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# Student Adoption and Effectiveness of Flipped Classroom Implementation for Process Simulation Class

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**Abstract:** A flipped classroom (FC) teaching approach offers a personalized learning environment for the learners to study the course using pre-recorded material prior to the in-class session. The synchronous sessions are then dedicated to knowledge confirmation and learning activities. Although this technique is considered promising, the learners' acceptance of FC for skill-based courses conducted entirely via open distance learning (ODL) has yet to be assessed in Malaysia. Thus, this study aims to evaluate the FC approach's effectiveness and student readiness and acceptance during ODL. A questionnaire was used to assess the students' adoption and overall implementation of FC. Results show that students who underwent the FC approach gave a better performance in their course. In fact, 39.29% of the students who underwent the FC approach managed to score A and A- compared to 19.82% of students that went for conventional delivery. Regarding the adoption, 100% of the surveyed students agreed that the pre-recorded video assisted them in preparing for the class. Furthermore, 100% of students surveyed agreed that they were able to prepare the simulation before the next class at the end of the semester, compared to 96.154% in the first 4 weeks. It can be concluded that the FC approach has been shown to be effective and easily adopted by students. Furthermore, the FC learning framework has been developed to map the learning activities and the learning domain. Principles such as How People Learn and Bloom taxonomy were embedded in the development of this framework.

**Keywords:** flipped classroom; student adoption; engineering education

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## 1. Introduction

The student-centered learning (SCL) approach has always been the focus for institutions of higher learning to deliver academic content to students. Approaches such as active learning [1], integrated project-based learning [2], problem-based learning [3–5], experiential learning [6], and case studies have shown great promise in students' knowledge attainment. It has also been proven to address each student's soft skill development, such as team working, critical thinking, and lifelong learning. However, an unprecedented event such as the COVID-19 outbreak has changed the academic landscape in institutions of higher learning (IHL).

The COVID-19 pandemic is an example of volatility (V), uncertainty (U), complexity (C), and ambiguity (A), termed as VUCA. This condition changes the norms and mindset of the people affected. In this condition, learners and instructors are forced to use online distance learning (ODL). VUCA conditions expedite the online learning environment to a point where students and instructors depend solely on technology for educational needs, from content to assessment.

Being forced to learn from home, students face difficulties due to the improper learning environment that their home offers. Attending to house chores, managing family members, and having poor access to the internet are a few of the students' challenges [7,8]. Thus, flexibility to learn needs to be given to the student in order for them to study. Thus, the flipped classroom (FC) approach is proposed to address this issue. FC offers flexibility in student learning hours, separated into synchronous and asynchronous sessions [9–11]. Both sessions are necessary and an essential part of FC whereby the student needs to view the pre-recorded material released by the instructor as a preparation step for the synchronous session. Meanwhile, the synchronous session is dedicated to knowledge confirmation and discussions with the instructor.

Aside from the pros and cons that FC can offer to the learning environment, the level of adoption and effectiveness towards the student in VUCA conditions has yet to be assessed. Thus, this study was proposed to assess the level of adoption of UiTM students toward the FC approach. It also aimed to study the effectiveness of FC in student knowledge attainment during VUCA situations.

The novelty of this study is in the implementation of FC, which is suitable for ODL application. The flexibility offered by FC should extend beyond university boundaries. It should be used by the student who needs to learn the material provided within the timeframe and prepare for the synchronous session with the instructor. It is suggested that during VUCA conditions, FC is the delivery method of choice for the basic student-centered learning approach instead of active learning. Active learning requires in-class participation from the student while simultaneously learning the material [9]. However, the FC approach imparts the knowledge before the class while the in-class sessions serve as knowledge confirmation through discussion and activities. Thus, the engagement from students who have already built prior knowledge is more rigorous than those who are learning during the discussion session. A structured FC framework to suit ODL implementation in a public university in Malaysia, particularly University Teknologi MARA (UiTM) settings, is proposed.

Many studies have reported that the FC approach has been a success in a variety of courses and contexts [12–14]. Thus, this study aims to determine the adoption level of students taking a skill-based course. The effectiveness of the flipped classroom in addressing student knowledge attainment is also addressed in this study.

## 2. Pedagogical Approach

The COVID-19 pandemic that has struck the world has created volatility, uncertainty, complexity, and ambiguity (VUCA). This situation has demanded changes and shifts that required prompt adaptation, including in the educational landscape. Although it became a particularly challenging time, it has forced almost all educational institutes to quickly adapt to new teaching and learning styles—which are almost completely conducted online. While there is no doubt that online education has endless benefits, particularly regarding the flexibility in learning, there are certainly challenges, especially when it is being implemented drastically or emergently [15]. There have been reported observations of issues that negatively influence online engineering education, and these include and are not limited to various logistical and technical problems [16]. A study by Asgari et al. (2021) focused on identifying the challenges met due to the abrupt transition to online engineering education due to the COVID-19 pandemic and proposed some resolutions to tackle specific issues. Some of the strategies include encouraging group discussion or problem-solving activities and breaking down long lectures into shorter segments, including breaks [16]. However, the internet connection must be stable throughout the class for this to be carried out, which may be challenging to achieve. It is also important to note that well-planned online learning differs from emergency response remote teaching [17].

Regardless of the problem, the most crucial thing that must be addressed is ensuring that despite the pandemic, the quality of education provided is maintained. Particularly, students must be able to grasp and attain what each course plans on imparting. Interactive learning or student-centered learning (SCL) is considered a useful tool to ensure that students are stimulated and interested in the subject to motivate them to take a deeper approach to studying it. Considering the difficulty with the internet connection, student-centered learning has become a beneficial alternative as it can be performed wherever the student is, especially during long lockdown periods. One particular interest is in FC where students are offered flexibility as they are given their own time to digest and learn the materials before classes and the classes are used to emphasize learning concepts further and clarify any misapprehensions [18].

As proposed by Khan and Abdou in 2021, the FC framework consists of two main activities. The first activity involves the instructor preparing and releasing the video to the learners before the synchronous session. In the second activity, the instructor facilitates the learning process by the student. The conventional FC framework is shown in Figure 1 [12]. However, this study wishes to incorporate other elements, such as student feedback and preparing the student for the FC approach. This addition aligns with the outcome-based education approach to close the loop by continual quality improvement.

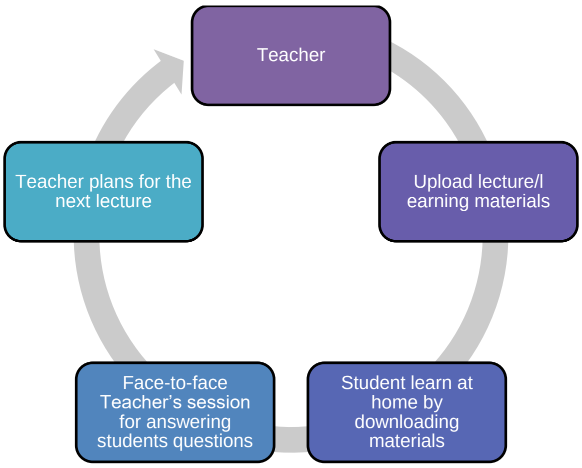


**Figure 1.** FC framework proposed by Khan and Abdou, 2021.

Apart from flexibility, integrating FC in online teaching has positively affected students' learning, attention, and evaluation of learning [19]. FC has been shown to positively correlate with motivating students despite being in a traditional or online classroom [18]. Not only that, but the participation in fully online FC is also proven to be as effective as the conventional FC classes [20].

There have been numerous studies over the years that have incorporated a flipped classroom approach. For example, both studies from Villalba et al. (2018) and Long et al. (2018) only focused on the educators' perspectives on factors which affect their decision to adopt FC [21,22]. Similarly, Wang in 2017 studied the barriers and concerns behind why teachers do not intend to adopt flipped classrooms in Hong Kong secondary schools and found that the main barriers are limited access to technology and preparation time [23]. More recently, Hoshang et al. (2021) investigated both students' and educators' points of view concerning the application of flipped classrooms but concluded that more training in the tools and concepts is needed before full adoption of the model can be applied as some students still prefer being guided step-by-step and could not cope with the heavy learning workload [24]. Meanwhile, Chen and Chen (2014) indicated encouraging outcomes for a university's student performance but did note that some students retained their former passive learning habits which hindered full adoption of the flipped classroom model [25].

Nonetheless, the literature has shown a positive relationship between the implementation of FC and the students' achievements [14].

Principally, the literature has shown a current need to understand the students' readiness to accept the FC approach [15]. The readiness of secondary school students is positive, especially for students who have access to a computer and perceive themselves as competent in using technology [26]. This is still less explored in institutes of higher learning, especially for courses that require more technical theories, such as engineering courses. Interestingly, a modified blended learning method has been shown to have positive outcomes for engineering courses if planned well [9].

### *2.1. Flipped Classroom for Skill-Based Course*

Engineering is considered more inclined towards skill-based courses due to the numerous involvements of laboratory work and projects. Conducting these types of courses remotely due to VUCA conditions is indeed challenging. Students, especially those from rural backgrounds, cannot be expected to have a stable internet connection for long periods while struggling to focus, during which they will have to stare at screens. This will make it challenging to deliver skills while allowing students to comprehend the steps and procedures needed. Therefore, proposing FC for a skill-based course is preferred during a VUCA situation.

Process simulation is a skill-based course where students can understand how to control or navigate chemical process plants via models, namely Aspen HYSYS. Exploiting FC for this course means the student can take their time playing and pausing the videos and following the steps needed to learn the basic skills and steps in using the software. After this is achieved, students can work on more complicated case studies or solve any issues during the limited synchronous class time. Ideally, the same concept is promoted as useful for other skill-based courses.

Skill-based courses typically require the student's involvement and hands-on ability, which proves difficult to achieve, especially during VUCA conditions. The ability to have some practice time on their own before classes can help engage students better in discussion and problem solving. This is proposed to help increase the efficiency of the time spent during classes despite being conducted online. This is in line with a study by Bhat et al. (2020) where they found that students prefer to utilize the limited class time for discussion rather than listening to lectures [13].

### *2.2. Flipped Classroom Framework Mapping to the Learning Domain*

According to the fifth annual Workplace Learning Report by LinkedIn Learning, the most important skills to have in the workplace are resilience and adaptability. Digital fluency and communication across remote teams come in second and third, respectively [27]. These skills are significantly being addressed in the implementation of flipped classrooms, whereby the students are required to adapt to the newly introduced learning method. Training the students in grit and being resilient in learning is essential to prepare them for joining the workforce later on.

In designing the FC learning framework, the learning taxonomy was taken into consideration. According to Bloom's taxonomy, in 2001 the revised taxonomy was categorized in six parts [28]. Conventionally, the lower order thinking skills which consist of remembering, understanding, and applying are imparted during the class session. Meanwhile, learners are expected to address the higher order thinking skills which are analysis, evaluation, and ability to create on their own. However, FC proposes to invert the learning algorithm whereby the class session should be addressing and facilitating learners in developing the higher order thinking skills. This opens up room for higher order intellectual discussion between learners and instructors in developing the required skills for the workforce. Other than that, using the How People Learn (HPL) framework, the learners, knowledge, assessment, and environment are taken and fitted into the FC implementation framework. The learner's background knowledge of the material needs to be taken into consideration when developing the learning material for the student. By doing this, learners may build their own knowledge upon pre-existing information. Well-informed learners that attend class with understanding of the material given can promote interaction which consequently builds a learning environment that supports one another's learning process [29].

Furthermore, effective education must engage in all of the learning domains, namely psychomotor, cognitive, and affective. While conducting education remotely, it would be difficult to accommodate all three learning domains, particularly the psychomotor domain. Thus, to accommodate this issue, this skill-based FC framework proposes learning material to be prepared by the student to be digested during the asynchronous sessions. During this session, the students will engage both their psychomotor and cognitive skills as they go about understanding the course's main concepts and attempt to digest, solve, and prepare at their own pace for the synchronous session. Specifically, learners can try to carry out the simulation and see how it can be applied without worrying about getting left behind during the class. They are also required to prepare a justification for the simulation they have proposed based on the fundamental principles of chemical engineering.

The synchronous class then allows the learners to engage at a higher cognitive level with more complex problem solving. Learners are expected to present their solutions to the class after the instructor holds a 10 min recap session. The recap session is taken from the advanced organizing method introduced in active learning [30]. The instructor then will probe and challenge the learner's solution to engage student thinking and problem-solving skills. Satisfaction from participating in the discussion and seeing how it applies in the bigger picture will then stimulate the affective domain. It will also prompt students to see the importance of preparing or doing the "homework" before the classes, which also maps nicely to the affective domain where students enhance their personal traits such as responsibility. This particular combination applied in FC shows a promising application to the learning domain. The mapping of the FC framework to the learning domain is portrayed in Figure 2.

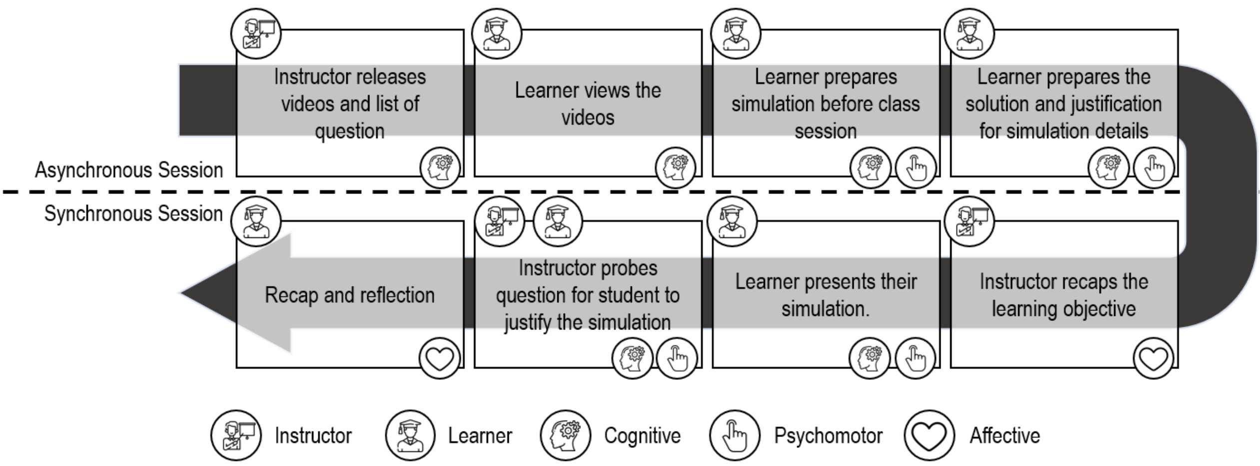


**Figure 2.** Proposed mapping of learning domain top learning activity for flipped classroom implementation.

## 3. Methodology

The research was conducted on chemical engineering students in part 6. The total sample size for the study is 100, in which only 28 students underwent the FC approach. The course selected for this study is Process Simulation. This course was selected due to its skill-based content and the need to use a chemical engineering process simulator such as Aspen Hysys for the learning process. The subject, class instructions, assessment methods, syllabus, and contact hours were kept fixed throughout the study. However, those who were exposed to FC approaches were provided with additional videos to be watched prior to class. This served as the manipulated variable for this study. The detailed method of teaching for students with the FC approach is further elaborated in Section 2.2. Data were collected through 3 means: (1) anonymous data collection for the adoption study shown in Section 3.2, (2) anonymous students' reflections on the implementation of the FC approach as shown in Section 3.3, and (3) student performance data were collected from the official marks obtained from the examiners. These three responses were then triangulated to obtain a holistic result based on qualitative and quantitative approaches on the adoption and effectiveness of the FC approach for a skill-based course. Then, the data were compared with those of students who underwent the conventional teaching mode.

### 3.1. Preparing for Flipped Classroom Implementation

The students who underwent the FC approach did not have prior FC experience. Thus, it was a good set-up to determine whether the students can adopt the learning method. Prior to class with the instructor, the learning material was released on Google Classroom at least four days before. The instructor mentioned the students' learning instruction to view the video prior to the in-class session. The video duration ranged from 10 to 30 min which encapsulated the learning objectives, equipment introduction, layout of the simulation environment, and conclusion. Embedded in the videos was a list of instructor expectations and questions to be discussed and asked during the in-class discussion.

The course selected is a skill-based course involving simulation carried out 100% via ODL. For this purpose, the students were exposed to Anydesk software for remote access to the process simulator which was Aspen Hysys. This process simulator was selected due to its wide capabilities in simulating chemical processes and equipment, having a vast library on chemical compounds and fluid packages, and being relevant to the current utilization in the industry.

Students were expected to prepare a simulation based on the case study presented in the particular video released. They needed to justify the unit operation, process parameters, and simulation layout and clearly define the purpose of the whole simulation sequence. During the in-class session, the instructor posed quick-fire questions for the student to justify every decision they made in the simulation prepared earlier.

This course does not have any final exams as it is a skill-based course. Students were evaluated in 4 separate assessments: interim report, interim report presentation, final report, and final report presentation. Eighty percent of the marks were contributed by the report content submitted by a team of 2–3 people, while the other 20% came from an individual assessment during the presentation sessions. The report was evaluated and multiplied by the weightage based on individual peer evaluation marks given by their teammates, ranging from 0.00 to 1.00. This value was then assigned to the student, contributing to their final marks of the course.

### 3.2. Measuring Student Readiness and Adoption

To assess the students' adoption level of the FC approach, the data collection was conducted in two time frames: pre-adoption (the first four weeks of the course) and post-adoption (after the four weeks of the course). The data were collected using surveys to determine the students' adoption of the FC approach. Data obtained are in a five (5)-level Likert scale: strongly agree, agree, neutral, disagree, and strongly disagree, which is simpler, time effective, and friendlier to the respondent [31]. Aspects that were asked about were the respondent's demographic, content of the material provided, the impact of the material provided on the student's understanding, student's preparation prior to the in-class session, activity conducted in the in-class session, and instructor's role in the in-class session. The questions were written in a Google Form and distributed to the students. It was an anonymous response to provide a safe environment for the students to give feedback on the FC approach implemented. The adoption study questions are shown in Table 1.

**Table 1.** Survey questions used to study the adoption level of the students.

| Num | Questions |
|---|---|
| 1 | I find the video very helpful for my understanding prior to the class. |
| 2 | The pre-recorded video assists me in preparing for the class. |
| 3 | I had adequate time to view the videos and lessons before the FC activity. |
| 4 | I am able to prepare the simulation before the class begins. |
| 5 | The discussion and activity in the class are easy to follow and enhanced my understanding of the material given. |
| 6 | The discussion session in class is very helpful in addressing my difficulty towards solving my simulation problem. |
| 7 | I can join in the discussion in the classroom because I have completed my task before the in synchronous session. |
| 8 | Overall, I have adopted this learning method. |

The survey questions were designed to address specific elements in the FC implementation. Questions 1 and 2 were developed to assess the student's ability to acquire understanding of the knowledge at their own pace which is the basis for the student-centered learning approach. Meanwhile, Question 3 assesses the learner's time management when preparing for the class. Question 4 looks into the student's preparedness in completing the assigned task before the discussion session during class. This is a crucial stage of the FC implementation as, mentioned in Section 2.2, learners need to be well prepared for the class. Completing the simulation before the synchronous sessions serves as an indicator of the level of student preparedness and that they are able to meet the lower order thinking skill requirement. On the other hand, Questions 5, 6, and 7 are designed to assess the learner's participation in the synchronous class and ability to join in the discussion and hence create a learning environment for everyone involved. The survey questions are mapped with the FC implementation framework proposed in Figure 2.

### *3.3. Evaluating the Effectiveness of the Flipped Classroom*

On the other hand, the effectiveness of FC implementation for the class was assessed based on 5 domains: FC approach, instructor, student participation, learning materials, and assessment. Three means of data collection were used to assess the effectiveness of the flipped classroom approach, namely student reflection, course exit survey, and student performance. Data analysis was carried out on the course exit survey, and student performance was analyzed using Microsoft Excel. Meanwhile, verbatim analysis was conducted on the student reflection to identify the pain points that need to be addressed to improve the flipped classroom implementation during ODL situations. The student reflection was structured by adopting Gibb's Reflection Cycle method. In developing the course exit survey, some of the questions were adopted from Valero et al. (2019) to ensure the validity of the questions posed [32]. However, an additional question was developed to obtain more insight into student readiness and FC effectiveness. The course exit survey questions are shown in Table 2.

To portray the effectiveness of the FC approach, performance data of students who underwent the FC approach were compared with data of those who did not. They are deemed comparable since the students were randomly placed in the class, with the same learning material, expecting the same output at the end of the semester and in the same semester to ensure the load for each student is the same. The only differences seen in the sample are the instructor and the learning approach implemented.

The questions posed to the respondents were meant to be reflective of the elements in FC adoption as well as its effectiveness. The number of questions was considered sufficient to answer the research questions. Furthermore, they were designed to be minimal to ensure quality of the result and increase the response rate from the respondents.

**Table 2.** Course exit survey questions used to measure the effectiveness of FC approach.

| Cluster | Num | Question Asked |
|---|---|---|
| FC approach | A1 | This approach of teaching increased my motivation when studying this subject. |
| | A2 | I found this approach intellectually challenging and stimulating. |
| | A3 | My interest in this subject increased as a consequence of this learning method. |
| | A4 | I have learned and understood the contents of the course using this approach. |
| Instructor | B1 | The instructor was enthusiastic about teaching the course. |
| | B2 | The instructor was dynamic and energetic in conducting the course. |
| | B3 | The instructor succeeded in making lessons enjoyable. |
| | B4 | The instructor's style of presentation held my interest during class. |
| Student participation | C1 | Students were encouraged to participate in class discussions. |
| | C2 | Students were invited to share their ideas and knowledge. |
| | C3 | Students were encouraged to ask questions and were given satisfactory answers. |
| | C4 | Students were encouraged to express their own ideas and question the instructor. |
| Learning materials | D1 | Explanations given in the videos were clear and easy to understand. |
| | D2 | Video contents were well structured. I always knew where I was and where the course was going. |
| | D3 | The duration between the release of the material and the class session is appropriate. |
| Assessment | E1 | The assessment conducted is relevant to the material provided. |
| | E2 | The time provided for the assessment is sufficient. |
| | E3 | The assessment helped to reinforce my knowledge about theoretical concepts. |

## 4. Results and Discussion

### *4.1. Student Adoption of the FC Approach*

From the survey conducted on the 28 students who underwent the FC approach, a 92.8% response rate was achieved. Even though the sample size was relatively small, due to high response rate (>90%), the data are deemed acceptable to represent the population who underwent the flipped classroom initiative. Table 3 shows the result of pre- and post-adoption of the FC implementation. Overall, 92.31% of the surveyed students adopted the FC approach within 4 weeks of introducing the method (referring to Question 8). After four weeks, the students who had adopted the learning method increased to 100%. This can be clearly seen as the instructor experienced an increase in attention and traction in the later class of the semester. As student participation increases, students can answer the questions posed during the in-class session. This shows student readiness for the in-class session and completion of the simulation before the in-class session. A reflection by a student who underwent the FC approach sums up the experience:

> *"During the first week, I had difficulties to understand the lecture because it was done synchronize and the screen is so small that I had difficulty to see clearly. Also, I think it is difficult to focus, because I have to focus on lecturer's screen, and go back to my hysys tab and some points I might missed. After the new method was introduced, I found it very systematic and very satisfied with it."*

Furthermore, this claim is supported by data from Question 7 that show an increment from 53.85% to 61.54% in student participation during the in-class discussion. Moreover, this can be observe in the result from Question 4 which is related to the ability to complete the simulation prior to the class. In the pre-adoption stage, 96.15% of students agree that they can complete the simulation before coming to class. The percentage increases to 100 % four weeks after introducing the FC approach to the students. Students tend to appreciate the time and space to have consultation and discussion during the class session, as demonstrated in the reflection below:

**Table 3.** Pre- and post-adoption study data.

| Question | Pre-Adoption (First 4 Weeks) | | | | | Post-Adoption (After 4 Weeks) | | | | | Difference (Post–Pre) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **5** | **4** | **3** | **2** | **1** | **5** | **4** | **3** | **2** | **1** | **5** | **4** | **3** | **2** | **1** |
| 1 | 20 | 6 | 0 | 0 | 0 | 20 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 24 | 2 | 0 | 0 | 0 | 23 | 3 | 0 | 0 | 0 | −1 | 1 | 0 | 0 | 0 |
| 3 | 15 | 8 | 3 | 0 | 0 | 18 | 7 | 1 | 0 | 0 | 3 | −1 | −2 | 0 | 0 |
| 4 | 14 | 11 | 1 | 0 | 0 | 18 | 8 | 0 | 0 | 0 | 4 | −3 | −1 | 0 | 0 |
| 5 | 19 | 7 | 0 | 0 | 0 | 21 | 5 | 0 | 0 | 0 | 2 | −2 | 0 | 0 | 0 |
| 6 | 19 | 7 | 0 | 0 | 0 | 23 | 3 | 0 | 0 | 0 | 4 | −4 | 0 | 0 | 0 |
| 7 | 10 | 4 | 8 | 4 | 0 | 13 | 3 | 8 | 2 | 0 | 3 | −1 | 0 | −2 | 0 |
| 8 | 17 | 7 | 2 | 0 | 0 | 22 | 4 | 0 | 0 | 0 | 5 | −3 | −2 | 0 | 0 |

5—strongly agree, 4—agree, 3—neutral, 2—disagree, 1—strongly disagree, sample size n = 28, response rate = 92.8%.

*"It is good that we prepare the simulation before class and the lecturer will focus on the discussion on class, so that we will gain more facts and knowledge and have ample time to ask anything we want know during the class."*

The result obtained is in good agreement with a study conducted on FC adoption in medical higher education. The study reported that the significant factors that impact the students' FC adoption its usefulness, enjoyment, self-direction, and flexibility [33].

On the other hand, the effectiveness of FC implementation for the class was assessed based on five domains: FC approach, instructor, student participation, learning materials, and assessment. Three means of data collection were used to assess the effectiveness of the flipped classroom approach, namely student reflection, course exit survey, and student performance.

### 4.2. Course Performance and FC Effectiveness

Students taught with the FC approach have shown a significant result in course performance. It is shown in Figure 3 that students who underwent the FC approach managed to score better results compared to those who did not. Of students who underwent the FC approach, 39.29% managed to score an A for the course. Meanwhile, only 8.33% and 11.11% of students who had conventional lectures managed to obtain an A and A-, respectively. The average mark for students who underwent conventional lectures is 68.8%. A significant increase in average marks of 74.2% was observed in the students who underwent the FC approach. Furthermore, it is observed that 0% of students who were exposed to the FC approach scored lower than B-. It is a good indicator as students undergoing the FC approach can grasp more than 60% of the overall course.

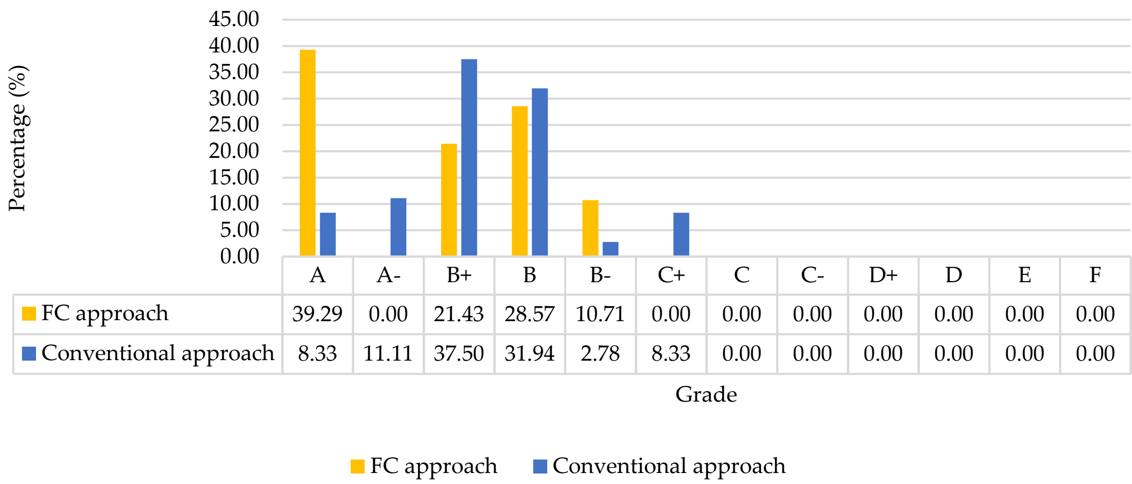


**Figure 3.** Comparison of student performance based on learning method (sample size for FC approach, n = 28, sample size for conventional approach, m = 72).

For the class that utilized the FC approach, student attention is more directed towards the in-class discussion than completing the simulation and mimicking the instructor's movement in the simulator. This is the advantage of FC whereby the student can understand and apply the fundamental theory prior to the in-class session. Meanwhile, the discussion session promotes higher order thinking skills, focusing on justification of the equipment selected and the relationship between application of the simulation and the fundamental knowledge they have learned previously. The connection was made visible to the student and the student appreciated it. The quick-fire questions mentioned in Section 3.1 probe the student's readiness and ability to think critically. The student is expected not to just be able to solve the case study given to them but also articulate the knowledge they acquired during the discussion, pre-recorded video, or any other means of learning. Shown below are some of the reflections by the students on their perspective of the learning process imposed on them.

> *"Satisfying moments are of course when I am able to answer the questions that Dr asked in class even though I didn't unmute my mic. It shows that the learning process is impactful for me."*

> *"YESS. I like this learning approach because I can explore myself first, and I really think that this method of learning can improve my critical thinking skills. In class, I can ask the lecturer on certain things that I don't understand or when I can't solve it. I really like the discussion in class, because I can understand it better."*

Similar results were obtained by other studies and in several fields. A study in the medical field in India shows a significant positive result for the students who underwent the FC approach compared to the conventional small group teaching and learning techniques. Eighty-two percent of the students agreed that the FC approach was engaging and 76% of the students would prefer to learn using this method in the future [34].

Apart from performance, student motivation to participate during the in-class discussion also increased. This can be seen in Figure 3, which shows that 100% of the respondents agree that the recorded videos, in-class discussions, and consultation sessions with the instructor significantly helped in addressing their understanding of the course. Having an engagement session with the student promotes motivation and keenness towards the learning method and materials. Due to the limitation of ODL, face-to-face interaction is not possible. However, other modes of engagement such as instant messaging and online consultation sessions can be used. Online engagement sessions should not limit the interaction between the instructor and student. Furthermore, it should serve as an advantage and it eliminates the need for logistics such as a venue and transportation.

Getting students involved in the discussion is crucial in maintaining the student interest and readiness in ODL settings. Allowing the students to showcase their work and understanding serves as feedback to the instructor. The FC approach capitalized on that sentiment as the students were asked to prepare a simulation prior to the in-class discussion. Keeping the student motivation high during ODL is essential. As shown by the reflections below, the students tend to enjoy the instructor's motivation and enthusiasm for in-class discussion and consultation sessions.

> *"For me, the instructor very energetic for every lesson that he teaches. He always asks students if there are any problems regarding to the subtopic and prefer students to volunteer to show their simulation. For me, that method is the best way to increase confidence about this subject."*

> *"I like the way my instructor explains things. Very clear and concise, with examples that helps me understand better. The instructor also provided us with some questions that needs us to solve and we will discuss it in class. I found it very interesting because I will find a way to solve it first, then we will discuss in class where the instructor was very helpful in helping us to find the best way to solve it and through an engineer perspective. I believed I've gained many knowledge from this class."*

Aside from that, Figure 4 shows that other online video sources were not favorable for the students. Even though the content is somewhat similar to the videos prepared by the instructor, students tend to rely more on the instructor's video. This shows the preference and connection made between the instructor and students during the semester.

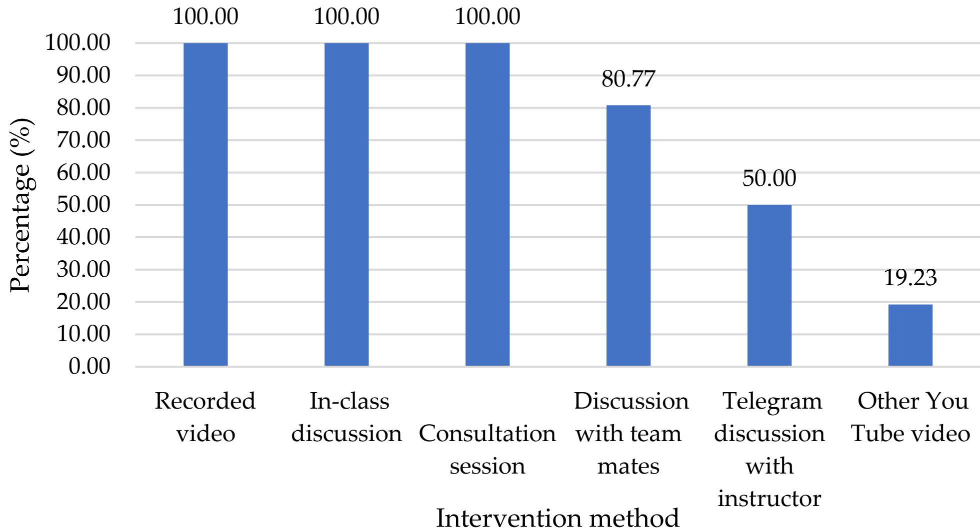


**Figure 4.** Intervention method preferred by the students to increase their level of understanding.

### *4.3. Course Exit Survey*

Figure 5 shows the course exit survey conducted on the students who underwent the FC approach. The data show that, in all cases, more than 80% of the students agree with the statements given in Table 2. The focus on successful FC implementation should be emphasized in sections C (student participation), D (learning materials) and E (assessment).

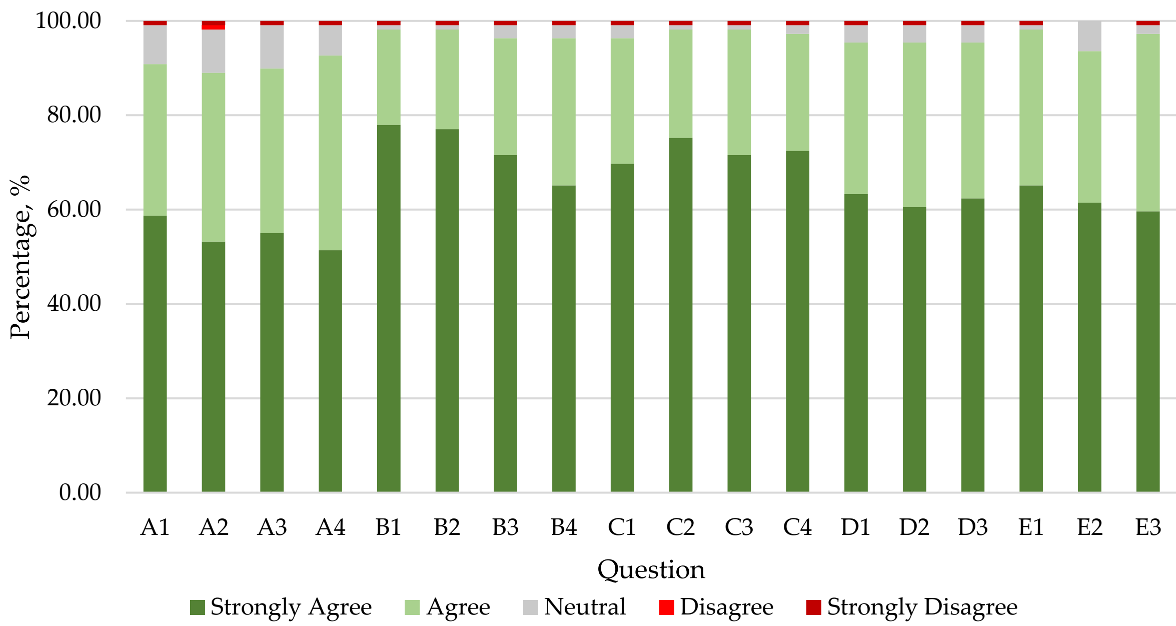


**Figure 5.** Course exit survey for students who underwent the FC approach.

Regarding the learning materials, 95.41% of the students agree that the videos provided before the class are easily understandable and well structured. This helps the student understand the material before coming to class which is fundamental to the FC approach. Furthermore, having enough time to view and study the video is equally important. In this study, it has been shown that the instructor is able to release the videos in a timely manner, allowing the student to gain maximum benefit from the FC approach.

Other than that, the in-class discussion and activities tie the FC principles together. Designing an engaging activity with the students boosted morale and promoted academic discussion. Opening the class for an open discussion and inviting the students to showcase their knowledge is part of the initiative in this study. The course exit survey shows that 98.17% of students agree that they were invited and encouraged to participate and share their ideas on their devised solution with the class. This practice allows the student to be independent and take control of their own learning process by asking quality questions to the instructor if they could not solve it. As practiced during the in-class discussion, obtaining the "converge" status in the simulator does not guarantee the student is able to justify their simulation because the data feed to the simulator also needs to be justified. This further develops the critical thinking and thinking skills of the student. Furthermore, learners showed interest in attending the synchronous session as it provides the opportunity for them to share their solutions. The results are supported by a study conducted in 2014 that shows that the students were satisfied with the course, increased their effort in completing the task, as well improved their attendance in the class [25].

The constructive alignment concept was adopted in aligning the assessment to the learning outcome and the learning activities. The alignment was made visible to the students via several briefing sessions regarding the analysis's expected depth and breadth. Furthermore, the rubrics were shared with the students to enforce transparency in marking the students' performance. By following these actions, 98.17% of students agree that the assessments conducted are relevant to their learning outcome and experience. Furthermore, 97.28% of the surveyed students concur that the assessment given to them assists in reinforcing their knowledge about the theoretical concept learnt during the FC approach.

Figure 5 illustrates that 88.99% of students agree that the FC approach is cognitively challenging and stimulating. However, this fact does not impact the student learning process as 89.91% of the students agree that their interest in the subject significantly increased due to this learning method. Aside from the learning method introduced, the role of an instructor in facilitating the student learning process is crucial. As the survey shows, on average, 97.25% of the surveyed students agree that enthusiastic, dynamic, and energetic instructors are key in making the FC approach relevant to them. Supported by the reflection of the student below, being able to build a connection with the students is also key in keeping the students interested in learning the course:

> *"I am very thankful and grateful for having Dr as my instructor because he is very enthusiastic in teaching. Besides, he is very easy-going and approachable, as these traits are very helpful in helping students to understand more about the course."*

Based on the available data, specifically the students' performance and reflections, it was proved that the FC approach in this Process Simulation course has provided a positive impact on the student learning experience. Positive feedback from the learners shows their satisfaction with and adoption of the learning method. Fast adoption influenced the students to use this learning method that offers engaging interaction between the learners and the instructor. This is backed up by the students' performance throughout the course. Based on the $t$-test conducted between the two sets of teaching approaches (conventional and FC approach) and comparing the student results, it is observed that the $p$-value obtained is 0.0216 ($<0.05$). This shows that the difference between the two sets of data compared is statistically significant. In this case, the FC approach significantly improved the students' performance compared to the conventional approach. This can be supported by the mean value for the FC approach which is 74.23% compared to 70.74% for the conventional approach. The learners' reflections presented in Sections 4.1–4.3 shows that there are significant factors that can influence the learning process which include the learners' readiness for the synchronous session, the instructor, and the learning activities during the synchronous session. Based on this data triangulation, it is suggested that the FC approach can be used for skill-based courses. Thus, the results obtained in this study reduce the gap reported in a previous study in 2021 that mentioned that lab classes in engineering disciplines are not encouraged to implement the FC approach [12]. Furthermore, the finding in this study concurred with a review study which reported that a positive relationship has been observed between the student performance and adoption of the FC approach [29].

## 5. Conclusions

In a nutshell, the FC approach is very flexible and can be adopted in a face-to-face or ODL setting. It is flexible enough and easily adopted by the students as early as 4 weeks. The students' and instructor's commitment to delivering the FC approach is critical to ensuring the effectiveness of the FC approach. In this study, the FC approach proves to have a significant impact on student knowledge attainment. It can be seen that the learners were able to adopt the learning pedagogies in a short period of time as 100% of the learners were able to adopt the FC approach by 4 weeks of implementation. The statistical analysis also shows that the difference in average marks between the FC approach (74.23%) and conventional method (70.74%) is significant. Furthermore, diversifying the mode of engagement with the students, such as utilizing online consultation sessions and informal academic discussions with students outside of class hours, really helped in maintaining the student interest in the course and the FC approach. Besides that, the instructor's proper planning and training are key to delivering an impactful learning experience for the students. Building a conducive learning environment as well connections between the learners, instructor, and community might boost the effectiveness of the learning experience of the learners. However, this study acknowledges the limitations of the student demographics as it is focused on a Malaysian public university setting.

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