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Integrated project-based learning (IPBL) implementation for first year chemical engineering student: DIY hydraulic jack project

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ABSTRACT

Implementation of student-centered learning has shown wide global acceptance within institutes of higher learning. Some methods, such as active learning, project-based learning, problem-based learning, and experiential-based learning, have significantly impacted the students' understanding of a particular subject. However, students will still have problems integrating the materials learned from one course to other courses. Thus, this is where the proposed initiative comes in. This paper discusses the implementation of integrated project-based learning (IPBL) to assist students in integrating the knowledge gained from one course to the other for first-year chemical engineering students of Universiti Teknologi PETRONAS. The mapping of assessments and learning domains to the learning activities are also shown in detail. This study was conducted on two courses offered in the same semester, namely, Principles of Chemical Engineering and Chemical Engineering Fluid Mechanics, in January 2019. A total of 214 students grouped in 43 teams were asked to develop a Do-It-Yourself (DIY) hydraulic jack, which uses the fundamentals taught in these two courses. The results show that 100 % student was able to come up with a working prototype within 5 weeks and 90 % of the students agree that the initiative increased their understanding in chemical engineering fundamentals and developed their leadership, problem-solving, communications and time management skills.

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1. Introduction

Standard STEM programs are typically offered to students through a series of courses that need to be completed in 4 years. Knowledge is imparted to the students in courses for a better understanding of the overall program. In the chemical engineering discipline, the courses were taught separately to have more focus within each intended course, such as separation, reaction, fundamentals, control, and safety. This was necessary to equip the students with an in-depth knowledge of the fundamentals in a sequential manner. Conventionally, the program requires an individual project or a team project to be given to the students. It was expected for the students to complete it and send in a report to the instructor. However, a recent trend in academia showed project-based learning and problem-based learning as alternative approaches for the projects. This initiative can be seen in subjects such as process control (Yusof et al., 2012), separation process (Calvo and Prieto, 2016), design project (Vega and Navarrete, 2019), unit operations and modeling and simulations (Ballesteros et al., 2019), reaction engineering (Azizan et al., 2018), and introduction to engineering (Sadikin et al., 2019).

However, a problem that can be seen in this approach is the failure to integrate the learning materials from one topic or course to another. Several methods have been proposed over the years, such as open-ended problems, problem-based learning, case studies, cooperative learning, and class debates (Hung et al., 2008; Hamouda and Tarlochan, 2015). Although there is still inconclusive evidence on which approach is most suited for enhancing critical thinking skills, addressing this issue only within individual courses would limit the students' time to gain other critical skills (Huber and Kuncel, 2016).

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To address this problem, it is proposed that integrating two or more courses to formulate integrated projects would help to facilitate critical thinking skills without compromising other crucial technical skills. In this study, integrated projects that combine two engineering courses were introduced. The courses involved were Principles of Chemical Engineering (PCE) and Chemical Engineering Fluid Mechanics (CEFM) with a cumulative total of 6 credit hours. This initiative was introduced to 214 students in the January 2019 semester. This approach was initiated to the first-year students to give an early exposure to connecting the knowledge between the courses.

2. The course

2.1. DIY hydraulic jack

An integrated project of developing a Do-it-Yourself (DIY) hydraulic jack was proposed to assess the students' ability in integrating the knowledge gained from the two courses. A hydraulic jack uses Pascals' principles whereby a pressure exerted on any part of a liquid in a closed system will be transferred omnidirectionally and equally throughout the fluid. A standard jack uses an external force. Usually, a mechanical force is exerted on a lever or a diaphragm. However, in this DIY hydraulic jack, the student should be using a chemical reaction to accumulate the pressure for the hydraulic jack to work. The aim was to design and commission a prototype with a sturdy design that can lift a 500 g load vertically and safely. This demanded the students to use the knowledge of PCE in aspects of reactive mass and energy balance calculation, selection of chemical reaction, ideal and non-ideal gas law, and pressure-volume-temperature (PVT) relationship in order to determine the amount of pressure being exerted by the chemical reaction. On the other hand, the CEFM course supplies the students with knowledge on the selection of hydraulic fluids, whether it is a compressible or incompressible fluid, and the detailed calculation of Pascals' principle, which is crucial to determine the pressure generated on the other side of the hydraulic jack. The solution is kept open-ended as the students are free to choose their chemical reactions and type of hydraulic fluid to come up with their own design to deliver the best outcome.

It is also a requirement for the prototype to be safely operable. The design is suggested to incorporate safety features such as waste streams or a venting line to accommodate the excess pressure in the reaction chamber. This simulates the purging line or relief valves that they encounter in the PCE course. The students were also encouraged to craft the device using recyclable items. The total overall operation and assembly of the prototype should not exceed MYR 50.

2.2. The challenge

In this project, the students are challenged to determine the best chemical reaction to generate the lift and stop the chemical reaction when the maximum height has already been achieved. Any emission of liquid or gas needs to have a proper discharge line and containment device. This requires some data collection and analysis to determine the best concentration and volume of the reactants. After the demonstration, the student would have to submit a report explaining the device's technical aspects. The calculations related to CEFM and PCE needs to be presented to show that they can relate the theoretical knowledge to the actual application. The principles used must portray their understanding of the two chemical engineering disciplines and show the continuity between the courses. Their capability, imagination, innovation, inspiration, and teamwork were assessed based on their team performance.

By doing the calculations and actual prototyping, the goal is to allow the students to see the application and integration of knowledge in their learning experience. The project will contribute to 6% of the students' overall marks in both the PCE and CEFM course.

3. Methodology

3.1. Approach

3.1.1. Project planning and classroom management

Discussion among the instructors at the early stages of the semester is crucial in ensuring a smooth project execution. The discussion includes a detailed summative assessment plan for the whole semester, i.e., to have a plan for the project that will be executed by the students. This also allows the instructor to plan their time well for other academic activities in that semester. This approach's project activities include team formation, project briefing, problem statement and restatement, consultation with the instructor, demonstration, project report submission, self-reflection, and an exit course survey. These activities were scheduled in a way such that students will have a fully immersive learning experience for that semester. The sequence and mapping of assessment and learning domains in the project are shown in Fig. 1.

Fig. 1 shows the mapping of learning domains and assessment type to the respective learning activities. Team formation was conducted at the beginning of the semester, as the same team will be used for any further team-based assessments in the classroom. This allows for team dynamics to take initial form, as the students start to become accustomed to one another as teammates. Students were required to answer 20 online questions to assess their personalities. The personalities were divided into 4 types of birds, namely Dove, Owl, Peacock, and Eagle; hence it was called a DOPE personality test, which was available online https://richardstep.com/. Dove's personality traits portray those who are steady, patient, and accommodating, representing a good and contributing team member. In comparison, Owl's personality leans towards being more analytical and systematic in task organization. The Peacocks are representative of those who are enthusiastic and optimistic, and Eagle represents those who are firms, go-getters, and dominant (Stephenson, 2012). Students were then required to fill up a form to inform the instructor of their top two personality traits. Each team requires a representation of all the qualities in each personality trait to be a high-performance team. The instructor would then be assigning the teams based on the student's personality, academic performance, and gender. These steps were conducted to avoid bias and ensure even team distribution to promote an environment for the students to have a meaningful learning experience.

Students were given an overview of the project and the rules and regulations they must follow during the project briefing. A working prototype sample was shown to the students physically, and the students could ask questions regarding the design consideration. However, since the briefing venue does not allow a chemical reaction to be conducted, a video was shown to the student to assist the student on the prototype's working principles. All parts of the design and components were explained, and some other design considerations were also discussed. In the problem statement and restatement phase, students were required to submit a restatement of the problem to gauge their understanding of the key deliverables expected from them. Students need to identify the possible chemical reactions, type of fluids to be used, and roughly determine the designs.

Students were allowed to explore all options during the project consultation phase as long as it is within the rules and regulations. Consultation can be done with the instructor on a face-to-face

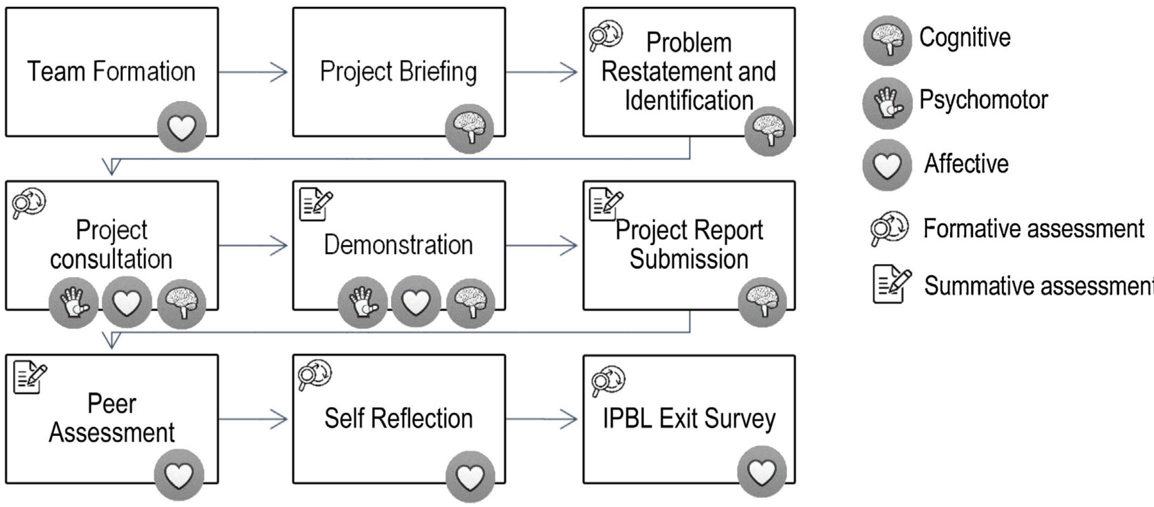


Fig. 1. Assessments and domain mapping to the learning activities.

basis or through telecommunication via phone or instant messaging apps. The objective for this phase is to ensure the students are able to make sound judgments on their DIY hydraulic jack prototype design. This challenges their cognitive skills in addressing the principles and calculations involved in the designing stage. Apart from that, this also engages the students' psychomotor skills, as their coordination fluency is tested in assembling and operating the DIY hydraulic jack. The affective domains were also assessed through how the students take ownership of their design, sense of belonging to the team, and the safety precautions in handling the chemicals and tools to assemble their prototype. For the consultation to be efficient, the student would typically seek the instructor's advice on their proposed solution. During the process, the instructor's role was to probe on the proposed design's technical feasibility. This was conducted to scaffold the student idea to be more reliable and workable model. The process is repetitive, and student by the end of the project, it was hope that the best version of the original idea can be achieved.

In the Demonstration and Project Report Submission stage, students were asked to explain their DIY hydraulic jack in terms of the chemical reaction used, their volume and concentration, the working principles, and the prototype's safety features. Students were required to show detailed calculations wherever required to justify the assumptions made. They were given 15 min for the presentation and demonstration and another 5 min for the following question and answer session. Since both phases used summative assessments to gauge student understanding, rubrics and marking schemes were given to the students before the assessments were conducted.

Students were given a chance to anonymously express their opinion towards other team members in the peer assessment phase. This is to provide a safe environment for the student to share their view of other team members. Students were also tasked to mention some appreciative and constructive feedback for each of their teammates. Details in peer rating and assessment are discussed in detail in the next topic. Meanwhile, for the self-reflection, students were expected to write a short reflection based on Gibb's reflection cycle to reflect on their actions during the IPBL implementation. This includes their decision-making, behavior, and things they wish they could have done better in design during the IPBL implementation. This step can also give a better understanding of the students' thinking process and their affective domain's maturity level. Finally, the IPBL exit survey allows the students to rate the project in several aspects such as project implementation, the initiative impacts on the soft skills such as communications skills, leadership, critical thinking, problem-solving, and time management. The Gantt chart on the implementation of the IPBL is shown in Table 1 below.

3.1.2. *Peer rating and peer assessment implementation*

Students were given a chance to give individual evaluations for each of their team members based on their contribution to the project. The ratings were in a qualitative term, whereby each term was describing the performance. A total of 10 terminologies with their respective descriptions were explained to the students to be used to evaluate their teammates' performance. The qualitative description of the team member's performance reflects the quantitative value. On this approach, qualitative peer assessment was done formatively for the student to give their feedback on their teammate's performance. The submissions were individually made via Microsoft Forms. Next, the qualitative ratings were converted to quantitative analysis, whereby weightage was given for each terminology. The conversion was made by assigning marks to each terminology and converting it to a quantitative value. For example, the term 'Excellent' signifies 1 mark while 'Marginal' represents 0.4 marks, and 0 marks were given for 'No Show'. Once the conversion was made for all terminologies, they are analyzed using the Autorating method (Brown, 1995).

The Autorating method awards the students' C-factor, which determines the students' weightage for the project. This step was crucial to isolate the free riders from the ones who are putting in the effort to deliver the project. Two types of averages were calculated from the quantitative analysis: individual average (Ai) and team average (At). The average team value calculates the team's average performance based on all the member peer rating score; meanwhile, the individual average is the average peer rating score marks gained by an individual student. The c-factor was calculated by dividing Ai over At (Ai/At), and it ranges from 0 to 1.05. An additional 5% was given to those who performed better than the team average. In the case of a student gaining more than 1.05, the marks are normalized to 1.05. The method can give a clearer picture of how the team operates.

3.2. *Pedagogical framework*

3.2.1. *Integrated project-based learning*

Project-based learning has shown great potential in addressing several skills such as critical thinking and problem-solving.

Table 1
Gantt Chart of IPBL implementation.

Learning Activities	Week						
	1	5	6	7	8	9	10
Team Formation	X						
Project Briefing		X					
Problem Restatement and Identification		X					
Project consultation			X	X	X	X	
Demonstration						X	
Project Report Submission							X
Peer Assessment							X
Self-reflection							X
IPBL Exit Survey							X

Application of knowledge is the distinguishing factor between project-based learning to problem-based learning. As project-based learning demanded a working model or prototype to be demonstrated at the final assessment, this allows the student to apply the knowledge hand-on the prototype (Guo et al., 2020). As the route for knowledge creation between problem-based learning and project-based learning is quite different, the students should be developing a different skillset. Problem-based learning focuses more on the cognitive and affective domain in coming out with a workable solution to the assigned problem, while project-based learning leaning towards active construction of knowledge via hands-on experience (Krajcik and Shin, 2014). This creates more room for creativity and experimentation as the student is able to test their ideas on a working model. Apart from learning things that work in a system, student indirectly is exposed on methods that are technically not feasible.

The Project-Based Learning approach was considered for this project due to the nature of the content needed to be delivered. It began with students brainstorming about the design and concept of the projects (Bell, 2010). In this approach, the content was revealed first to the student to use later in delivering the required works. It is an application of knowledge rather than an inductive method of teaching. The students were given sets of rules and were asked to follow them strictly. This was done to ensure student safety since it involves the use of commercially available chemicals. Peer teaching and in-class discussion were held several times to check the students' progress and understanding of the project. The students were also briefed on the demonstration protocol and the content needed to be presented in the report. The fundamental principles in this project-based learning are the students' demonstration skills, inquisitiveness, and imaginativeness. Students would need to demonstrate to the public their work. In developing the prototype, students will be subject to thought-provoking questions to incentivize creativity in their design. Integration of knowledge was made visible to the students by carefully constructing the problem, which can accommodate the application of both knowledges from PCE and CEFM. The final report also required the student to write a chapter on their perspective of the knowledge integration, which will be discussed later in the result and discussion

The project intends to address one learning outcome from each course. For CEFM, the students should be able to describe and calculate the fluid flow application of a given system. Meanwhile, for PCE, the students are required to be able to define and analyze the conservation of mass and energy for a given process.

3.3. *How people learn framework application*

In crafting the problem, the How People Learn (HPL) Framework was referred. The four lenses were used to assess the problem's feasibility (Bransford et al., 1997). Four lenses, namely the learner, knowledge, assessment, and environment centered lenses, are used in crafting the problem. These lenses are critical in crafting a feasible and realistic problem to be solved by the students. The student should have a basic knowledge of the project and have available material to look for more information on the web or books. The measurement tools should be aligned with the project's intended outcome, and the environment has to be supportive of the project's completion. Several projects that have succeeded in embedding the HPL framework in their practices include cooperative problem based learning in process control and instruction to engineering courses (Mohd-Yusof et al., 2012, 2015; Mellon et al., 2017)

A learner-centered lens considers the student's prior knowledge and the student's context in perceiving a problem (Bransford et al., 1997). From a general knowledge standpoint, chemical reactions such as one between carbonated water and salts can be used to generate pressure. This pressure can be used to move certain mechanical parts in a machine. However, given that the student has to control the chemical reaction and take into consideration several factors such as the amount of pressure being generated from the reaction, the load to be lifted, and the friction between the mechanical parts, it would be a challenge for them to finish the tasks to a certain standard.

Knowledge-centered lenses see the problem from the required content that the student can achieve by completing this project (Bransford et al., 1997). The students need to know and apply the knowledge of reactive mass balance calculations in PCE to determine the amount of gas being generated from the chemical reaction. They would also have to control the limiting reactant so that the reaction can be controlled using precisely the right amount of chemicals. Furthermore, in CEFM, the students will have to apply the knowledge of compressible and incompressible fluids and connect it to Pascals' principle to calculate the force being applied to overcome the load's weight.

This project allows the students to deliver the task with a proper understanding of the working mechanism behind the DIY hydraulic jack through the assessment-centered lens. The project outlines two learning outcomes, one for each course whereby the student will be assessed during the demonstration and report submission. Meanwhile, the community-centered portion allows the student to discuss with the instructor to discuss the device. They can have a technical discussion with the instructor, whether it is an in-class or out-of-class discussion. Social media platforms and instant messaging apps were also used to give the student access to ask any question at any given time about the project expectation and seek technical consultation.

4. Results and discussion

4.1. *Team formation*

For the January 2019 semester, 214 students were enrolled in both PCE and CEFM courses, whereby the semester lasted for 12 weeks. Student profiling and personality test were conducted

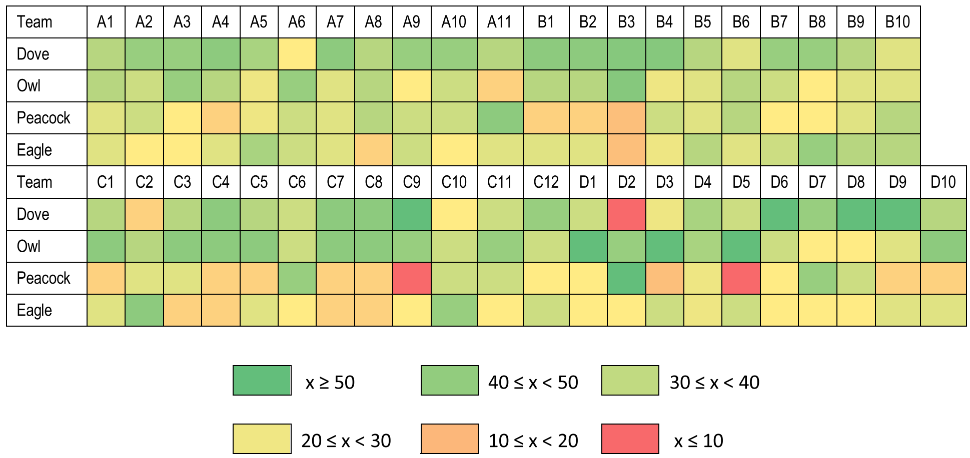


Fig. 2. Students' Personality Grouping Distribution.

before the team formation was done. For the semester, 43 teams were formed with 4– 6 members per team.

Fig. 2 shows the primary and secondary DOPE personality trait distribution across all 43 teams. Overall, the distributions are balanced with almost all of the teams consisting of more than 25 % of all the DOPE personalities, except for team D2, which lacks a Dove, and C9 and D5 teams did not have a Peacock in either team. Based on the analysis, team D2 scored the highest with 91.6 % marks in the demonstration assessment. Their presentation outline and flow are well prepared and delivered. This tallies up with their personalities, consisting 50 % of the Peacock personality trait who were useful in communicating ideas verbally and presenting the works. Meanwhile, a similar trend was observed in teams C9 and D5, where the teams scored relatively low in the demonstrations. However, the teams did very well in the report writing, where both teams scored marks of 90 % and 91 %, respectively. This shows that they can connect the knowledge and communicate better in writing. It is also noted that the 3 teams described above comprised 12%– 25% of members with an Eagle, which are good at directing the project progress and take action in leading the team.

It was seen that most of the students were more inclined to be detailed, methodical, hard-working, cautious in their decision making, and possess a generally introverted characteristic. Thus, this project was considered very suitable for them since they would have to be more outspoken to teammates, be vocal in the discussion, conduct chemical tests, and learn to become tolerant of one another. Only less than 20 % of the students have the Peacock as their primary personality trait, thus the students were noted to have problems in their presentation and demonstration. The distribution also shows that only 18 % of the student possesses the primary attributes of an Eagle, which are the dominant types within a group. The lack of Eagles in the teams was noted to induce an environment of slower decision making. Without an actual team leader to give proper direction, the teammates will have tendencies to become lost.

This is where the instructor is advised to distribute the character traits more evenly among the team members. Too many Eagles can cause the team to be too aggressive in their team dynamics, while too many Doves can cause the completion of a project to become too slow.

A good team dynamic may lead to students performing better than individuals. This project allows vigorous physical and mental interaction between the students. As the student argues to solve the project, they exchange ideas and opinions to develop the best solutions. Having a level of respect and responsibility to other teammates has been inculcated along with the project's duration, as shown in the reflection given below. Moreover, students can make new friends and discover themselves in the process.

> *"This was a very good experience to me because it let me to make new friends, discover my strength and weakness and learn how to apply what I had learned in my daily life. Through this project, I realize that everyone in group has to play their role responsibly and even to be punctual. We cannot be just waiting for others' order, but also have to give our own opinions."*

4.2. Project delivery

The project briefing was given in week 5 of the semester, and the project commences at week 6. The students were given 4 weeks to complete the project prototype and submit a report via the Schoology platform. During the briefing session, all of the intended learning outcomes and marking rubrics were shared with the students. Along with the duration of the project, teaching and learning activities were run as usual. However, once a week, the instructor would open for a 10-minute in-class discussion to check on the students' progress. Students would often share their DIY hydraulic jack assembly progress and trial run data to the instructor. Feedback was given on how to improve the design and make it more applicable, stable, and efficient. This step shows the students' creativity in designing their prototype. Seeking feedback is also an indicator that the students are learning from experience. This falls right into the community-centered lens in the HPL framework.

As for the demonstration, students were given 7 min to present their prototype, another 8 min for the demonstration, followed by another 5 min of a question and answer session. The questions asked were designed to check the student's understanding of each component in the design. The student would have to justify their type of fluid used in the hydraulic system, the chemical reaction used, and materials to construct the device. A week after the demonstration, the report was due. Students would have to portray their understanding of both subjects in the reports. Proof of calculation and decision making has to be made visible in the report in order for them to obtain high marks. Fig. 3 shows samples of students' works during the presentation and demonstration.

4.3. Peer rating and self-reflection

The distribution of the c-factor of the students is shown in Fig. 4. The data shows that 37.85 % of the students obtained a c-factor lower than 1.00, which means they are underperforming based on their teammates. Meanwhile, 46.85 % of the total students contributed well in the discussion and performed above

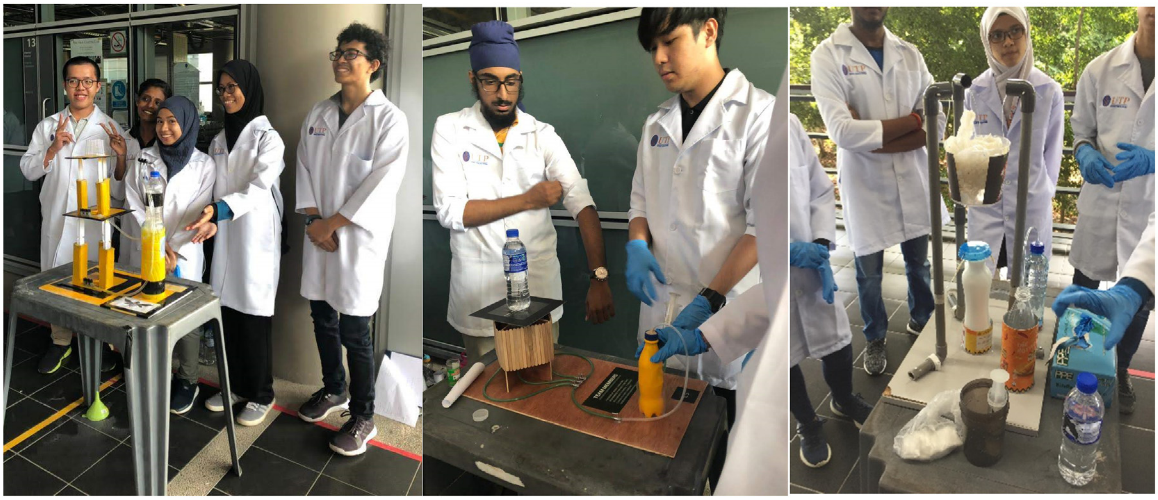


Fig. 3. Students presenting and demonstrating the DIY hydraulic jack.

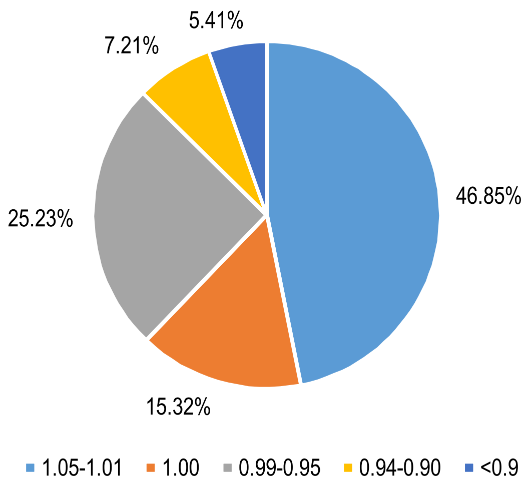


Fig. 4. C-factor distribution.

their teammates' expectations. Students were reminded to rate their teammates fairly and professionally to impart some sense of accountability to the student. It has been reminded that their action and reaction during the IPBL implementation will be reflected in the marks. The c-factor approach has been explained to the student clearly on several occasions, such as the project briefing, in class discussion, and during the concluding remarks after the instructor's demonstration.

Individual reflection was also performed at the end of the project. Using the Gibbs reflection cycle, the students were guided on how to reflect based on their actions and decisions throughout the project (Gibbs, 1998). After a thorough analysis of the verbatim, student reflection can be clustered into three categories: team dynamics and performance, trauma cycle, and technical awareness. Students could reflect on their time management, decision-making, team play, and leadership roles for team dynamics and performance. Their reflection shows that they were aware and conscious of the learning process happening around them. One reflection by a student below mentions that the learning experience can improve their interpersonal skills and care for the team members deeply on learning the materials.

"this integrated project had taught me to cooperate with different kinds of people, more than it taught me the science behind what we're learning. Frankly, I think that it is nevertheless a treasurable lesson for me as it improved my interpersonal skills. In honest words, I admit that this is the first time I ever cared of my peers to have a good grasp of what they're learning. Particularly, the in-Class Team Challenge and the Team Quiz made my learning easier, less stress, and more fun since I'm making stronger friendships".

Another interesting observation in the reflection was on the trauma cycle. The students initially thought the project was straightforward due to the availability of online resources. However, later they realized that the actual assembly was more challenging than it looks. It was an eye-opener as the student learned that several trial and errors had to be done to complete the project as shown in the reflection below.

"I was thinking that it shouldn't be that hard to complete the prototype as I've surveyed ways to build a hydraulic jack prototype on Youtube. Truth to be told, it wasn't an easy journey where there were leaks and we had to do trial and error many times in order to get the right composition".

As for technical awareness, the students were able to pinpoint on how to improve their design. This reflection was taken one week after the project completion. This shows that the student is still thinking about the project even after submitting it. The student even proposed a new mechanism to optimize the device's performance, as shown below.

". . .one thing I figure out that can improve our prototype when I was writing the report is that we could have capture the excess gas by any means so that our system become a closed system and mass is conserved. The excess gas harnessed can be used to power other sources so that wastage is as low as possible."

4.4. Course exit survey

Table 2 and Fig. 5 show the course exit survey questions and the students' responses, respectively. The questions asked were reflective of the project's intention apart from achieving the technical understanding of the project. 196 out of 214 students responded to the survey which totals up the response rate to 91.59 %. On average, 90 % of students agree that the project managed to enhance their understanding of chemical engineering fundamentals. Students also agreed that this project allowed them to polish their communication skills, time management skills, leadership, team player skills, and respect others' opinions in a professional discussion. Note that only 73 % of the student agrees with question number 8 by saying that the project time allocation is sufficient.

Table 2
Detailed question of course outcome survey.

Question number	Description
1	The project has helped me to relate on the fundamental and application of knowledge to the actual practices.
2	The project has further enhanced my understanding on other chemical engineering knowledge
3	The project has helped me to strengthen my technical skill to solve chemical engineering related problems
4	The project has helped me to enhance my soft skills (e.g. communication, leadership and decision making)
5	The project has helped me to sharpen my teamwork/leadership skill and the ability to work in a team
6	The project enhance my time management skills and be respectful towards others time also
7	The project thought me to respect others opinion and discuss the topic in an academic manner
8	Time allocation for the project is enough.
9	I would recommend the project to my juniors
10	The project is time consuming but it was balance out with only 1 project were required instead of different project for each subject
11	The complexity of the problem is just right for a team of 4–6 person
12	The number of team members (4– 6 person) is just enough to prevent any sleeping partner in solving the problem
13	Team members strength and weakness is evenly distributed
14	Application of integrated project and cooperative learning enhanced my learning experience and learning skills.
15	The implementation of the project is smooth with clear direction by the coordinators and lecturers

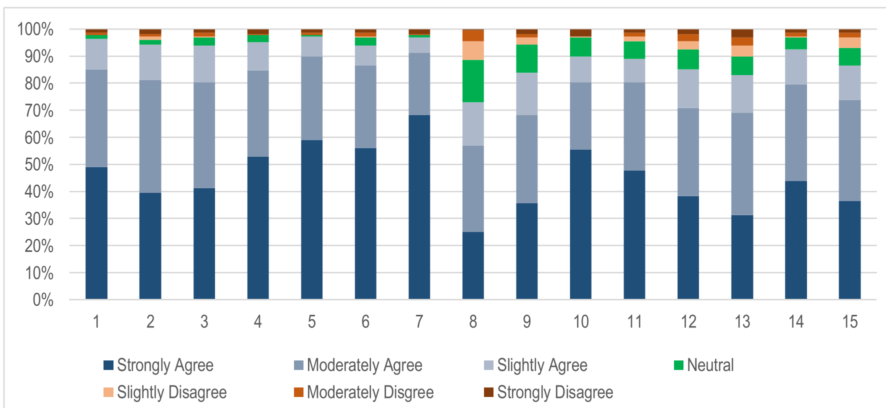


Fig. 5. Result of course outcome survey.

However, upon reading the reflection, it was also likely that the students lacked time management skills. This also can relate to the students' personality as shown in Fig. 2. Most students tend to have a very careful thought process and progress at a steady pace. This project also taught them to be more proactive rather than to wait for instruction.

Throughout the consultation phase with the students, it can be seen that the students have shown creativity in the process of designing their best prototypes. As seen in Fig. 3, some of the students also took the challenge of implementing a two-tier design, in which their chemical reaction was made to support a two-story hydraulic system. It shows that the students are willing to put in the extra effort to deliver the best system design. This action also demonstrates that IPBL implementation utilizes the student cognitive and psychomotor domain in learning and manages to have an impact on the affective domains.

Another example that can portray the students' problem-solving skills was in the selection of the hydraulic fluid. Initially, the student would be manipulating the amount of gas and pressure released by the chemical reaction in the reaction chamber to lift the jack. However, the forces needed for this is exceptionally high since gas is a compressible fluid. After the consultation with the instructor, it was advised that the team use an incompressible hydraulic fluid to transfer and amplify the forces exerted by the gas. The team made some adjustments to the hydraulic and piping system's design to accommodate the modifications and performed well during the demonstration. Some students also went the extra mile by using vegetable oil instead of tap water for the hydraulic fluid to allow for smoothness in the syringes system in lifting the required load. It may seem like a logical idea to begin with, but for some of the students, the sense of satisfaction in solving the problem themselves was gratifying. Some examples of the students' self-reflection regarding the design process are given below.

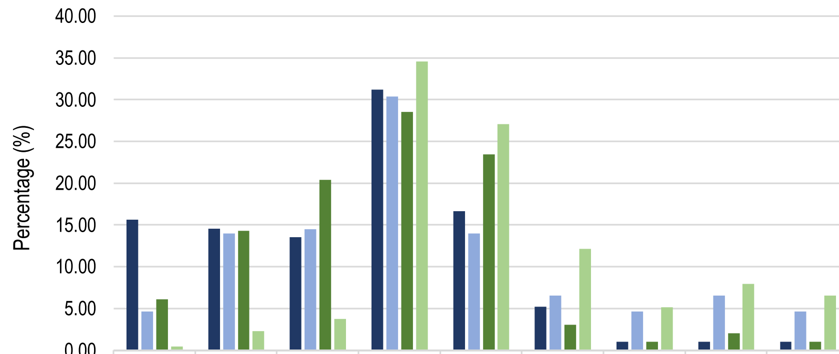
> *"A good experience I had was solving problems as a team. The satisfaction of overcoming failure together felt good. In the last couple of meetings, our prototype started to have problems. We assumed some syringes had lost its friction, causing the unequal lift issue.. . . If there was one thing I could have done to improve my performance, it would be to come up with a better design. Looking at other groups' prototypes, it made my group seem like we put minimal effort, when we just genuinely thought ours looked neat enough. It impacted our confidence, and it made me wish that we spent more time on making it more attention-grabbing."*

> *"My team and I decided to do a minimal yet efficient design to get the best out of what we had. Initially our problem was finding a design that could provide the maximum lift and stability. Despite coming up with complicated ideas, we decided to go for the simplest one and made sure the execution was perfect. To validate all our efforts, the prototype we came up with was satisfactory and near flawless."*

These examples show that the students understood what was demanded of the project and what it indeed took in delivering the best prototype of the DIY hydraulic jack.

4.5. Integration of knowledge

It is very important that students realize this initiative's intention, whereby integration of knowledge is key to solving the problem given to them. Thus, a dedicated chapter in the final report



	A	A-	B+	B	C+	C	D+	D	F
PCE FE Sept 18	15.63	14.58	13.54	31.25	16.67	5.21	1.04	1.04	1.04
PCE FE Jan 19	4.67	14.02	14.49	30.37	14.02	6.54	4.67	6.54	4.67
CEFM FE Sept 18	6.12	14.29	20.41	28.57	23.47	3.06	1.02	2.04	1.02
CEFM FE Jan 19	0.47	2.34	3.74	34.58	27.10	12.15	5.14	7.94	6.54

Grade

PCE FE Sept 18 PCE FE Jan 19 CEFM FE Sept 18 CEFM FE Jan 19

Fig. 6. Comparison of Student Performance of January 2019 and September 2018 semester students.

was assigned to gauge their level of understanding and ability to integrate the knowledge. Referring to the report, one team explain their taught process in detail as below.

> *"The basic idea of the hydraulic system was a device that used to lift heavy load up using the force generated by exerting pressure through the smaller cylinder, connected to a larger cylinder by a tube. Thus, the larger cylinder will produce higher force due to larger area even though the pressure transmitted is the same. In addition, since the task given was to have the volume expands itself which means chemical reaction should be used. For our project, we decided to use acetic acid reacted with sodium bicarbonate to produce carbon dioxide, salt and water."*

This portrays that the student understands the problems' demands—the interrelation of producing work using volume expansion and transferring force from one hydraulic arm to the other. As the forces exerted on the smaller cylinder was translated to the larger cylinder, it will generate the lift that was demanded by the project. The pressure exerted by the gas generated can be calculated using the ideal or non-ideal gas equation, given that they can measure the volume and temperature of the released gas. This shows the critical thinking ability of the student in solving a technical problem. Another example also shows the students' ability to relate the safety aspect to the hydraulic jack operation as shown below.

> *"One the challenges faced is that an uncontrolled chemical reaction can lead to huge disasters, such as the possibility of the plastic bottle exploding, and the syringes used will burst due to too much pressure generated. Hence, there is a growing need to control the extent of chemical reactions, harness their energy and use them effectively. Besides chemical reactions, leakages, and the uneven distribution of pressure into each hydraulic jack made the journey tough."*

This report's content illustrates the students' ability to think beyond the assessment. The safety aspect is one of the most important criteria in any engineering discipline. Being able to relate the behaviour of a simple chemical reaction in a closed environment to the impact of not controlling the reaction shows that the student can connect and create an insight of an engineer. Thus, several engineering solutions were proposed, such as calculating the right amount of reactant inserted into the reaction chamber and proposing a purging line to release the excess gas and energy generated by the chemical reaction.

4.6. Overall performance

Fig. 6 shows the student coursework score and overall performance for the semester for PCE and CEFM course. Note that the coursework marks total up to 50 % and that the integrated project accounts for only 6% of the coursework marks. Even though the number is relatively small, the impact on learning styles and student learning behavior can be seen in the analysis. In this discussion, the baseline to measure the effectiveness of IPBL was considered. For the past cohort (September 2018), the mean and median of PCE and CEFM were B for both subjects. The comparison was only possible for one cohort since a new structure was implemented just before the September 2018 cohort. Thus, it is only possible to compare with the most recent cohort.

Fig. 6 also shows that most of the student manages to score B and above for both PCE and CEFM in January 2019. Most of the student was able to perform well in the PCE coursework, leading to the overall median of A-. On the other hand, students manage to score an overall median of B for CEFM. Compared to the previous semester, an increase of 2 grades was observed in the PCE course, showing that a better impact was achieved by implementing IPBL to the course. Meanwhile, a constant trend was observed for CEFM during the IPBL implementation. In this context, PCE was made visible to the students. They observed the chemical reaction occurring, calculated the amount of gas being generated, measured the volume of gasses generated by the chemical reaction, and calculated the amount of pressure exerted by the gas by using the PVT relation. The observation was made much more tangible from a PCE standpoint, hence enhancing the students' understanding of the subject. However, in CEFM, much improvement needed to be done for the students to relate the compressible and incompressible fluids to Pascals' principle. The students must also consider the friction between the fluid to the walls of the tube to understand the principles being applied. Hence, it is recommended to add complexity in the CEFM discipline in this project so the student can better understand the materials.

5. Conclusion

The implementation of IPBL was a success in elevating the students' thinking capabilities. Besides achieving the technical understanding of the two courses, this project also successfully imparts critical social skills to the student, such as time management, leadership, communication, and respect. Furthermore, the application of IPBL in more courses will allow more variation of the student project. It is also an avenue to teach additional practical and theoretical applications in a particular project. This research has successfully mapped out the learning domain and assessment planning to the learning activities. It had been proven to a certain extent that learning through IPBL allows all three learning domains to be engaged simultaneously, thus making the learning experience more meaningful to the learners. The project can be improved further to increase the CEFM subject's impact by increasing the level of complexity in the intended learning outcome to be addressed by IPBL. The current learning methods will require a relook into how human interaction can be highlighted once more to become part of the learning process to craft a more meaningful learning experience for the students from not only an academic perspective but also through growth and development in character.

Declaration of Competing Interest

The authors report no declarations of interest.

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References

Azizan, M.T., Mellon, N., Ramli, R.M., Yusup, S., 2018. Improving teamwork skills and enhancing deep learning via development of board game using cooperative learning method in Reaction Engineering course. Educ. Chem. Eng. 22, 1–13, http://dx.doi.org/10.1016/j.ece.2017.10.002.

Ballesteros, M.A., Daza, M.A., Valdés, J.P., Ratkovich, N., Reyes, L.H., 2019. Applying PBL methodologies to the chemical engineering courses: unit operations and modeling and simulation, using a joint course project. Educ. Chem. Eng. 27, 35–42, http://dx.doi.org/10.1016/j.ece.2019.01.005.

Bell, S., 2010. Project-based learning for the 21st century: skills for the future, the clearing house: a journal of educational strategies. Issues Ideas Educ. 83 (2), 39–43, http://dx.doi.org/10.1080/00098650903505415.

Bransford, J., Vye, N., Bateman, H., 1997. Creating High-Quality Learning Environments: Guidelines from Research on How People Learn. National Academy of Sciences, pp. 159–197, 2004.

Brown, R.W., 1995. Autorating: getting individual marks from team marks and enhancing teamwork. Proc. – Front. Educ. Conf. 2, 571–574.

Calvo, L., Prieto, C., 2016. The teaching of enhanced distillation processes using a commercial simulator and a project-based learning approach. Educ. Chem. Eng. 17, 65–74, http://dx.doi.org/10.1016/j.ece.2016.07.004.

Gibbs, G., 1998. Learning by Doing: A Guide to Teaching and Learning Methods. Oxford Brooks University, Oxford.

Guo, P., Saab, N., Post, L.S., Admiraal, W., 2020. A review of project-based learning in higher education: student outcomes and measures. Int. J. Educ. Res. 102, 101586.

Hamouda, A.M.S., Tarlochan, F., 2015. Engaging engineering students in active learning and critical thinking through class debates. Procedia – Soc. Behav. Sci. 191, 990–995.

Huber, C.R., Kuncel, N.R., 2016. Does college teach critical thinking? A meta-analysis. Rev. Educ. Res. 86 (2), 431–468, http://dx.doi.org/10.3102/0034654315605917.

Hung, W., Jonassen, D.H., Liu, R., 2008. Problem-based learning. Handbook of Research on Educational Communications and Technology, vol. 3., pp. 485–506.

Krajcik, J.S., Shin, N., 2014. Project-based learning. In: Sawyer, R.K. (Ed.), The Cambridge Handbook of the Learning Sciences. , 2nd ed, pp. 275–297, http://dx.doi.org/10.1017/CBO9781139519526.018.

Mellon, N., Ramli, R.M., Rabat, N.E., Amran, N.A., Azizan, M.T., 2017. Instilling the 4Cs of 21st century skills through integrated project via Cooperative Problem Based Learning (CPBL) for chemical engineering students. 2017 7th World Engineering Education Forum (WEEF), 17–20, IEEE CFP17L16-POD.

Mohd-Yusof, K., Syed-Hassan, S.A.H., Phang, F.A., 2012. Creating a Constructively Aligned Learning Environment using Cooperative Problem Based Learning (CPBL) for a Typical Course. International Conference on Teaching and Learning in Higher Education (ICTLHE 2012) in conjunction with RCEE & RHED 2012. Procedia Soc. Behav. Sci. 56, 747–757, http://dx.doi.org/10.1016/j.sbspro.2012.09.712.

Mohd-Yusof, K., Wan Alwi, S.R., Sadikin, A.N., Abdul-Aziz, A., 2015. Inculcating sustainability among fir0st year engineering students using cooperative problem-based learning. Sustain. High. Educ., 67–95.

Sadikin, A.N., Mohd-Yusof, K., Aliah Phang, F., Abdul Aziz, A., 2019. The introduction to engineering course: a case study from Universiti Teknologi Malaysia. Educ. Chem. Eng. 28, 45–53, http://dx.doi.org/10.1016/j.ece.2019.04.001.

Stephenson, R.N., 2012. DOPE Bird Personalityt Test, 5th edition. Smahswords.

Vega, F., Navarrete, B., 2019. Professional design of chemical plants based on problem-based learning on a pilot plant. Educ. Chem. Eng. 26, 30–34, http://dx.doi.org/10.1016/j.ece.2018.08.001.

Yusof, K.M., Hassan, S.A.H.S., Jamaludin, M.Z., Harun, N.F., 2012. Cooperative problem-based learning (CPBL): framework for integrating cooperative learning and problem-based learning. Procedia - Soc. Behav. Sci. 56 (Ictlhe), 223–232, http://dx.doi.org/10.1016/j.sbspro.2012.09.649.