

Studying the Effectiveness and Complexity of Incorporating Flipped Classroom to Project Based Learning

Abstract

This paper reports and evaluates the findings of a research study conducted for a group of year-2 Engineering students participating a flipped classroom (FC) experience that is incorporated to a project-based learning (PBL) module. The purpose of the research was to identify whether this hybrid approach to learning, resulting in new pedagogy, is a positive experience for students seeking to promote their active learning. Results from the two classes of students are collected and evaluated – one is subjected to a conventional PBL while the other undergoes a hybrid PBL-FC learning format. Key findings indicate a significant improvement in fundamental formative knowledge; enhanced problem-solving abilities; and production of better performing artefacts with regards to the set of design skills for students undergoing hybrid PBL-FC groups. Some complexities related to the incorporation of FC to PBL are also comprehensively discussed. This paper hopes to provide new knowledge and insights relating to the introduction of flipped learning into a project-based module.

Keywords: *hybrid project-based learning; flipped classroom; problem-solving; active learning*

Introduction

Project Based Learning (PBL) provides a sustainable platform for deep inquiry, which often leads to improved understanding on how to apply acquired basic knowledge (Schlemmer and Schlemmer, 2008). Within the active learning framework, many global studies (Chinnowsky et al., 2006; Johnson, 1999; Padmanadhan and Katti, 2002) have proposed PBL as one of the most suitable means of achieving effective competence-based education that integrates self-learning, knowledge, problem-solving skills and creativity (Palmer and Hall, 2011; Pierce and Jeremy, 2012). The PBL model facilitates students to generate their own learning process and to develop personalized solutions that are unique to a specific engineering problem. Despite the numerous benefits of adopting the PBL approach, there exist several key challenges. These include the amount of time and resources needed to organise and administer PBL (Frank and Elata, 2003; Helle et al., 2006). Often than not, within the constraint of time and resources, PBL needs to be feasible and manageable for both facilitators and students to yield maximum benefits from the active learning components (Blumenfeld et al., 1991). Further, students who are involved for the first time in a collaborative learning environment may encounter issues to simultaneously grapple with learning fundamental theories,

1 working in groups, and engaging in active learning activities (Johnson and
2 Johnson, 1989).

3 One key question that has been puzzling educators is that can we
4 further promote the productivity levels for both teachers and students in a PBL
5 framework? The infusion of a Flipped Classroom (FC) might just be the
6 answer to enhance PBL outcome. FC was first evolved with the idea that
7 lectures are pre-recorded and to be watched at the students' leisure pace outside
8 of classes while the teacher assists students with their learning in class.
9 Advancement in technologies has made this operational mode a reality. By
10 porting teaching materials to an online platform to facilitate home learning,
11 teachers have found innovative ways to employ during class time to engage
12 students in their active learning process. While theories and conceptual
13 teaching videos can be viewed at home, they also assisted in shortening the
14 explanation of basic theories time in class. Accordingly, Several FC case
15 studies that have highlighted significant improvement in students' learning and
16 achievements as they become more engaged and empowered to take on added
17 ownership of their learning (Mok, 2014; Lewis et al., 2018; 13. Chen et al.,
18 2018).

19 20 21 **Literature Review**

22
23 The flipped classroom is often introduced or hybrid with other
24 pedagogy methods to promote collaborative learning and to achieve higher-
25 order learning objectives. Compared to the traditional classroom, the flipped
26 classroom has students learning basic concepts through lecture videos and
27 online learning materials before coming to class and then the physical class
28 becomes a place for deeper interaction to enable discussion and working of
29 problems, advance concepts, and also improved engagement in collaborative
30 learning.

31 Yan et al. (2018) applied the active flipped learning method to an
32 engineering mechanics class of 80 students. It serves to combine flipped
33 classroom with active learning in order to establish an active flipped learning
34 (AFL) model with the chief aim of promoting active learning. Key results have
35 revealed that the AFL model enhanced students' learning motivation, improved
36 students' interest, curiosity and learning initiatives. Further, students
37 undergoing the AFL model were also able to employ more strategies of
38 resource management, such as time and study environment, effort regulation,
39 peer learning, and help seeking in contrast to the traditional model.

40 In an attempt to answer the question "does flipping promote
41 engagement?", Burke and Fedorek (2017) conducted a comparative study
42 comprising traditional, online, and flipped classes. One of the key findings
43 from their study is that flipped classroom may not necessary ends up promoting
44 better engagement in class. The flipped classroom leverages on the notion that
45 students arrive to class prepared and are ready to learn. Flipping a classroom
46 relies on the reliability of the students to participate the out-of-classroom

activities whereby students must have attempted to learn the material prior to actual class time. However, this is not always the case and students often arrive to class unprepared. Exploring students' learning attitude and achievement under flipped learning environment in a computer aided design curriculum, Chao et al. (2015) found that the flipped learning approach has a positive effect on the transfer of learning and impacted positively on students' achievements. Additionally, students' learning attitudes, motivation and self-evaluation were enhanced with the incorporation of a flipped environment.

Talley and Scherer (2013) observed that students tend to spent more time engaging in the course content in flipped classrooms which resulted in improved performance in their examinations.

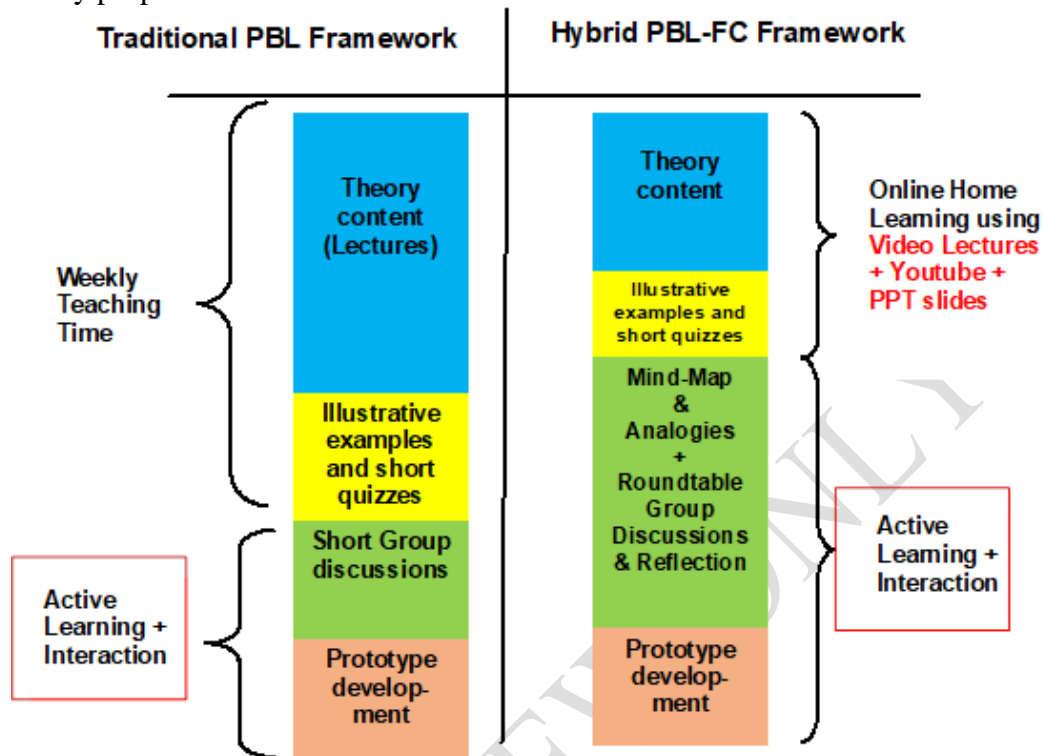
Having surveyed students in three different classes taught by three separate instructors, Kim et al. (2014) found that the flipped classroom assignments facilitated self-regulated learning in terms of setting targeted goals, monitoring learning progress, and evaluating their own achievements". A key aspect of flipped learning that would impact students' learning is tailored pace learning that agrees with their learning style. Tailored-paced learning has been deemed to be effective for many online classes (Roach, 2014) and is an essential component that can determine the potential success of a flipped classroom.

Thus far, the above literatures have documented both key advantageous aspects of flipped classroom learning as well as some drawbacks by comparing flipped learning to traditional classroom learning. What is then the impact of flipped learning on a project module that employs project-based learning?

Initially, it may appear that combining PBL and FC can potentially turn out to be numerous educational initiatives, instead it converges two initiatives into one that works in harmony with each other. For this hybrid PBL-FC, several pedagogy components are in fact being blended into one entity including (1) technology integration, (2) digital curriculum and literacy, (3) PBL, and (4) flipped learning. It is noteworthy that this blended learning facilitates authentic learning experience; mimicking real-life working experience.

The focus of this paper is to present key aspects of a hybrid PBL-FC pedagogy that influence its effectiveness and contribute to an improved student learning experience. Figure 1 provides a schematic diagram comparing the new hybrid PBL-FC with conventional PBL learning environment that was designed and implemented in this design project case study. Freeing up the time taken up for weekly lectures to discharge theoretical content to students, the hybrid PBL-FC facilitates more active learning and interactive activities including the employment of innovative learning methods such as mind mapping, engineering analogies and round-table group discussions.

Figure 1. A schematic comparison between traditional PBL framework and newly proposed PBL-FC framework.



A statistically validated study that draws on evidences from the comparison of two groups of students is presented in this study. Sixty second-year engineering students were enrolled in a design project module entitled ESP2109 – Dryer Design Project. One class, comprising 6 groups of year-two engineering students, are subjected to pure PBL learning. The other class also comprising 6 groups of year-two engineering students undergoes hybrid PBL-FC learning. This paper commences by briefly discussing some of the basic ideas about the design project, key learning outcomes and the module assessment. The process of data collection related to students' grades and questionnaires survey results are then detailed. Next, the data analysis tools employed to determine the statistical significant differences between the two classes of students are described. Finally, the impact of PBL-FC and conventional PBL on the pedagogical experience of both sets of students is discussed. The possible benefits of this study are both practical and tangible; evolving better pedagogical knowledge content will be useful and impactful for future batches of students with varying PBL and FC experiences.

Methodology

ESP2109 requires students to design a small dryer that is scalable up to process 500 kg of a selected agricultural product daily for a client. In this dryer project, students apply principles of heat and mass transfer, fluid flow, and

computing skills learned from earlier modules. The problem statement that was posted to the students is as follows: “Recently, a reputable consultancy firm has hired you to work for them on various design projects. One of these involves the design of a thermal drying system. Firstly, the mode of heat transfer for drying will be by pure convection. Secondly, the basic resources are provided to you and whatever materials that can be procured with a limited budget. Thirdly, think outside the box as only your creativity/ingenuity sets limits on your designs”.

A total of 60 second-year engineering students were judiciously selected to participate in this comparative PBL versus PBL-FC design module (ESP2109) study. Each group had 5 students which resulted in a total of 12 groups being formed. Due to the large number of students involved in the design project, two classes were designed for this study. The first 6 groups were time-tabled for a weekly three-hour Thursday session (class 1 – experimental group). The remaining 6 groups were time-tabled for a weekly three-hour Friday session (class 2 – control group). Table 1 presents key demographic information on the 60 students participating in this design module. Accordingly to the design of experiment, there were two classes - 30 in the experimental class, and 30 in the control class.

Table 1. Demographics of students

	Experimental (Hybrid PBL-FC groups)	Control (Pure PBL groups)
Number of students	30	30
Number of female students	12	11
Number of male students	18	19
Number of Chinese students	25	25
Number of Indian students	4	3
Number of students from other race	1	2
Number of local students	23	20
Number of international students	7	10

Each team has to design a small-scale drying facility using hot-air blowers, with a drying capacity that accommodates the slices from an entire potato. For this purpose and to ensure that the local drying conditions are properly accounted for, each team should design and build a preliminary version of this facility to test all the relevant parameters and their impact on drying; for example, drying times, relative humidity, flow rates, temperature etc. In addition, each team is required to formulate and solve a numerical model to aid them in their dryer design and, as a result, develop a deeper understanding of the drying process. Based on their preliminary findings, the team is to design a final small-scale drying prototype.

Data were collected by using four tools namely, knowledge written test, students' scenario-based problem-solving oral evaluation, product performance evaluation and students' opinion questionnaires sheets. In addition, the project deliverables (dryer performance and product quality) provided the final assessment tool which enabled the evaluation of the overall performance of students.

To verify the students' achievement differences in these two classes, the students' last semester scores from a fundamental heat transfer and fluid mechanics module were obtained in order to perform a student t-test analysis. Results showed that the computed student t-test = 1.463 which is less than critical t-value, which is $t = 1.672$ ($p = 0.05$) as indicated in Table 2. Because the absolute value of our test statistic value is smaller than the absolute value of our critical value, it can be statistically concluded that there are no significant differences between the two classes.

Table 2. T-test for students' score before embarking on PBL module.

Characteristic	Class 1 (experiment) – Hybrid PBL-FC		Class 2 (control) – Pure PBL		df _T	t-test*
	M	SD	M	SD		
Scores for heat transfer and fluid mechanics Module	73.2	7.47	73.6	7.65	58	1.463

Note: p-value* > 0.05

The key learning outcomes of this design module include: (1) upon successful completion of the module, the students should acquire first-hand knowledge on the principles of transport phenomena; (2) the students would be able to conduct numerical simulations to strengthen their experimental observations as well as obtain values that cannot be directly measured *in situ*; (4) the student would be able to design and build a simple and inexpensive lab-scale convective air dryer based on creative ideas; and (5) like most industrial engineering problems, students would be able to experience an open-ended project, with no unique solutions.

Method of data collection

The method of data collection included:

1. PBL was implemented for students for both study groups using a simple case study of designing and testing the performance of a lab-scale dryer having constraints such as specific drying time and product quality.
2. Evaluation of the effect of students' acquiring essential theoretical knowledge was assessed through a knowledge test. This evaluation was conducted during the third week of the semester. The test was

conducted for both experimental and control group based on a series of 10 short calculation questions. The total score of the test was 100. Test scripts were marked and scores from both groups were tabulated.

3. Evaluation of the problem-solving skills for both groups was conducted during the fourth week of the semester. Several dryer problems were formulated and presented. Students were asked to present their solutions to several scenario-based problems. Based on the technical-correctness, creativity and pragmatic aspects of their solutions, scores were given. Total scores out of 100 were collected and evaluated.
4. Performance evaluation of the dryer artefacts was conducted at the end of the semester when all dryers have been built and tested by each group. Product samples were weighed periodically to determine their dryness until their weights were relatively constant. Drying times were then recorded and samples' colours were measured to determine product quality. Test scores out of 100 were recorded.
5. Evaluation of the hybrid PBL-FC versus conventional PBL advantages and disadvantages using students' Likert-based 5-point scale opinion questionnaire sheets for the two study groups was conducted to understand their opinions at the end of the design module.

Instruments of data collection

It is worthy to know that essential data for this study were collected using four key tools:

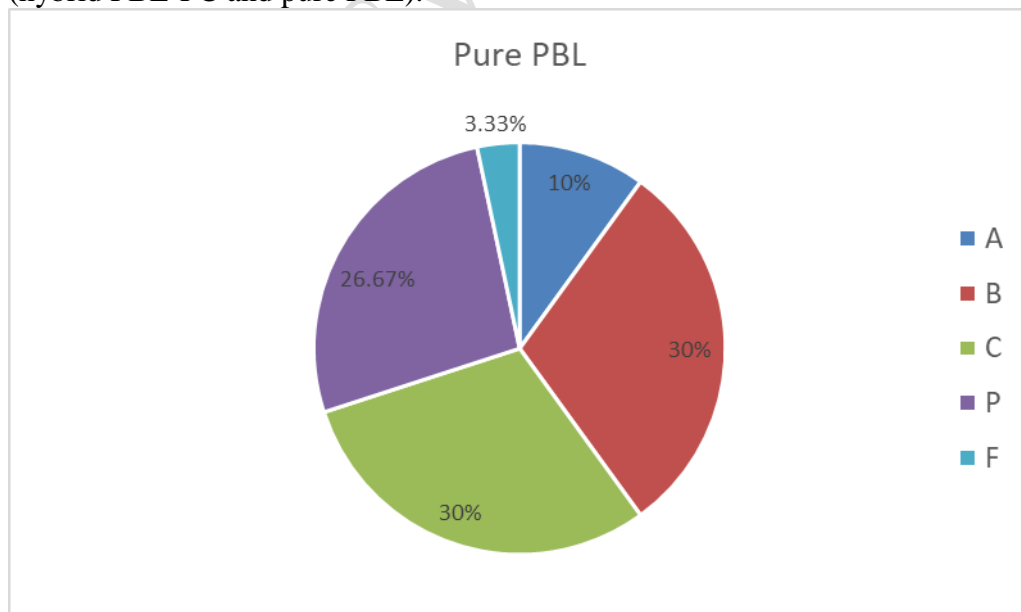
Tool 1 - Students' self-directed knowledge scale: A written test comprising 10 short calculation questions related to heat and mass transfers, and fluid mechanics was developed to test students' fundamental knowledge. The questions were based on key topics that the students were directed to learn in order to acquire essential knowledge to complete the project. Test scripts were then marked based on a maximum score of 100. The students' performance were then ranked based on a 5-point scale where the highest acquired point of 5 corresponds to grade A, point 4 corresponds to grade B, point 3 corresponds to grade C etc according to the department grading policy. Tool 2 - Problem solving skills: An oral scenario-based test was developed by several faculty members who conduct research related to heat and mass transfers particularly in drying. Several different scenarios related to industrial drying problems were developed. These problem scenarios examined students on their core learning concepts, problem solving strategies, contents of managerial skills and teamwork. The test evaluated the students' performance in carving out creative approaches to solving different scenario-based problems. The approaches included identifying problems, gathering data, analysing data to identify causes, identify consequences, listing alternatives to solve the problems, advantages and disadvantages of proposed method, ranking alternatives, selecting the best alternative and finally evaluating the results to achieve the optimal outcome. Tool 3 - Artefact performance: A scoring rubric was developed by the same group of faculty members. Components included in the

rubric were dryer's innovative design to achieve enhanced heat and mass transfers, product dryness, drying time and product quality. The total score for this segment was 100. The students' group performance were then ranked based on a 5-point scale where the highest acquired point of 5 corresponds to grade A, point 4 corresponds to grade B, point 3 corresponds to grade C etc. Tool 4 - Students' opinion Likert's 5-point scale questionnaire sheet: It served to assess study group students' opinions related to advantages and disadvantages of PBL-FC and PBL as a teaching/learning strategy. It included eight items related to advantages of teaching/learning strategy and six items related to its disadvantages.

Results

Figure 2 shows the percentage of students' knowledge grades for PBL-FC and PBL groups. Based on the Chi-test conducted, it was observed that there is a significant difference of student' knowledge grades for both study groups (significant $p \leq 0.05$). The figure shows that a higher percentage of students obtaining A (16.7%) and B (36.7%) grades during the knowledge test for those who had undergone the hybrid PBL-FC format compared to those (A-grade: 10% and B-grade: 30%) who were undergoing traditional PBL. In terms of failure, students from the conventional PBL group register a 3.3% failure rate while there were none for the hybrid PBL-FC groups.

Figure 2. Relative comparison of students' knowledge grades for both classes (hybrid PBL-FC and pure PBL).



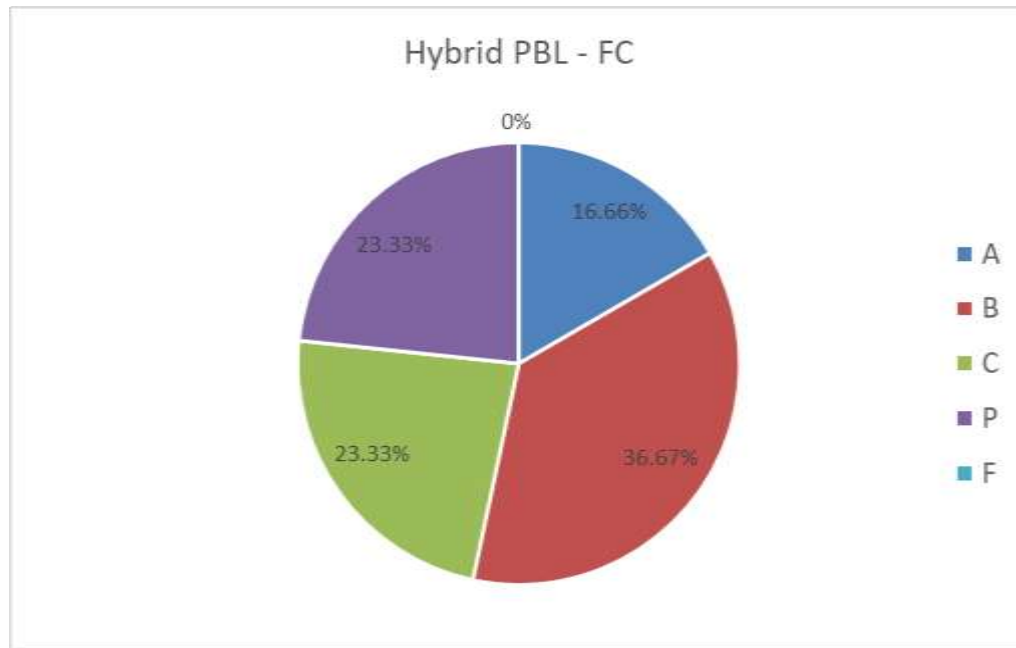
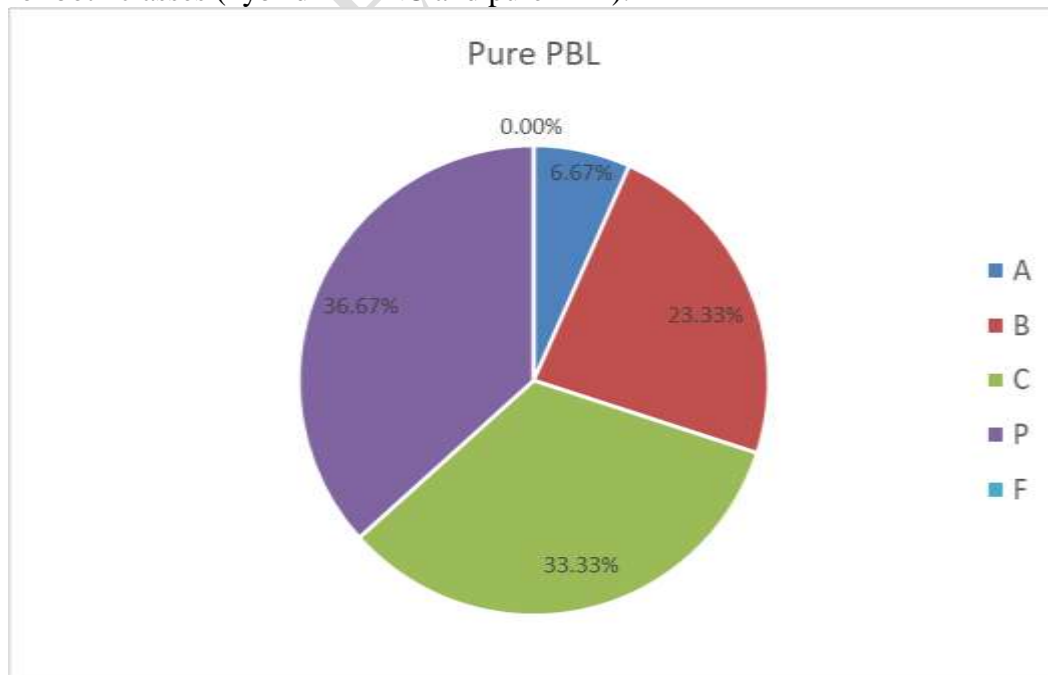


Figure 3 displays the relative distributions of students' problem-solving grades for both study groups. A significant difference of the students' problem-solving grades for both study groups (significant $p \leq 0.05$) was observed. The figure shows that a higher proportion of 46.7% achieved A and B grades for hybrid PBL-FC students while 30% acquired A and B grades for students undergoing pure PBL pedagogy.

Figure 3. Relative comparison of students' problem-solving scenario grades for both classes (hybrid PBL-FC and pure PBL).



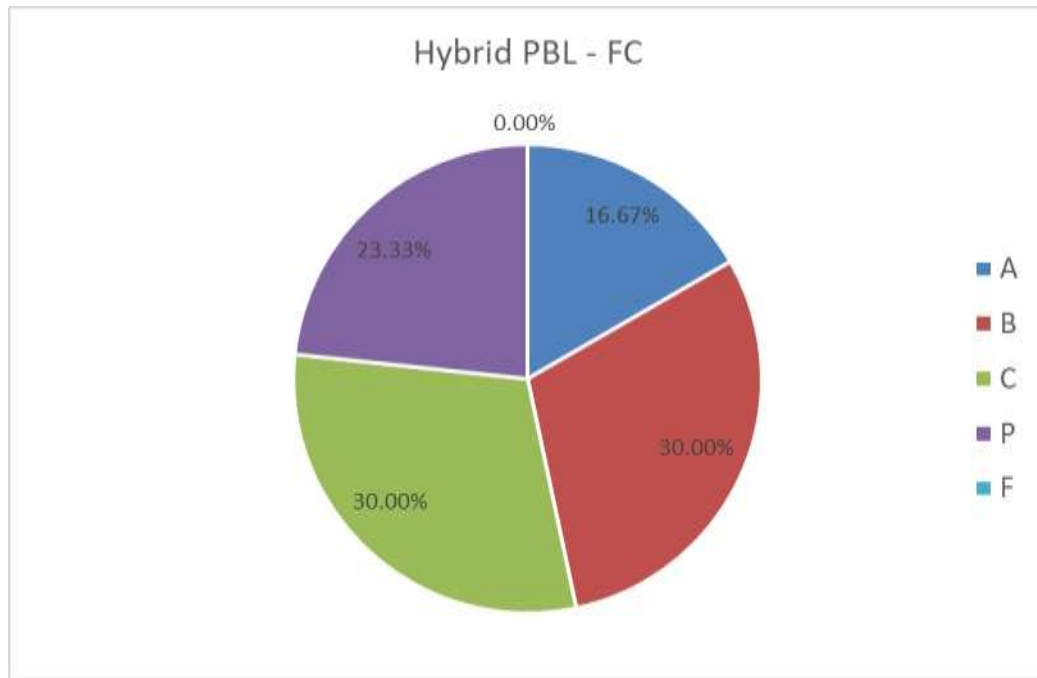


Table 3 shows the mean and standard deviation of knowledge, problem-solving skills, and project performance for both study groups (significant $p \leq 0.05$). There were significant statistical differences for all the items tested between the two study groups. The table further indicates that the highest mean was 69.3 for the prototype performance among students who are PBL-FC trained, followed by 66.8 for students who were undergoing traditional PBL. Other interesting indicators include the lowest mean values of 62.5 and 61.5 that were reported in connection to problem-solving skills for hybrid PBL-FC students and traditional PBL students, respectively. There was also significant difference between the knowledge mean test scores for both groups of students.

Table 3. Mean and standard deviation for knowledge, problem solving skills, and project deliverables

Characteristic	Hybrid PBL-FC groups		Pure PBL groups		df _T	t-test*
	M	SD	M	SD		
Knowledge test	66.23	5.45	63.85	5.32	58	24.53
Problem solving skills	62.45	5.67	61.48	5.45	58	28.45
Prototype performance	69.31	5.35	66.78	5.57	10	7.657

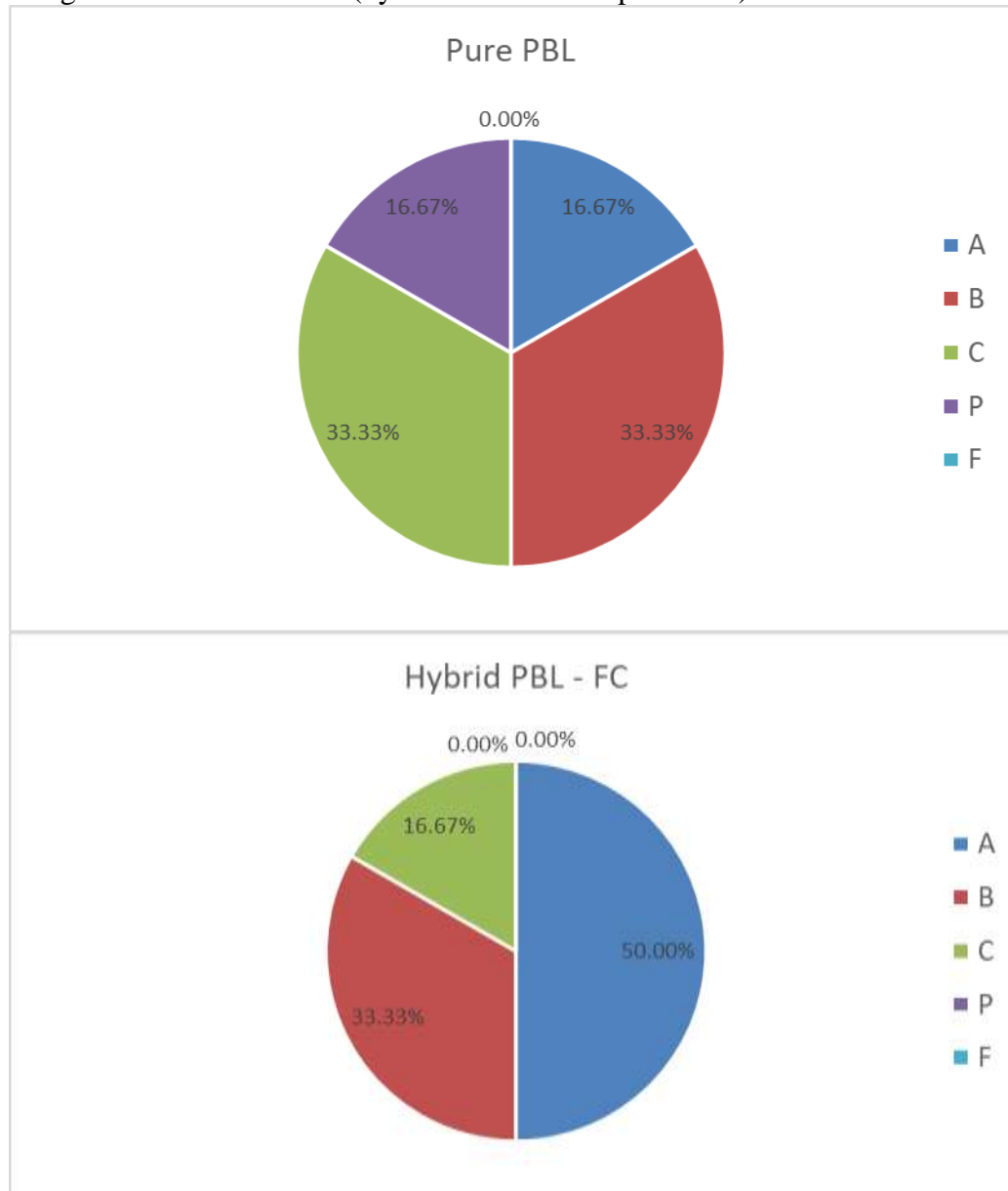
Note: p-value* < 0.05

After undergoing the PBL-FC program for a period of 7 weeks, a total of 6 air dryers were designed. Many unique prototypes were developed and fabricated. A few employed unconventional drying mechanism including the

1 rotational drying system, a few fabricated dryers using the counter-flow drying
2 method, while a few had dryer designs that combined different drying methods.

3 Figure 4 portrays the prototype performance results and the quality aspect
4 of the dried potato slices. Comparatively, a significant number of students
5 achieved A and B grades (83.3%) for the hybrid PBL-FC groups while the
6 percentage of students achieving A and B grades (50%) was much lower in
7 comparison for groups experiencing traditional PBL.

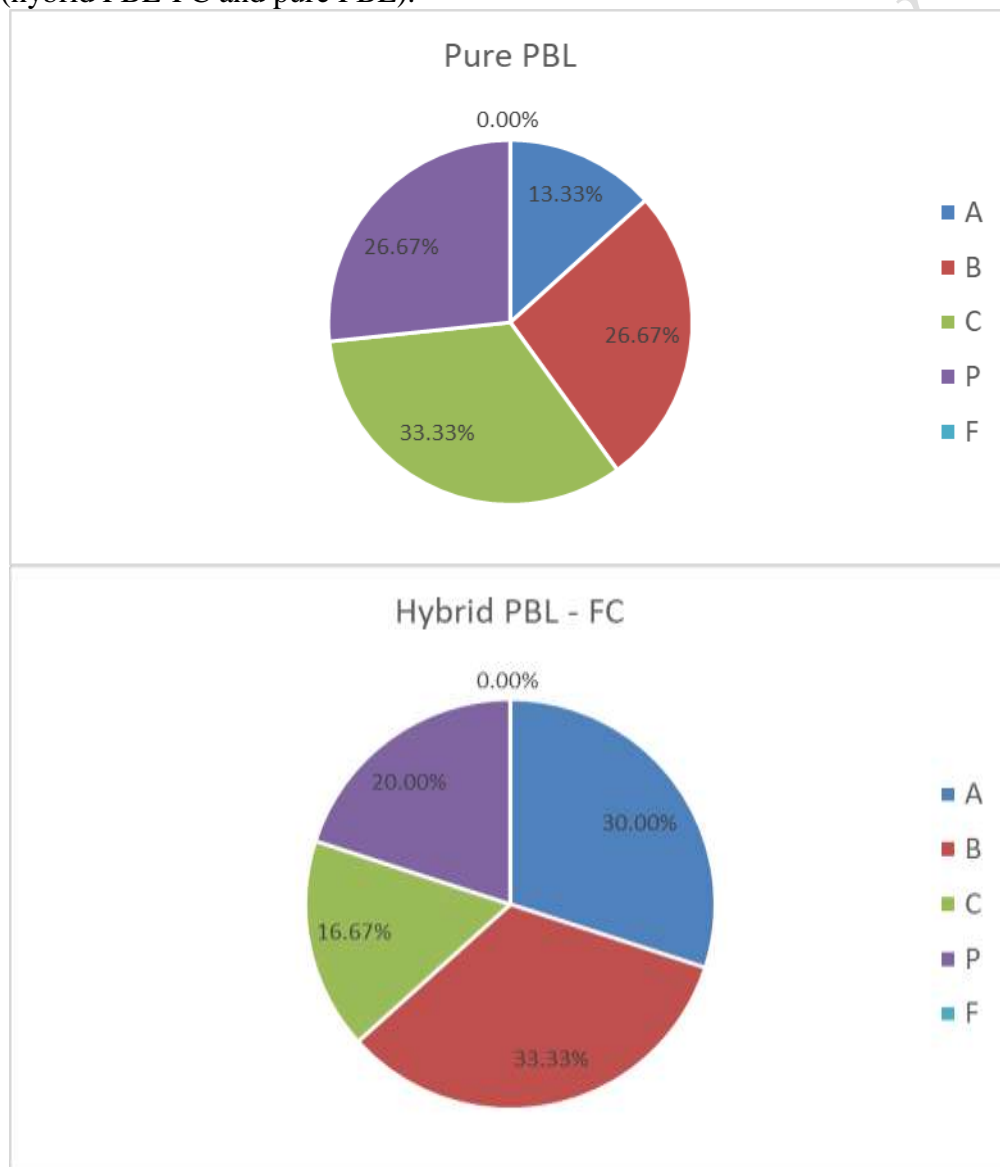
8
9 **Figure 4.** Relative comparison of students' prototype performance and quality
10 test grades for both classes (hybrid PBL-FC and pure PBL).



12 Towards the end of both PBL-FC and PBL facilitation methods, individual
13 scores were tabulated for all students, Figure 5 provides the final grades
14
15

achieved by students from both classes (PBL-FC versus pure PBL). It is highly indicative that the final outcome illustrated that students who were subjected to the hybrid PBL-FC learning process fared much better than students who were subjected to conventional PBL method (significant $p \leq 0.05$). It is apparent that up to 66.7% achieved A and B grades for the hybrid PBL-FC groups in contrast to 40% obtaining A and B grades for traditional PBL groups. This final outcome is not unexpected considering earlier results displayed in Figures 2-5 which had presented clear indicators on the students' performance.

Figure 5. Relative distribution of students' final design module grades for both (hybrid PBL-FC and pure PBL).



Tables 4 and 5 portray the Likert open-ended surveys of the percentages of students' agreements regarding their perceived advantages and disadvantages of the learning under conventional PBL and hybrid PBL-FC frameworks. It

was observed that 80% of the students believed that through the hybrid PBL-FC learning method, their problem-solving skill has been improved. 90% of the same group also indicated better ability to integrate knowledge to solutions. In addition, close to 74% of the PBL-FC students indicated that they had more time to participate in active learning sessions and benefited from them. Most importantly, about 93% of the PBL-FC students related a highly positive and wonderful learning experience after undergoing the hybrid pedagogy.

Table 4. Survey results of students' survey questionnaire on the advantages and disadvantages of hybrid PBL-FC groups (n =30) using the five-point Likert scale.

Description	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
<u>Advantages</u>					
Being motivated to learn	53.3% (16)	36.7% (11)	10% (3)	0% (0)	0% (0)
Enhancing critical thinking	46.7% (14)	40% (12)	6.7% (2)	6.7% (2)	0% (0)
Promotes problem-solving skill	50.0% (15)	30% (9)	6.7% (2)	6.7% (2)	0% (0)
Developing effective communication skill between students	46.7% (14)	36.7% (11)	10.0% (3)	3.3% (1)	3.3% (1)
Enhancing self-directed learning.	56.7% (17)	40% (12)	3.3% (1)	0% (0)	0% (0)
Better integration of knowledge to practical solutions	53.3% (16)	36.7% (11)	6.7% (2)	3.3% (1)	0% (0)
More time for active learning and better team working synergy among members	46.7% (14)	26.7% (8)	13.3% (4)	13.3% (4)	0% (0)
Overall hybrid PBL-FC provided a wonderful learning experience	66.7% (20)	26.7% (8)	3.3% (1)	3.3% (1)	0% (0)
<u>Disadvantages</u>					
Time-consuming.	10% (3)	33.3% (10)	30% (9)	16.7% (5)	10.0% (3)
Feeling stressed.	10% (3)	26.7% (8)	33.3%	16.7% (5)	10.0% (4)

			(10)		
Experiencing heavy workload	30% (9)	33.3% (10)	16.7% (5)	6.7% (2)	13.3% (4)
Having insufficient time to complete tasks	20.0% (6)	20.0% (6)	33.3% (10)	16.7% (5)	10% (3)
Spending too much time to look for materials	10.0% (3)	10.0% (3)	23.3% (7)	36.7% (11)	20.0% (6)
Causing conflict among students	13.3% (4)	30.0% (9)	33.3% (10)	16.7% (5)	6.7% (2)

1

2 **Table 5.** Survey results of students' survey questionnaire on the advantages
3 and disadvantages of Pure PBL - groups (n =30) using the five-point Likert
4 scale.

Description	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
Advantages					
Being motivated to learn	16.7% (5)	43.3 % (13)	20% (6)	10% (3)	10% (3)
Enhancing critical thinking	23.3% (7)	30% (9)	26.7% (8)	13.3% (4)	6.7% (2)
Promotes problem-solving skill	26.7% (8)	36.7% (11)	23.3% (7)	10% (3)	3.3% (1)
Developing effective communication skill between students	10% (3)	43.3% (13)	26.7% (8)	13.3% (4)	6.7% (2)
Enhancing self-directed learning	20% (6)	33.3% (10)	26.7% (8)	6.7% (2)	13.3% (4)
Better integration of knowledge to practical solutions	10% (3)	43.3% (13)	26.7% (8)	10% (3)	10% (3)
More time for active learning and better team working synergy among members	23.3% (7)	30% (9)	23.3% (7)	16.7% (5)	6.7% (2)
Overall traditional PBL provided a wonderful learning experience	10% (3)	30% (9)	33.3% (10)	16.7% (5)	10% (3)
Disadvantages					
Time-consuming	13.3% (4)	80% (24)	6.7% (2)	0% (0)	0% (0)
Feeling stressed	10% (3)	83.3% (25)	6.7% (2)	0% (0)	0% (0)
Experiencing heavy workload	16.7% (5)	79.7% (23)	3.3%(1)	3.3% (1)	0% (0)
Having insufficient time	6.7% (2)	83.3%	16.7%	3.3% (1)	0% (0)

to complete tasks		(25)	(2)		
Spending too much time to look for materials	6.7% (2)	86.67% (26)	3.3%(1)	3.3% (1)	0% (0)
Causing conflict among students	13.3% (4)	70% (21)	10% (3)	6.7% (2)	0% (0)

PBL-FC students innovated based on key fundamental heat and mass transfer knowledge that they pursued prior to each PBL studio session, enhanced by creative ideas generated through the use of mind-maps, analogies and round-table discussions. They developed a deep appreciation of these fundamental principles by simplify them through conducting stepwise experiments using reduced experimental models. In contrast, a number of dryer designs from the conventional PBL groups were rather one-dimensional, adopting a basic chamber tunnel-like design as the drying mechanism.

Discussion

PBL has been widely recognized as an active, collaborative and integrative learning approach that engages learners while focusing on practical-oriented education (Bergmann and Sams, 2012; Gibson, 2003; Mills and Treagus, 2003). Studies on PBL have highlighted its advantages including (1) PBL has a positive effect on student content knowledge and the development of skills such as collaboration, critical thinking, and problem-solving (Brush and Saye, 2008); (2) PBL induces key benefits by increasing their motivation and engagement (Krajcik, 1998); and (3) PBL enhances active learning because it simulates learning in real-world problems and makes students responsible for their learning (Hmelo-Silver, 2004). On the other side of the coin, studies conducted on PBL have also documented several distinctive disadvantages including (1) PBL requires a lot of time, particularly for first time students, to be provided to solve complex project problems (Grant, 2002). This often led to a lack of time available for the material/content; (2) Undergoing conventional PBL in a studio session can be quite an intimidating experience even for mature students and it may be even worse for beginners (Grant, 2002); and (3) Many successful PBL outcomes depends heavily on the success of cooperative or collaborative learning (Land and Greene, 2000). Students who are weak in experimental-based projects and ignorant of the methods needed to collect key project information will have trouble (Kurz F and Rath, 2004); and (4) Students who have difficulties interacting with their peers and knowing how to handle conflicts with the group will be greatly disadvantaged when undergoing PBL (Sumarni, 2014).

FC has the capability to address some of above-mentioned weaknesses of PBL. The freeing up active and peer learning time is the key to facilitate students in dealing with group discussions and group learning problems. In addition, FC enables more time for students to complete various stages of their project during each studio session by providing the quintessential online

1 learning tools for student to conduct out-of-class self-directed learning and
2 assessments.

3 Pivoting on the flipped classroom activities dimension, this design module
4 incorporated various participatory learning and learning-by-doing activities
5 such as knowledge sharing, brainstorming, round-table group discussions,
6 practical work, Q &A and presentations, in order to improve students' learning
7 effectiveness and cultivate diverse skills. Accordingly, one of the key findings
8 that this study has shown is that there were statistical significant differences
9 between students' basic knowledge and problem-solving grades between the
10 two sets of students participating in PBL-FC and conventional PBL. Having
11 more time for PBL-FC students to discuss problems in group activates relevant
12 prior knowledge and facilitates the development of new information that will
13 impact project outcomes. Results from the present study have also highlighted
14 that there were significant grade differences in terms of delivering the final
15 outcome of this dryer design project between the two groups of students (PBL-
16 FC versus PBL). More innovative and better performing artefacts were
17 designed and prototyped by students from PBL-FC groups. These observations
18 may be attributed to better techniques of acquiring relevant key knowledge
19 through FC and enhanced development of problem-solving skills through
20 enhanced active-learning PBL experience. Problems in design projects are used
21 to create a gap between existing knowledge and new knowledge in order to be
22 able to handle and manage problems adequately, and consequently guide the
23 self-study (Gijbels et al., 2005). The design of a FC framework to adequately
24 incorporate to PBL helps to bridge this gap faster and more efficiently;
25 enabling students to produce better project end-results.

26 The students' survey further indicates that up to 86.6% of the PBL-FC
27 respondents have opined that PBL module to have provided a wonderful
28 learning experience whereas only 40% of the pure PBL respondents evaluated
29 their PBL experience as being average or below average. According to several
30 PBL studies, there exist evidences that many PBL students potentially have
31 difficulties benefiting from self-directed learning without providing good
32 resources involving out-of-class technical-content related materials,
33 particularly when these content are necessary in complex projects (Bell, 2010;
34 Krajcik et al., 2008). By confining the engineering and mathematical theories
35 to pre-recorded video lectures provides the advantageous platform for highly
36 personalized learning experience, developing inquiry minds, and enhancing the
37 productive use of technology.

38 Even though the FC environment is supposed to encourage more student
39 engagement and increase student satisfaction. There have been instances when
40 the students in the FC did not score higher on many of the theoretical
41 constructs that the flipped environment was intended to help students to
42 accomplish (Burke and Fedorek. 2017). Facilitators of FC then need to
43 examine what went wrong and what corrective actions need to be taken for
44 subsequent classes.

45 It is noteworthy that the incorporation of a FC to any existing pedagogical
46 platform rides on the key assumption that students arrive to class well prepared

1 and ready to learn. By virtue of the fact that “flipping” the classroom enables
 2 students to keenly participate in active learning and engage in more
 3 unstructured learning and activities, the students must have deemed to have
 4 learnt the material prior to entering the class. Often than not, this is not always
 5 the case and students often arrive at class unprepared. A method of policing the
 6 pre-class activities is necessary. As far as this design module presented in this
 7 study is concerned, it comes in the form of online quizzes that the students
 8 have to partake after going through the online materials. And it is made known
 9 to the students that these online quizzes constitute a significant portion of the
 10 continuous assessment marks. Also, essential to the success of FC, is the
 11 resources that need to be furnished for students to conduct online research that
 12 is beyond the loaded online materials. A guided online resource leading to
 13 useful information that facilitates and develops students’ innovation and
 14 creativity can make the incorporation of FC to PBL a positive impact.

15 One other challenge of FC is that some students may logged into the
 16 online platform only to deliver assignments, observe others’ assignments, or to
 17 use other resources without spending much time reading the teaching materials.
 18 If these are being done, then the key objective of flipping the classroom would
 19 not be met. Hence, this aspect of the study requires further investigation. In
 20 addition, the roles of the FC-PBL facilitators are crucial to the successful
 21 outcome of this hybrid pedagogical learning. Facilitators need to be highly pro-
 22 active in encouraging students to lead discussions and participate in activities
 23 that generate ideas or solve problems related to the project. Further, they may
 24 explain the purpose of the flipped classroom to students and convey to them
 25 that they should be responsible for their own learning and the benefits of
 26 maximizing their classroom time to engage in learning activities through
 27 interactions and use of innovative learning tools such as mind-mapping, round-
 28 table discussions, engineering analogies etc. Also, the successful flipping of a
 29 project-based module depends markedly on synergy between teachers and
 30 students, and necessitates constant encouragement and guidance. It is
 31 imperative that students change their passive learning habits to become active
 32 learners during both off-class and on-class periods.

33 Nevertheless, the advantages of having incorporating FC to PBL are
 34 apparent which include: (1) a flexible environment during FC activities
 35 provided them with multiple learning vehicles and opportunities for learning-
 36 by-doing (Shih and Tsai, 2017), (2) opportunities to facilitate enhanced active
 37 learning sessions that are highly engaging to promote creativity and innovation
 38 in their final project delivery, and (3) enhanced linking of theory to practice as
 39 FC promotes active discussion and participation which is associated with
 40 improved learner attitudes and efforts to deliver best project outcomes.
 41 Therefore, students who also experience FC certainly possess key advantages
 42 over pure PBL students. It is, therefore, not unexpected that these PBL-FC
 43 students are more receptive of PBL and are able to relate to a more positive
 44 PBL experience.

45

Conclusions

This study employed an array of research methods to investigate the perceived effectiveness of FC-PBL from the standpoint of students' cognitive, innovative, and skilled learning. Qualitative and quantitative analyses were implemented and the salient findings that have emerged from this hybrid PBL-FC vis-à-vis PBL study include

- (1) Analyses, quantitative and qualitative, have indicated a significant increase in fundamental formative knowledge; enhanced problem-solving abilities; and production of better performing artefacts with regards to the set of design skills for students undergoing hybrid PBL-FC compared to pure PBL.
- (2) Likert open-ended students' survey responses have conveyed an overall positive students' perception of the PBL-FC approach, and qualitative analysis has shown apparent evidence of students' efforts to conduct pre-class self-directed online learning and to actively and deeply participate enhanced in-class interactive learning.
- (3) Through PBL-FC, students have realized the importance to have sufficient time for active-learning through discussions, group interactions and ideations when dealing with a large-scale project.
- (4) Last but not least, students have endorsed the fact that the PBL-FC approach has made their learning a positive experience as they better equipped to address the challenges of exploring unfamiliar technical fields and carve out their own unique project solutions.

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