and submit their proposal at the beginning of the semester. Subsequently, the course coordinator screened the proposed project to see whether it is doable or not to avoid a project that is too ambitious or a project that does not meet the minimum requirement of this subject. Upon approval, the student can proceed with their assigned tasks with a detailed guide from the lecturers. Each assignment, presentation, and report have a specific rubric for the assessment and have been shared with all students in the online learning portal. Therefore, the student knows how they will be assessed and perform the given tasks since everything has been disclosed.

At the end of the semester, a survey was conducted on students willing to gather their feedback on the PBL implementation, whether it was a success or vice versa. Sixty-nine respondents are recorded, from the total of 178 students, which represents 38.8% of the total population. Following are some questions asked in the survey:

- Do you enjoy learning this subject?
- Is group-based work bringing difficulty to you?
- Do you have any suggestions for the group formation?
- Does shared-teaching is a good approach? If the answer is no, please tell us why.
- Is the percentage of assessment set for this subject acceptable? If no, please tell us why.
- Is the instruction and assessment rubric for Assignment 1 -4 clear?
- What are the things that you dislike about this subject?
- Do you have any recommendations for this subject?

2.3 Statistical Analysis

The analysis used includes descriptive statistics and tests of significance. The distribution of students' scores is examined using the Jarque-Bera test. Pearson correlation test between individual assessment and project-based assessments is performed to the three groups of students, where the H_o is that $\rho = 0$ (variables are not correlated) vs. the H_a of $\rho \neq 0$ (variables are correlated). The analysis proceeds with a Chi-square test of association to determine whether grades obtained by students are related to gender. The H_o is that grade and gender are not associated. The H_a is that grade and gender are associated. Then the correlation between the test and project-based scores is tested using Pearson's coefficient for male and female students. Lastly, the T-test for independent samples is conducted to compare whether the performance between gender is statistically different, where the H_o of $\mu_{female} = \mu_{male}$ vs. H_a of $\mu_{female} \neq \mu_{male}$.

3. RESULTS AND DISCUSSION

Table 4 shows the CLO-PO achievement for the subject. CLO1 and PO4 do not achieve the KPI set for this subject, where only 36.87% have obtained scores more than 60% out of 25 points. Assignment 1 and Test represent the CLO-PO mapping of CLO1 and PO4. According to the score, this might be due to the lower score in the test for most of the students since the test represents 15 points out of those 25 points (refer to Table 3). The student did not perform in the test because the question was set to an open-end type question.

Table 4 CLO-PO achievement for the subject.

CLO	PO1	PO4	PO8	PO9	PO10
CLO1		36.9%			
CLO2			100%		
CLO3	99.4%				
CLO4					99.4%
CLO5				100%	

According to the feedback obtained from the survey, students' perception towards this subject has been gathered. 75.4% of the students enjoyed this subject. The remaining did not enjoy the subject for similar reasons: online learning is complex, and the assignments are too many. Then, 23.2% responded that group project is challenging, but they agreed that 4-5 team members are sufficient. Concerning the shared teaching, 13% disagreed that shared teaching should be adopted since they claimed that it was hard to adapt to different lecturer's teaching styles. 95.7% agreed that the assessment percentage is acceptable. However, some were highlighting the tutorials that added their workload in addition to the given assignment. The students were satisfied with all instructions for the assignment. They agreed that the rubrics had helped them understand the assignment with the limitation of online learning. Last but not least, the portion of the individual final score for each group-work has to be based on the peer rating for each group task, as suggested in Equation (1).

$$Group\ Score \times \frac{Total\ peer\ rating\ mark\ (for\ student\ to\ be\ assessed)}{Total\ peer\ rating\ mark} \quad (1)$$

In this section, the impact of theoretical assessment in the test on the overall score was studied. The reason for doing this analysis is that the overall score for all students is normally distributed, where most students only obtained grade B. It is pretty unfair for the student who had put so much effort into the project work. Students in this subject are divided into three groups, and the final grade of each group was also analyzed.

Statistical analysis was performed to see the distribution of the data set. The average scores between the groups were compared as tabulated in Table 5. On average, we can note that students from group 2 had the highest mark of 68.24%. The statistic of Jarque-Bera showed that the data from all groups are normally distributed. The Pearson correlation between students' performance in the test and the project-based work was tested. Table 6 indicates that the relationship between test and project was weak and not significant. This shows that students' performance between theoretical knowledge (test) and project-based ability does not affect each other.

Table 5: Summary statistics for the final score.

	Group1	Group2	Group3
Mean	66.114	68.245	63.032
Median	65.750	67.100	62.750
Maximum	84.750	82.200	73.100
Minimum	54.950	55.250	50.400
Std. Dev.	6.749	5.837	5.691
Jarque-Bera	0.935	0.894	1.445
Probability	0.627	0.639	0.485
Observations	75	43	61

Table 6: Correlation between individual assessment (test) and project-based assessments.

	Correlation coefficient
Group 1	0.133376 (p-value >0.01)
Group 2	0.115149 ((p-value >0.01)
Group 3	0.053714 (p-value >0.01)

Descriptive statistical analysis was performed to see the distribution of the data set. The average scores between the male and female students were compared as shown in Table 7. On average, we can note that female students performed better than male students (mean score 14.82% vs 14.68%). However, the marks obtained for project-based assessments are almost similar, about 51%. The range of the score for project-based is higher for male students with maximum and minimum scores 60.5 and 22.95, respectively. The higher value of standard deviation implies that the score for male students is also more dispersed than female students.

The inferential analysis began with a test of association between gender and grade obtained. As shown in Table 8, the value of Pearson Chi-square statistics, 7.188, was not significant. Thus, the H_o of no association can be rejected. We can conclude that the grade obtained by students was not associated with their gender.

Table 7: Summary statistics by gender.

		Test	Project
Mean			
	Male	14.68	50.99
	Female	14.82	50.98
Maximum			
	Male	27.75	60.5
	Female	25.5	60.5
Minimum			
	Male	4.5	22.95
	Female	5.25	43.7
Std. Dev.			
	Male	4.80	4.82
	Female	4.35	3.67
Observations			
	Male	57	57
	Female	121	121

Table 8: Chi-square test of association between gender and grade obtained.

	GENDER		
GRADE	Female	Male	Total
A	0	4	4
A-	6	9	15
B+	12	27	39
B	18	33	51
B-	16	30	46
C+	3	16	19
C	2	1	3
D	0	1	1
Total	57	121	178
Pearson Chi-square (df,7) =7.188			P-value>0.01

Moving to Table 9, the Pearson correlation coefficient 0.038 and 0.125 for male and female students were not significant. The results suggest the H_o of no correlation between the variables failed to be rejected. Therefore, there is evidence to confirm that students' performance in theoretical knowledge was not related to their project-based ability for both males and females. To compare whether male and female students equally performed, we implemented independent samples T-test as reported in Table 10. Again, the H_o of equality between means can be rejected for test and project-based assessments. Therefore, we can conclude that there was no difference between gender on their performance in the test and project-based work. The mean difference score between gender was small, about 0.142 and -0.007.

Table 9: Correlation test between individual mark (test) to the group mark (project-based assessment).

	Pearson correlation	Probability
Male	0.038	p-value>0.01
Female	0.125	p-value>0.01

Table 10: T-test for equality of means between male and female students.

	t-value	df	Mean difference	Probability
Midterm exam	0.189	176	0.142	p-value>0.01
Project	-0.011	176	-0.007	p-value>0.01

4. CONCLUSION

PBL was successfully implemented in the subject. The statistical analysis has concluded that student's final grades are not affected by the individual assessment (test) or gender. The result shows that students' performance between theoretical knowledge (test) and project-based work does not affect each other. However, the assessment weightage must be revised, including the number of assignments to motivate the student. Peer rating has to be used in each group-work assessment to give the project-based score individually and promotes better teamwork among group members.

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