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From Online to Hybrid: The Evolution of Flipped Learning in a First-Year Engineering Mechanics Course

Rania Al-hammoud (Dr.)

Dr. Al-Hammoud is a Faculty lecturer in the department of civil and environmental engineering at the University of Waterloo. Dr. Al-Hammoud has a passion for teaching where she continuously seeks new technologies to involve students in their learning process. She is actively involved in the Ideas Clinic, a major experiential learning initiative at the University of Waterloo. She is also responsible for developing a process and assessing graduate attributes at the department to target areas for improvement in the curriculum. This resulted in several publications in this educational research areas. Dr. Al-Hammoud won the "Ameet and Meena Chakma award for exceptional teaching by a student" in 2014 and the "Engineering Society Teaching Award" in 2016 and the "Outstanding Performance Award" in 2018 from University of Waterloo. Her students regard her as an innovative teacher who continuously introduces new ideas to the classroom that increases their engagement.

Kylie Wan Yue Chan

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Abstract

This paper examines the evolution of a first-year engineering mechanics course, Solid Mechanics I, over the two iterations that it has been flipped. It discusses the teaching strategies that have and haven't worked when delivering the course in both an online and hybrid approach. These include recommended durations for lecture videos, types of assessments, grade distributions, etc.

Flipping the classroom was a result of the forced transition online due to Covid-19. To best support the students in the unprecedented times, the instructor opted to combine components from both asynchronous and synchronous teaching styles. Asynchronous lecture videos were accompanied by synchronous class time where the instructor clarified concepts, demonstrated real-life applications, solved higher-level problems, and implemented group activities. A combination of these active learning strategies was the key to structuring the course to keep the students engaged despite being online for all, or part, of the term as delivered in Fall 2020 and Fall 2021, respectively.

In the Fall 2020 iteration, the course was delivered fully online to roughly 325 students in civil, environmental, geological, and architectural engineering. Since then, the course had been improved and adjusted in response to the students' feedback collected from an end-of-term survey. Approximately 270 students were enrolled in the course in the subsequent Fall 2021 term which took a hybrid approach as Covid-19 restrictions began to lighten. With students being able to learn in-person again, the course had shifted to emphasize student-to-student and student-to-instructor interactions. Feedback became immediate, allowing for the course to be molded to the students' satisfaction as the term progressed. Changes between the two years have been documented in the paper along with recommendations for future adaptations.

Introduction

The sudden propagation of Covid-19 worldwide forced a rather quick transition to online teaching. Having to transition fully online meant, for many classes, losing the interaction that would take place in a regular classroom setting. In efforts to avoid this situation for incoming first-year students, the instructor of the first-year engineering mechanics course, discussed in this paper, decided to flip the classroom. This involved creating pre-recorded lecture videos for students to view asynchronously, designing ungraded quizzes for self-assessment purposes, and developing group activities for online and in-person deliveries to keep the students engaged in their learning.

Flipped learning, or a flipped classroom, is nothing new. It has been around for decades with no specific person or persons claiming to be the creator. In 2012, however, the pedagogical model gained popularity after the release of [1] by Sams and Bergmann which describes the flipped classroom and what it has to offer. As teachers, Sams and Bergmann wrote the book documenting the methods used in their own flipped classroom followed by a discussion on what worked and what didn't. The book concludes with a recommendation for educators to turn to flipped classrooms, using their experience as a starting point which details its success and effectiveness in improving a student's performance in a course [1], [2].

Summarizing the main elements of flipped learning as discussed by Sams and Bergmann in [1] is a literature review, white paper, and executive summary [3] written by Hamdan et al. which condenses the model into four pillars: flexible environment, learning culture, intentional content, and professional educators.

Flexible environment – The flexible environment accommodates varying learning habits and differing schedules that students may have in any given day. It is likely that the course is designed asynchronously to allow students to watch the lectures and go through the content at their leisure. Students are able to take control of their schedules and work school around their schedule and not vice versa.

Learning culture – The learning culture pushes the focus onto the students, placing them at the center of their learning, namely the learner-centered approach. This approach involves clarifying concepts from the videos, demonstrating real-life applications, solving higher-level problems, and implementing group activities to encourage the students to be involved and actively engaging with the course [4]. According to [5], it has been found that students who are more involved in their learning tend to succeed in their academic careers and later in the workplace. This can be accredited to the opportunities provided through flipped learning to develop and refine their practical skills such as problem-solving, innovation and collaboration, among others.

Intentional content – Intentional content is content curated according to the students' needs. For example, students in engineering tend to be visual or kinesthetic learners. They require physical demonstrations and the exposure to hands-on activities that will allow them to best understand the concepts. Part of being an engineer also means working in a team which suggests that engineering courses should include group activities where possible.

Professional educators – The professional educators are the ones responsible for directing the use of class time. It is up to the educators to provide support to the students and help in progressing their learning. Overall, the pedagogical model is rather valuable for engineering courses as it provides the opportunities to incorporate activities and other active learning tools that are best suited for students in engineering. Supporting this notion are three studies, [5], [6], [7] found that the flipped classroom model had a positive impact on the students' performance [5] in a course along with helping them build the necessary soft skills sought in the workplace [6], [7].

Several studies have been conducted in review of the effectiveness of flipped learning on a student's experience in engineering courses. Nahar and Chowdhury [2] compiled their findings of multiple such studies and discovered that the most common approach to the flipped classroom in engineering involves pre-recorded lecture videos. Time in class then shifts to student-centered learning which emphasizes student involvement, improving their retention of the material by reviewing the concepts rather than teaching them for the first time. Dr. Al-Hammoud, the course instructor and co-author of this paper, has also experimented with the flipped classroom model back in 2017 with another mechanics course [8]. Results from this delivery showed a noticeable improvement in the students' performance based on grades from online quizzes. When comparing the flipped classroom model to the traditional approach, Dr. Al-Hammoud found that student satisfaction was elevated based on feedback collected from end-of-term surveys completed by the students.

The past couple of years also saw a spike in studies related to flipped learning. The cause being the impacts of Covid-19 and the search for a suitable method of teaching under our given circumstances. Many instructors including Rodriguez-Paz et. al [9] and Mu et al. [10] shared the sentiment of taking advantage of flipped learning when teaching online since part of the model is already made available online through pre-made lecture recordings. Grodotzki et al. [11], Suárez et al. [12], and Campillo-Ferrer and Miralles-Martínez [13] have also discussed how activities implemented through flipped learning help improve student motivation which has generally been lower during the pandemic. The activities provide students with opportunities to engage with and find enjoyment in their learning despite the lack of interaction that comes with studying remotely.

Though many studies describe the benefits of flipped learning and its suited application during Covid-19, there are few that document the continual evolution of a flipped classroom as it is being delivered. Starting fully online in the Fall 2020 term and transitioning to a hybrid term in Fall 2021, this paper discusses the process behind the development of a first-year engineering Solid Mechanics I course. Changes between both years reflected the feedback collected from students in an end-of-term survey where they were free to voice their opinions. Looking back on what worked and what didn't with the 325 students in the Fall 2020 term, the instructor developed the second iteration for the incoming group of 270 first-year students in civil, architectural, environmental, and geological engineering. New components were added to facilitate a better learning experience which have been well-received. Any issues that students had throughout the Fall 2021 term were addressed by the academic class representatives in divisional meetings with the instructors. Listening to the student's advice and their recommendations, modifications were made throughout the term to best satisfy the student's experience in the course. Going forward, this paper lists some recommendations for future adaptations of this model, working towards the ideal, or best-fitting, flipped classroom that can be used in other engineering courses.

General Classroom Guidelines

The general classroom guidelines cover the important elements that were common across the two iterations and their respective frameworks. Such elements include the online learning management system used by the school, the organization of the class in terms of sections and class hours, and the role of academic class representatives.

Online Learning Management System – The University of Waterloo delivers all its courses through an online learning management system (LMS). For the Solid Mechanics I course, the LMS served as a space where students could view the pre-recorded lectures, submit quizzes and assignments, and stay up to date on the latest announcements. Pre-recorded lectures were made available on a weekly basis with related quizzes and assignments due by the end of the week on Fridays and Sundays for each respective assessment. The quizzes were unlocked upon watching the entire set of videos for the week, and assignments were either unlocked upon achieving 100% on the quizzes prior to the Friday deadline, or automatically on Saturday to give all students a chance to get marks regardless of quiz completion.

Course Organization – Completing the Solid Mechanics I course is part of the degree requirement for the four engineering programs: civil, architectural, geological, and environmental, as per university guidelines. The course runs in three distinct sections, or classes, with geological and environmental engineering students being lumped together due to the relatively smaller class size as opposed to the civil and architectural engineering programs. During the two iterations in 2020 and 2021, each class was scheduled to meet once a week with the instructor for 1.5 hours of lectures, and once again with either the instructor or a teaching assistant (TA) for an hour of tutorial time. Details on how the time was spent in both lectures and tutorials are further discussed in the Online Framework and Hybrid Framework sections, below.

Academic Class Representatives – Within the engineering department at the University of Waterloo, each class will elect Academic Class Representatives which will be referred to as academic reps for the remainder of this paper. The position is open to all students in the class and for those who volunteer, a vote will be held to determine who will be appointed based on a majority count. An academic rep is responsible for liaising between the class and the professors, TA's, and the department. Over one term, the academic reps will participate in two divisional meetings with all their course instructors to discuss how a class is doing. In these meetings, the academic reps can bring forward feedback collected from their classmates through surveys. For the most part, it is through these meetings that the Solid Mechanics I instructor adjusted and improved the course to best satisfy the students.

Online Framework

This section discusses the elements of the flipped classroom model as applied in the Fall 2020 delivery of the first-year engineering mechanics course. Following health regulations, the term was run completely online with no opportunity for students to meet each other or the instructor in-person. Reliance on online platforms became the new normal for teaching and communicating.

Synchronous Tutorials and Office Hours

Lectures were made to be completely asynchronous, provided to the students as recordings through the University of Waterloo online learning management system (LMS). With no scheduled time for synchronous lectures, the instructor opted for using tutorial time to host online, synchronous sessions where students would direct the use of time by asking their questions. Much of the time spent in these sessions were focused on reviewing the concepts by going through step-by-step solutions of examples shown in the videos. The instructor took time to go through any questions that students had, making sure that they understood the concepts clearly before moving forwards.

Pre-recorded Lecture Videos

All lectures were made accessible to the students through the university's LMS. Each week, a set of videos would be released on Mondays giving students until the end of the week, on Fridays, to complete all the content which included the lecture videos, and the quizzes. The end-of-week assignments were made available until Sunday, giving the students extra time to work through them. Attached at the beginning of each module was a weekly breakdown of what was expected [14] to be completed to help guide their personal scheduling. The lecture videos were designed to be no longer than 10 minutes in duration [15] to avoid losing the students' attention partway through. With each week averaging about 4 videos, students were only required to spend 40 minutes watching the lectures as opposed to the usual hour and a half that would have been the case in a traditional classroom setting. By providing the lectures asynchronously, students also had the opportunity to pause and rewind as many times as they liked, following along at a comfortable pace.

Quizzes and Assignments

Both the quizzes and assignments were made to contribute a significant percentage of the final grade. The quizzes which unlocked after viewing all lecture videos for the week were set with unlimited attempts. This allowed the students to re-attempt the quiz as many times as necessary to fully understand the concepts, and to receive full marks. Achieving 100% on the quizzes also unlocked the assignment which students had one attempt to answer. By this time, students would have had plenty of opportunities to ask questions during the synchronous class time as described in part I, and enough practice with the quizzes to successfully complete the assignment even in a single attempt. The goal behind the quizzes with unlimited attempts was to help the students discover where they may be lost or confused so that they could join synchronous sessions prepared with questions.

Group Activities

The group activities allowed students to begin applying concepts learned in the course to real-word applications [14] relevant to their engineering fields like suspension bridges, arches, gothic cathedrals, dams, culverts, and more. An activity handout was created specifically for the online delivery which allowed students to complete them using materials found at home or using online software applications. Students were placed in groups to promote student to student interaction despite being online. Following up with the activities, each group was required to write a report and answer the prompt questions as provided in the activity handout.

Assessments

Given the circumstances as laid out by Covid-19, the First-Year Office at the University of Waterloo had recommended, at the time, to remove final examinations. Following their policies, the instructor decided to exclude a midterm and final exam. Since there were no exams, the grades in the Fall 2020 term were distributed among the three major components of the course: weekly online quizzes, weekly online assignments, and three group activities. Towards the final grade, quizzes were worth 20%, assignments worth 50% and the three activities totaled to the remaining 30%, each weighing 10%.

Hybrid Framework

Between the course deliveries in the Fall 2020 and Fall 2021, many adjustments had been made in response to the student's feedback from the first iteration. Most of the commentary was aimed at the pre-recorded lecture videos with overall satisfaction of the course, otherwise. In addition, in the Fall 2021 term, students were now allowed to return to class at 50% capacity. Each class was split into three groups: Section 1, Section 2, and Online. The online group comprised of students who could not be present on campus and therefore attended class hours online. On the other hand, the rest of the students were relatively evenly split between sections 1 and 2 to abide by the 50% class capacity enforced by the university. Students in sections 1 and 2 alternated between being online one week and attending class in-person the next. For instance, the first week, Section 1 would be in-person while Section 2 attended online and vice versa for the following week. These newer circumstances prompted the implementation of several newer components to the course structure in comparison to the Fall 2020 delivery. The following points address the new structure along with the limitations found with the initial delivery.

Synchronous Lectures and Tutorials

In the first Fall 2020 iteration, students felt lost with the short amount of time that was spent with the instructor. They had hoped for more in-depth, hand-written explanations provided directly by the instructor as opposed to the pre-written solutions from the lecture videos.

Since students were now able to join classes in-person, the instructor ran synchronous lectures and tutorials. Students were expected to come to class having watched the pre-recorded lectures. In-class time was then dedicated to various activities that would help in furthering the students' understanding of the material. Each class started off with a quick review of the week's material, paired with live demonstrations to provide a visual example of the theoretical concepts. The instructor encouraged students to interact by asking for volunteers and prompting discussions

[14] regarding their predictions and the connections that could be made with the lecture videos they would have watched. In addition, the instructor worked through more practice problems, pausing whenever necessary to answer questions from students attending both in-person and online.

Tutorials were scheduled twice a week and led by the TA's. Each week, the TA's would prepare two to three problems to solve together with the class. At the beginning of each session, the students would be given time to work through the problems on their own. The students were encouraged to work together with their seatmates in case they got stuck, to foster peer-to-peer connections.

Pre-recorded Lecture Videos

Overall, there was a consensus that the videos provided in the Fall 2020 term were not very helpful in learning the concepts. Students attributed the problem to a lack of explanation for major concepts, errors in calculation and spelling, emotionless narration, and most importantly, the delivery of the lesson. They were rather disappointed and claimed that they could have easily taught themselves the concepts since the videos were no different than reading directly from the provided lecture notes. In addition, students hoped to see more examples in preparation for the quizzes and assignments which shared different levels of difficulty from the videos.

To avoid getting the same response, the instructor worked with a group of students over the following term to re-make the entire set of videos. The main areas where the videos were improved upon are as follows:

- Errors in both grammar and calculations were identified and fixed.
- A blank set of lecture notes was developed for students to follow along and fill out for themselves.
- Solutions for examples were hand-written while the narrator explained each step to allow students to follow along and understand how a solution or conclusion was made.
- Colours in the form of ink and highlighting were used to emphasize key points.
- Small activities were interspersed within the videos to allow students to apply the concepts in the comfort of their homes.
- Captions were added for clarity and to account for accessibility.
- The pace of the videos were slowed down to allow students to follow along with the video, writing down solutions as the video progressed.

Fig. 1 and 2 show the comparison of the lecture videos between the 2020 and 2021 iteration, respectively. In this example, the same problem in Fig.1 was enlarged in Fig. 2 to better show the different elements that would be used in solving the problem. Unlike the solution in Figure 1, lots of different colors were also used in the solution shown in Fig. 2 to differentiate between what elements were needed for which part of the problem. Captions were also added to the second set of videos allowing students to turn them on or off as necessary whereas the first set of videos did not have that option.

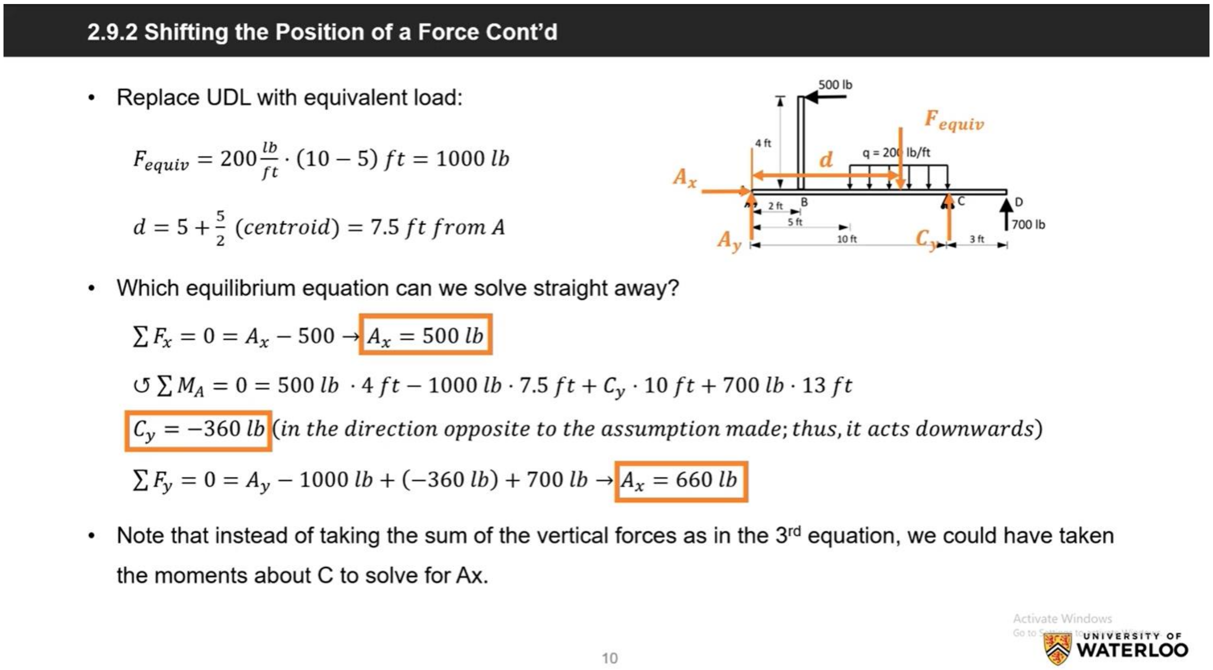

Fig 1. Screenshot of a lecture video used in the fully online, Fall 2020 iteration.

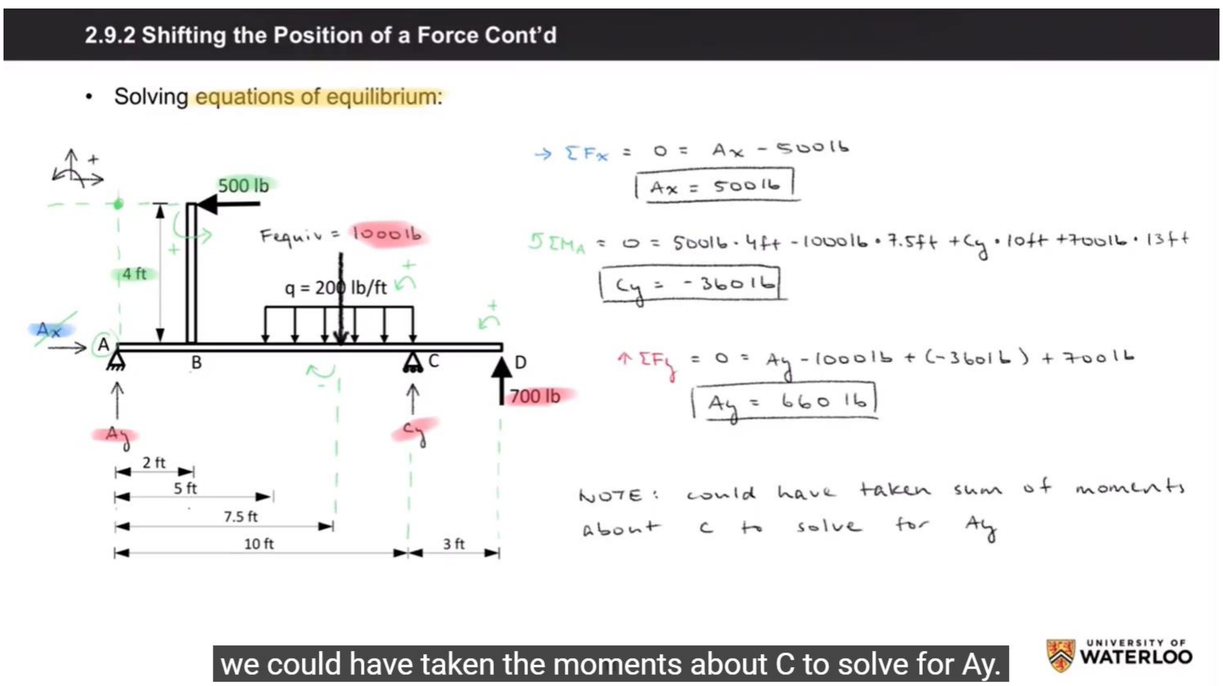

Fig 2. Screenshot of a lecture video used in the hybrid, Fall 2021 iteration.

The new video set has been made publicly available on a YouTube channel called "UW Mechanics". The instructor encourages others to use them and has added them to YouTube to give the students continual access to the content even after the course closes in the LMS once the term comes to an end.

Quizzes and Assignments

The quizzes and assignments followed the same principle as in the first iteration. Quizzes were intermittent between lecture videos, and assignments were to be completed at the end of the week. The same restriction in terms of availability were applied where students were required to view all the lecture content and achieve 100% on the quizzes before accessing the assignment. The key difference between the Fall 2020 and the Fall 2021 term was the release date for the weekly content. Initially, the content was set to be made available every Monday morning, however, the date was pushed ahead for an earlier release on Sundays to give students the extra day to work through the content.

Group Activities

In the second iteration, the group activities remained the same, however, students were now able to work together, face-to-face. This allowed students to make connections with their peers and learn new perspectives through discussion and experimentation. Students were provided with lab activity kits during select tutorial dates and were tasked with following along with the activity handout. At the end of the tutorial, students would have completed their activities and were left to submit a written report answering questions from the handout. In summarizing the activities, students were prompted to reflect on their learning which is linked to better retention of material [14].

Kahoot: Learning Platform

Each week, the instructor prepared a multiple choice Kahoot quiz as a review for students to gauge their progress. The appeal with Kahoot is the interactivity as well as the gamification of learning as students compete to get first place on the podium by scoring the highest number of points from answering the questions correctly. Initially, the Kahoots were made with up to 15 questions, however, the number dropped to an average of 6 questions in the later weeks after finding that students were losing interest the longer it lasted. The Kahoots were not for marks, but the student who came in first place would receive a small prize from the instructor in the form of goods from the university’s store as incentive.

The major component of the Kahoots was the timed aspect of the questions which according to the academic reps, added unnecessary stress to the activity. Students felt defeated after leaving class knowing that they were unable to answer many of the questions. The questions from the Kahoots, however, were posted to the online learning management system afterwards to provide extra practice problems in preparation for the assessments.

Teaching-Based Group Project [16]

At the end of the term, students were asked to select one of the group activities that they completed earlier on in the course for their final project. The project entailed an hour-long presentation to a local grade 7 or 8 science class to inspire the younger students on their potential future. The first-year students were tasked with developing an interactive lesson plan with activities of their choice to engage the students. Part of the presentation involved researching societal or environmental impacts that were tied to the structure of interest. For example, a group who chose dams as their structure would explain that there's a potential for damage to aquatic habitats, but there is also the benefit of jobs being created during its construction. Having to perform the research for themselves and become the teachers, students were able to further their understanding of the course's core concepts. More details on this project can be read in [16].

Assessments

The high weighting of the quizzes and assignments in the Fall 2020 term affected the students as they became pre-occupied with getting the best grades. Their fixation on the percentages shifted the focus away from the actual learning and eventually their retention of the material as explained in [17]. To replace the students' focus on the content, the grading scheme of the course was drastically changed for the second iteration with the quizzes and assignments being dropped to 10% each. The rest of the final grade was distributed among the activities which were also lowered to a 20% weighting, a 20% project, and the addition of a final exam worth 40%.

Results

Despite the challenges of delivering a course to students in a hybrid manner (both online and in-person) the second iteration of the course in Fall 2021 was met with much satisfaction, as seen in Fig. 3. Students were asked to answer questions on a scale of 0 to 5 where 0 was "Very Dissatisfied", and 5 was "Very Satisfied". The values were calculated as an average from all students between the two terms. For the most part, students were a lot more satisfied with the delivery in the second iteration which followed the hybrid approach to the flipped classroom.

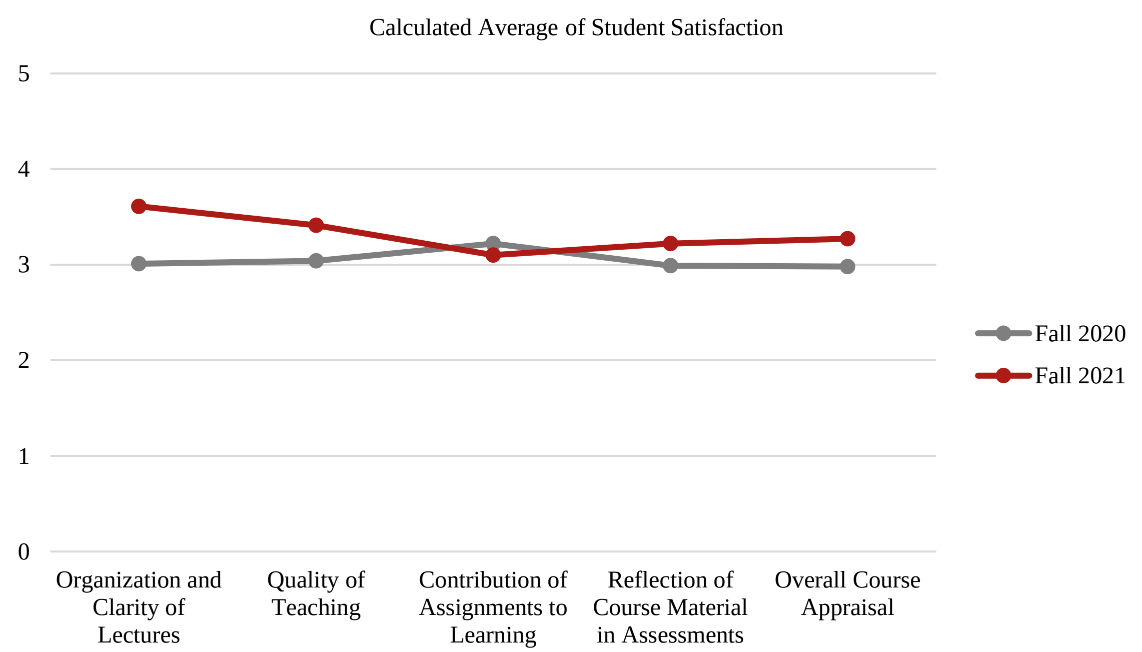

Fig 3. Chart comparing the calculated average of student satisfaction in varying topics relating to the course between the two deliveries.

In another survey conducted at the end of the Fall 2021 term, the students were asked to select the components of the course that they thought were most and least helpful, as shown in Figures 4 and 5, respectively.

According to the results, roughly a third of the students were in agreeance that the in-class demonstrations were the most helpful component when it came to helping them understand the concepts. Its popularity was linked with the interaction and opportunities for discussion that would have been difficult in a fully online delivery. The students enjoyed being able to connect with their peers and learn from one another, taking in new perspectives. In addition, students appreciated the visual aspect of the in-class demonstration with many stating that they learned best in this approach. Unlike the pre-recorded lecture videos, students were also able to ask questions in real-time and get immediate answers in high detail. In sharing a common space in the classroom with half of the class joining online, students were also able to listen in on each others' questions and the corresponding answers without delay.

Tutorials were also among the most helpful components of the course with 74 votes. The TA's ran the tutorials, arriving to their sessions with extra problems prepared to be solved with the students. For the most part, students were satisfied with the tutorials. Concepts were reinforced through the step-by-step solutions of harder questions which students appreciated. With each TA teaching in their own style, students were also exposed to varying approaches in solving the problems which was helpful. The drawback with the different teaching styles, however, as highlighted by a few students seen in Fig. 5, were the inconsistencies between the TA's. While some were detailed in their explanations and wrote in an organized fashion, some were not as detailed, skipping over important steps that students could not follow.

With 61 votes, the group activities were rather popular among the engineering students. Conversations surrounding the application of the concepts to existing structures were formed as students were able to work directly with the activity kits. For many of the students this was ideal since the activities were suited to their preferred style of learning. Among those who voted, there was a general sense of enjoyment that came from learning in groups and with the kits.

In Fig. 5, we see that the Kahoot quizzes were the leading component that students found least helpful. This was no surprise as the dissatisfaction was discovered later in the term, leading to its removal for the civil engineering class who voiced their opinion on the matter.

As for the rest of the components, the votes for least and most helpful were roughly equal. Some students enjoyed them while others didn't. Based on these results, the course is likely to continue changing for the benefit of the students. Components that are integral to the students' learning as judged by the instructor, however, will continue to appear like the office hours, tutorials, weekly quizzes and assignments.

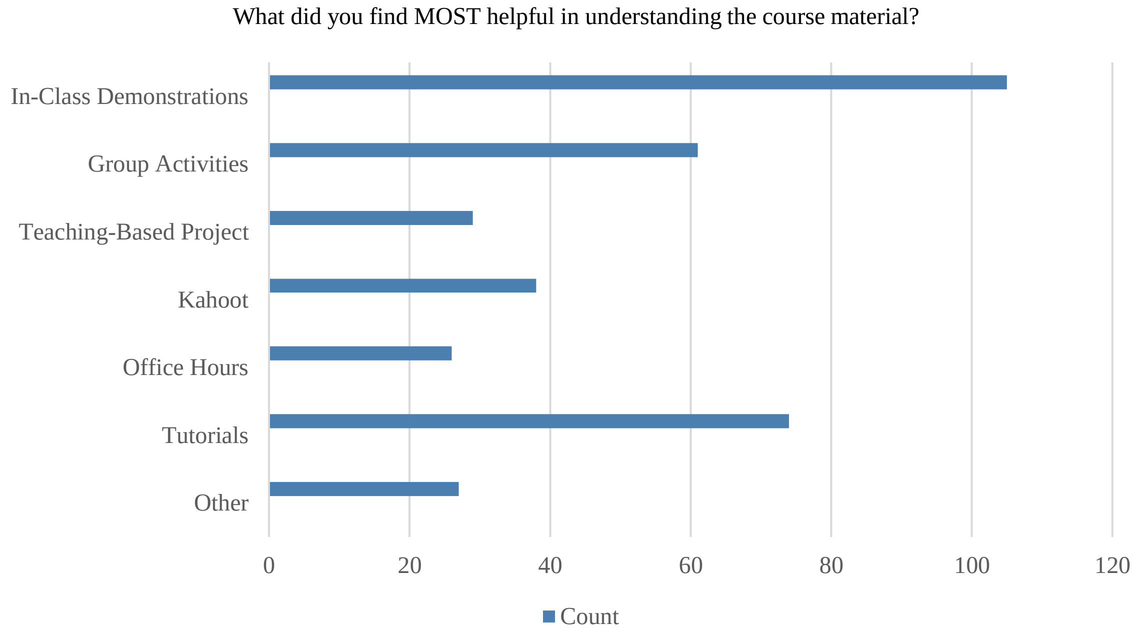

Fig 4. A column chart showing the total count of what students deemed the most helpful component of the course. Students were able to choose multiple options.

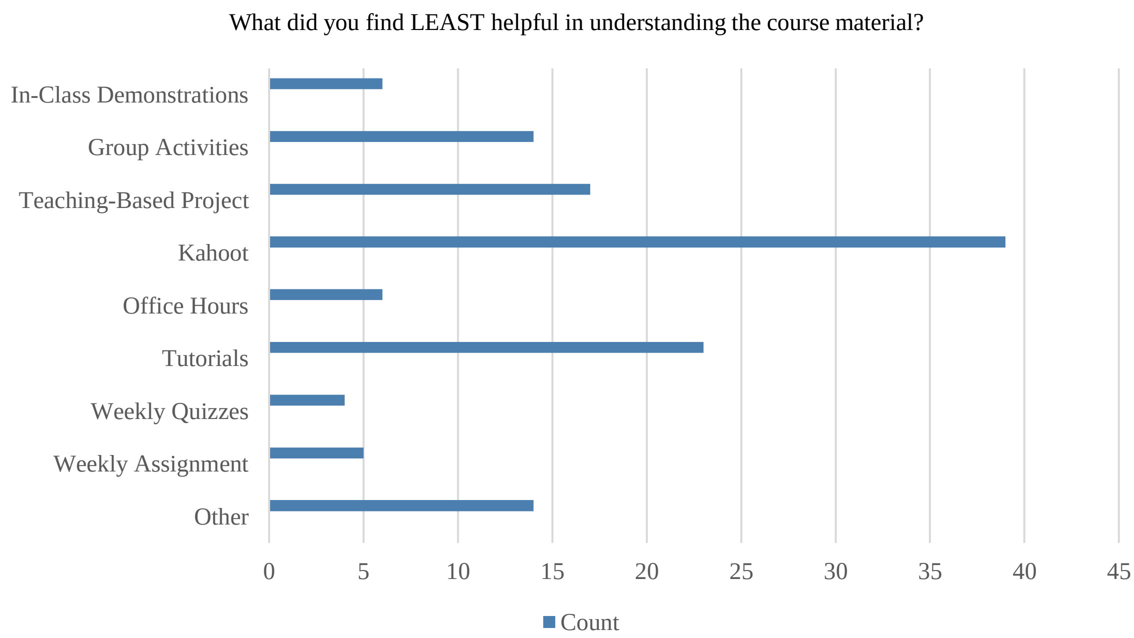

Fig 5. A column chart showing the total count of what students deemed the least helpful component of the course. Students were able to choose multiple options.

Recommendations and Conclusion

Covid-19 disrupted many aspects of our everyday lives including instructional approaches. A significant portion of the world was forced to move online and engage in a newly remote society.

An entire year of education was spent completely online and not many were prepared for the change. With flipped learning, part of the learning happens online through pre-recorded lecture videos making any future transitions a lot easier and less stressful. Besides flipping the classroom simply to follow protocols, the pedagogical model comes with many benefits, especially for students in engineering. Applying flipped learning to an engineering course should involve the use of visual aids along with the implementation of activities or physical demonstrations that are more suited to the learning type of most engineering students.

For the future, a list of recommendations has been created with some being based on student suggestions received from the end-of-term survey in both terms. The following items highlight what worked and what didn't as outlined in this paper with potential for adaptations by other instructors.

- Pre-recorded lecture videos can run up to 20 minutes in duration if it means providing thorough explanations of core concepts and sufficient coverage of varying examples. Students wouldn't mind sitting through an extra 10 minutes as long as they are able to understand the concepts by the end of the lecture.
- Examples completed in the pre-recorded lectures, the synchronous lectures, and the tutorials should all be different to provide students with more opportunities to practice without having to repeat the same questions over and over.
- Minor assessments (quizzes and assignments) should remain within the same level of difficulty as the lecture examples, otherwise more examples should be shown in the pre-recorded videos to show how to approach various problems.
- Grades should be distributed in a way that will prevent students from obsessing over their marks to keep the focus on the content.
- Make use of the LMS used by the institution to deliver all content to the students in an organized manner.
- Schedule enough synchronous class time to maintain student-to-instructor interactions throughout the term. Being able to see their instructor will help students feel less detached from the course and prevent the deterioration of their motivation.
- Listen actively to your students' opinions and feedback. It is important that they are benefitting from the course as opposed to working through it for the sake of completion. Students won't enjoy a course that remains unchanged despite voicing their dissatisfaction. This, however, does not mean that a course should be completely altered according to the students wishes. All core teaching points should remain, but it is the delivery that can be adjusted to fit.
- Many students preferred that the instructor teaches the material in-person. This is not to discount the benefits of the pre-recorded lectures provided in this pedagogical model, rather it indicates that either the videos are to be created by the instructor themselves, or that the videos are to be used as backup to support the students' understanding of the concepts.

Although there is no such thing as the "perfect" pedagogical model, flipped learning comes close. The possibilities are endless as different routes can be explored with heavier emphasis on certain aspects of the model. The evolution of the first-year engineering course as discussed in the paper shows that continual refinement and improvements based on student feedback will eventually turn the course into one in which students will succeed and enjoy.

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