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A study of flipped classroom approach in chemical engineering core courses

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ABSTRACT

CONTEXT

The term "flipped classroom" refers to a pedagogical strategy that shifts information-transmission teaching outside of the classroom while the class time is used for active and social learning, in addition to mandatory pre- and/or post-class assignments (Abeysekera & Dawson, 2015). The reported benefits of flipped classroom approach include increased learning flexibility (Velegol et al., 2015), enhanced student engagement (Lavelle et al., 2013), and improved critical thinking ability (Chetcuti et al., 2014). According to a recent systematic review, research on flipped classroom approach in engineering education is still in its early stages (Karabulut-Ilgu et al., 2018). This study implements the flipped classroom approach in CHEMMAT 301 (Transfer Process 2) and CHEMMAT 303 (Chemical Reactor Engineering). These are core courses for the chemical engineering programme.

PURPOSE OR GOAL

The course materials of CHEMMAT 301 and 303 are dense with heat and mass transfer equations and derivations, which tends to make teaching and learning tiresome and ineffective. This study aims to evaluate the impact of flipped classroom approach on the student's learning achievement, motivation, and engagement in the chemical engineering core courses.

APPROACH OR METHODOLOGY/METHODS

This study applied a mixed-method approach. The primary data are gathered through a questionnaire distributed to students at the end of the semester. The questionnaire contains closed questions for collecting quantitative data and open questions for collecting qualitative data. Furthermore, the quantitative approach is also supported by the analysis of students' assignments/tests grades.

ACTUAL OR ANTICIPATED OUTCOMES

According to the courses questionnaire responses, more than 80% of students felt the learning environment provided opportunities to collaborate with their peers and allowed effective communication between students and the teacher. Moreover, the assignment grade assessment for this course showed an improvement by +6.8/100 compared to the previous year's result when the flipped classroom was not implemented. The standard deviation is reduced by -3.7, and the grade distribution profile for this year's result is closer to the typical distribution. This positive result is likely to be replicated for CHEMMAT 301.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The preliminary findings of this study suggest that implementing a flipped classroom approach can improve students' academic success and learning experience in chemical engineering courses.

KEYWORDS

Flipped classroom; Student engagement; Chemical engineering.

Introduction

CHEMMAT 301 (Transfer Process 2) and CHEMMAT 303 (Chemical Reactor Engineering) are mandatory core courses for the third-year undergraduate Chemical and Materials Engineering students of The University of Auckland, New Zealand. These courses serve as the foundation for many specialised fields and are crucial to solving the industrial problems that fall under the purview of a chemical engineer. The course materials of CHEMMAT 301 and 303 are dense with heat and mass transfer equations and derivations, making teaching and learning through traditional lecture methods challenging and ineffective. Thus, a "flipped classroom" approach was introduced to CHEMMAT 303 class in the 2nd Semester of 2022 and CHEMMAT 301 class in the 1st Semester of 2023.

In the literature, not many studies have reported flipped classroom implementation in chemical engineering courses. Therefore, this study aims to evaluate the impact of flipped classroom approach on the student's learning achievement, motivation, engagement, and problem-solving ability in the chemical engineering core courses.

Literature Review

The most common form of teaching utilised in engineering programmes at universities worldwide is traditional lecture (Munir et al., 2018). In a typical chemical engineering core course taught with traditional lecture methods, the teacher spends lengthy class time attempting to explain the fundamental of complex physic theoretically (Valero et al., 2019). The majority of the students attend the lecture with little prior knowledge of the material and little understanding of what to expect (Munir et al., 2018). Following the class, the students are given homework assignments, which generally include problems with high levels of similarity. Students feel they have learned everything necessary when they can find the correct answer (Valero et al., 2019).

Students taught via the traditional lecture method become passive and reliant on their teachers to provide all the required knowledge (Najdanovic-Visak, 2017). This method is viewed as ineffective in teaching higher-level thinking skills, e.g., application, analysis, and synthesis (Chasin, 1995) as cited in (Bonwell, 1996), skills essential in most chemical engineering courses. Future chemical engineers should use a new approach to learning because the demand for professionals in this field is growing in step with current global changes (Bawadi & bin Azizan, 2017). In a meta-analysis research, Freeman et al. (2014) concluded that STEM (Science, Technology, Engineering, and Mathematics) students perform better when engaging in active learning.

There are several approaches to apply active learning in engineering education. Among them, the flipped classroom is the most used (Rodríguez et al., 2018) and the most effective approach for improving student learning (Bawadi & bin Azizan, 2017). The flipped classroom is a pedagogical approach in which a conventional learning environment and its activities are flipped or reconfigured (Awidi & Paynter, 2019). Figure 1 shows the comparison between traditional lecture and flipped classroom. In a flipped classroom, the information-transmission teaching is shifted outside of the classroom while the class time is used for active and social learning, in addition to mandatory pre- and/or post-class assignments (Abeysekera & Dawson, 2015).

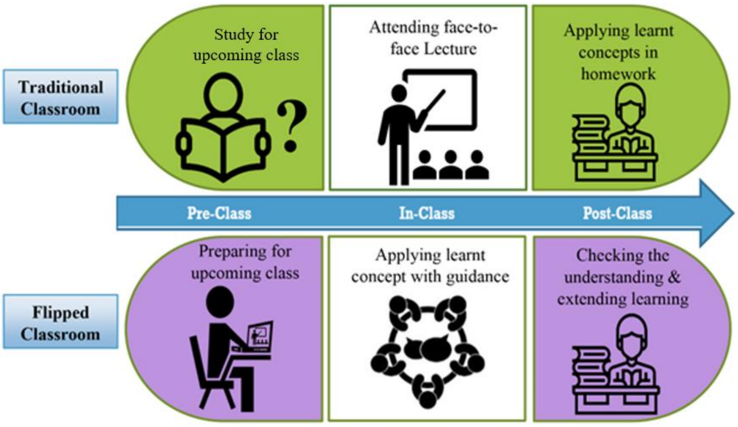

Figure 1: Comparison of traditional lecture and flipped classroom (Adapted from Youhasan et al., 2021)

The flipped classroom approach can guarantee the students' active participation in the learning process (Fidalgo-Blanco et al., 2017). There are many different ideas, resources, and activities that can be incorporated to create a hands-on learning environment, but there is not just one model for the flipped classroom (UNSW, 2022). Figure 2 shows one of the flipped classroom models. In a recent systematic review, Karabulut-Ilgu et al. (2018) described that higher education has seen a rise in the popularity of the flipped classroom method. This method was thought to be especially well suited to engineering education, as it's essential for engineers to be able to apply theory to resolve problems (Munir et al., 2018). However, up to now, the research on flipped classroom approach in engineering education is still in its early stages (Karabulut-Ilgu et al., 2018). In chemical engineering education itself, only a small number of research have documented the use of flipped learning in its courses.

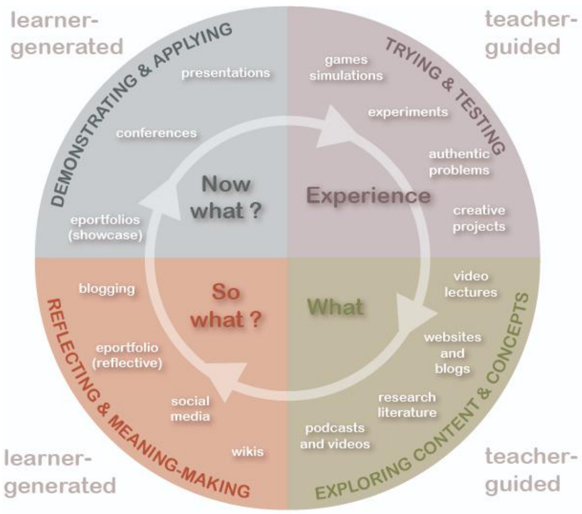

Figure 2: An example of flipped classroom model (UNSW, 2022)

Two of these studies applied the flipped classroom approach to the Chemical Engineering program's core subject of Transport Phenomena (equivalent to CHEMMAT 301). The first study was conducted in Teknologi PETRONAS, Malaysia (Bawadi & bin Azizan, 2017), and the second study was conducted at Universitat Politècnica de Catalunya, Spain (Valero et al., 2019). The first study applied both quantitative and qualitative methodologies, while only qualitative methodology applied in the second study. In both studies, the flipped classroom approach was partially applied to the course (i.e., only applied to one unit/topic, while the remaining units/topics were still taught with the traditional lecture method). In this particular unit/topic, the theoretical explanation delivery was conducted through short videos and online quizzes made available for the students a few weeks before classroom sessions. During in-class sessions, the first study implemented various activities (group discussion, think-pair-share, peer-teaching, and teach for junior). In comparison, the second study applied participative discussion and cooperative work during in-class sessions. Post-class assignments were not involved in both studies; but the students were asked to participate in a survey after class to provide feedback on their learning experience.

Based on the survey results, both studies reported positive outcomes from the flipped classroom approach implementation. In the first study, the students shared that they enjoyed the new learning method. While in the second study, the students gave feedback that the flipped classroom approach has increased their motivation and helped them learn both theory and practice. Additionally, quantitative analysis in the first study revealed that the students' grades for tests, assignments and quiz have improved. Therefore, it was concluded that flipped classroom is ideal for a highly technical subjects with a lot of difficult theory, and it aids in comprehending and applying such material (Valero et al., 2019).

In addition to Transport Phenomena, other chemical engineering courses where flipped classroom approach has been reported to be implemented are Process Control (Marlin, 2017; Rodríguez et al., 2018), Mass and Energy Balance (Lai, 2020), and Food Process System Engineering (Munir et al., 2018). Some notable conclusions from these studies are summarised below:

- Students embraced the flipped classroom approach with enthusiasm. The course evaluation revealed that the students in the flipped classroom achieved a little higher grade, although the difference is not statistically significant (Marlin, 2017).
- When the flipped classroom approach was used, students were more engaged, motivated, and comprehended material better. However, it is not the only effective active learning strategy, and combining it with other techniques (such gamification and peer instruction) would enhance the learning environment for students even further. The challenge will be finding the time and resources to create all the necessary materials to use these techniques (Rodríguez et al., 2018).
- In comparison to traditional lecture, the flipped classroom method led to a steady and persistent improvement in student exam scores. From the perspective of the teacher, the in-class sessions provide real-time feedback on content that is difficult or perplexing for the majority of students, giving the teacher the chance to clarify misconceptions with the entire class right away (Lai, 2020).
- The students showed resistance to the flipped classroom-cooperative learning strategy early in the semester. However, more than 90% of the students were content with this approach at the conclusion of the semester, despite the initial resistance. The flipped classroom assisted in the growth and improvement of students' critical thinking and learning abilities. While cooperative learning helped students develop their problem-solving and teamwork abilities as well as their communication skills (Munir et al., 2018).

Method

CHEMMAT 301 course is structured in 7 modules, and CHEMMAT 303 is structured in 9 modules. Until 2021, all modules in these courses were taught following a traditional lecture method. The flipped classroom method was implemented in the two modules of each course. Each module implemented in the flipped classroom method consisted of 6 in-class sessions (5 lectures and one tutorial).

<u>Pre-class</u>

For the pre-class, the students were provided with lecture videos (40 minutes duration/video) and lecture notes to go through before each in-class session. In each video, the lecturer presented the theoretical part of the lessons. These materials were uploaded to the Canvas platform three weeks before the class schedule and were kept available until the end of semester, so students could go back and re-watch.The number of students watching the pre-class vide was not tracked and no online quiz/assessment was attached to the material to push the student to complete them before class time.

In-class

The duration of the in-class session was 55 minutes/session. In-class time was used to work on the calculation exercise related to the theoretical material delivered in the pre-class. The students worked on the calculation exercise individually or in groups, with the teacher's availability to answer questions or provide more explanations. In two in-class sessions of each module, a student (voluntary basis) worked calculations in front of the class and presented/explained the solutions to their peers.

Post-class

Additional calculation practice questions were given to the students to work independently at home. There was no obligation to submit the answer to these questions (not graded), but the students were welcome to present and discuss the solution with the teacher.

At the University of Auckland, all qualifying courses and the respective teachers are evaluated by students through SET (Summation Evaluation Tool). At the conclusion of the semester, all enrolled students in the relevant course receive the SET evaluation request. Its completion is voluntary. Completing the SET evaluation allows students to provide constructive and honest feedback that can assist teachers in improving a course, including modifying their teaching methods (University of Auckland, 2023).

This study did not issue specific questionnaires/surveys to evaluate the flipped classroom method implementation. Instead, this study takes advantage of the SET evaluation of CHEMMAT 301 and CHEMMAT 303 courses to gather students' opinions on flipped classroom method implementation.

The SET questionnaire contains closed questions for collecting quantitative data and open questions for collecting qualitative data for this study. Furthermore, the quantitative approach is also supported by the analysis of students' assignment and test grades and the qualitative approach is supplemented by observation during in-class sessions.

Results and Discussion

The summary of students' feedback related to the implementation of flipped classroom method, as gathered from the open-question responses, is presented in Table 1 below.

Table 1: Summary of student feedback

Positive feedbacks
• "I like Amar's flipped classroom method, it feels like it saves us a lot of precious time and is more engaging. Not being assessed on derivations, class discussions and IQ quizzes that break up the pace of the lecture and our classmates presenting the tutorials are all things I really liked." • "The flipped classroom Amar introduced was very helpful in getting a better understanding of the concepts." • "Lecture recordings were good for extra review of material, and flipped classroom meant less pressure on writing important notes and more focus on how to analyze a problem with the topics learnt." • "Amar's delivery of lectures and flipped classroom style of teaching really had effective ways of improving learning." • "I really enjoyed the flipped lecture format as it streamlined the learning process." • "I personally liked the flipped classroom method. I was one of the tutorial volunteers and I thought it helped me a lot in getting a much better understanding of the concepts." • "The flipped class for tutorials helped me understand the course content."

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• "I also found the flipped classroom approach very useful and again another opportunity for students to discuss content. This was a great approach to teaching as it also meant that students were able to learn from different teaching styles." • "I also enjoyed the 'flipped' method of teaching where he allowed the students to teach sections, as well as giving them an opportunity to answer tutorial questions." • "His teaching style is inspiring and empowering to our learning as he also incorporates flipped classroom approach."
Negative feedbacks
• "There was a lot of 'student teaching' within a flipped classroom environment. I found this very difficult as there were different thinking styles, very varied presenting skills and often a lack of detail and ability to answer questions and expand on why they chose ways of working out. The lecturer often had to step in to explain or go over their way of working, which took time out of the lecture. I felt this was a waste of time and hindered the students that were not presenting." • "Less of the flipped classroom please, CHEMMAT students much prefer your working out and your ability to really explain important concepts."

The table above shows the students' positive and negative feedback about the flipped classroom method implementation. The positive feedback was received for CHEMMAT 301 and CHEMMAT 303, while the negative feedbacks were only received in CHEMMAT 301. Overall, there are more positive responses are obtained compared to negative ones. On a positive note, students feel that flipped classrooms are more engaging and effective in their learning process and have helped them better understand the course material. This result is aligned with the conclusion from the flipped classroom implementation in the Process Control course reported by (Rodríguez et al., 2018), whereby the students' engagement, motivation, and level of material understanding improved.

A higher level of engagement was facilitated by using the whole duration of in-class sessions for establishing the interaction among students and between students and the teacher. Marlin (2017) argued that more interaction would boost student knowledge acquisition, which was shown in the feedback as the students felt that they learned more effectively and understood the material better.

The student's grades also represented the outcome of more effective learning. The distribution of students' grades (assignment and test of the course modules delivered with flipped classroom method) of the CHEMMAT 303 course, compared with the previous year's grades on the same modules, is shown in Figure 3. Both courses were delivered by the same teaching staff.

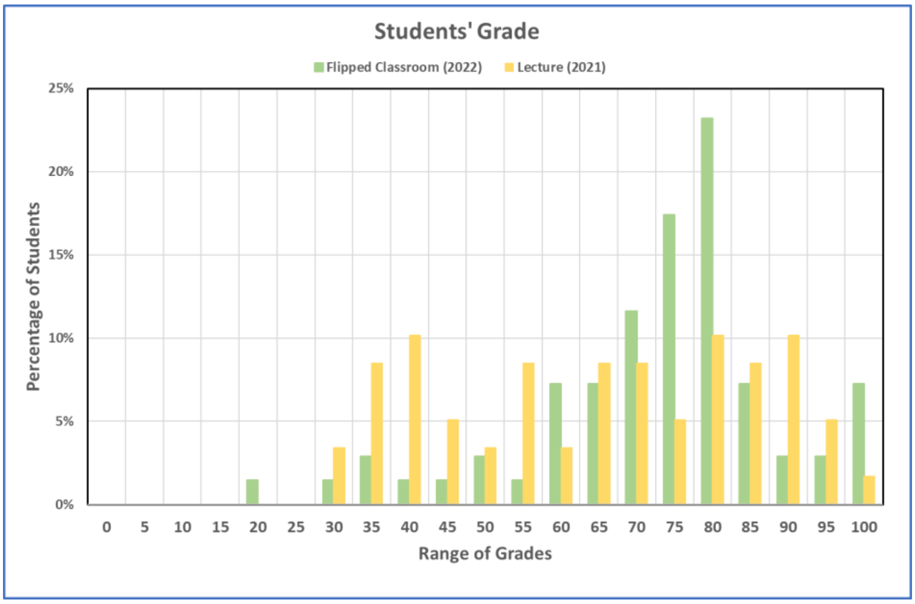

Figure 3: Distribution of grades

The graph shows that the percentage of students who earned a "B" grade (65-75) and an "A" grade (80-100) increased from the previous year. When the flipped classroom method was implemented, 80% of the students earned a grade of 65 or higher. This number represents a 37.9% increase over the prior year. Additionally, the average grade obtained by the students increased from 63.4 to 70.2, and the standard deviation decreased by 3.7. These results indicate that student performance in the CHEMMAT 303 course has considerably improved. This grade improvement finding is consistent with the result reported by other papers (Bawadi & bin Azizan, 2017; Lai, 2020; Munir et al., 2018; Rodríguez et al., 2018).

The negative feedback for the flipped classroom method centred on the dislike of some students to peer-teaching activities. They preferred the teacher to explain in front of the class as they argued that the variety of presenting skills and capability to answer the presenting students made the learning process inefficient for the audience. This feedback is noted as one of the limitations of the flipped classroom method, which is that not all students participate equally in group activities (Bawadi & bin Azizan, 2017). This criticism contradicts the positive feedback given by one of the presenting student volunteers who thought that being a presenter has significantly helped him/her to obtain a substantially better understanding of the concepts. Furthermore, it should not be an issue as the teacher was always available during peer-teaching activities in class to provide guidance or corrections to the presenting students and ensure the correct solutions were presented to the audience.

The negative feedback can also be linked with the students' resistance to an unfamiliar learning method which has been reported in other studies (Bawadi & bin Azizan, 2017; Munir et al., 2018) when the flipped classroom method was introduced for the first time. However, as shown in the SET evaluation, the negative feedback did not affect the course score, as summarised in Table 2 below. Although the evaluation result is for the entire course (not only for the modules delivered with flipped classroom method), it also indicates the student's satisfaction with the overall course delivery. The results show that more than 80% of students felt the learning environment provided opportunities to collaborate with their peers, allowed effective communication between students and the teacher, and they could stay motivated and engaged with their learning.

Table 2: SET evaluation (closed questions) result

Questions	**Agree and Strongly Agree**	
	CHEMMAT 301	CHEMMAT 303
The learning environment provided me with opportunities to communicate and/or collaborate with my peers.	87.5%	95.6%
The learning environment allowed effective communication between teaching staff and students.	91.7%	95.7%
I felt I could stay motivated and engaged with my learning.	83.3%	82.6%
I was satisfied with the quality of the small-group teaching (e.g. tutorial, laboratory, seminar, workshop) associated with this course.	87.5%	95.6%
Overall, I was satisfied with the quality of the course	83.3%	91.3%
Overall, Amar was an effective teacher.	95.8%	95.6%

Conclusion

This study's findings suggest that the flipped classroom method implementation successfully raises students' performance in terms of their assignment/test grades. After the flipped classroom was implemented, there was an increase in the number of students receiving "A" and "B" grades. A grade of 65 or higher was earned by 80% of the students. This figure represents an increase of 37.9% from the previous year. This significant number demonstrates that the flipped classroom has accomplished one of the study goals to evaluate its impact on learning achievement. Regarding the qualitative outcomes, according to student feedback, most students find flipped classrooms beneficial for their learning and believe it has improved their understanding of the course material by making learning more engaging and effective. Although a couple of negative feedbacks were also received due to some students' dislike of peer-teaching activity, the overall score of the course was not affected.

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