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Enhancing student learning in online courses through flipped classroom and multi-stage assignment structure

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Abstract

As the demand for online learning keeps growing in higher education, developing teaching pedagogies that are effective in online education is of importance. Teaching courses remotely involves challenges such as difficulties in retaining student attention and promoting collaborative in-class activities. These can adversely affect students' motivation for learning, comprehension of new concepts, and application of knowledge in realistic problems. In this study, the efficacy of flipped classroom pedagogy in online classes is investigated, with a focus on student engagement and learning outcomes. An undergraduate fluid mechanics course was reconstructed as an online flipped classroom; the student performance was compared to that of the previous in-person, non-flipped sections taught by the same instructor. The paper discusses three main design aspects in implementing an online flipped classroom: 1) syncing the material delivery paces with assignment deadlines, 2) multi-stage assignments on the same topic at incremental difficulty levels, and 3) web-friendly and well-defined deliverables for group problem-solving activities. In both sections offered as the flipped online classroom format in Fall 2021, remarkably high student participation was observed, with an average of 1.1 students absent out of 88 students throughout the semester. Furthermore, compared to the two previous in-person, non-flipped sections offered in Spring 2018 and Spring 2019, the online flipped classroom students earned a 3.5% higher average score on the same final exams. Overall, improvement in both student engagement and learning outcomes has been observed for the online flipped Fluid Mechanics course. Finally, the paper discusses the advantages, implementation strategies, and limitations.

Introduction

Since the late nineties, web-based remote teaching and learning, namely online courses, have been growing rapidly to meet the educational demands of those limited by location, time, and availability. Based on studies performed prior to COVID-19 pandemic, students perceived online learning to be more convenient [1], but less effective for learning compared to face-to-face instructions [2], [3]. The effectiveness of online education has been under debate for many years, with some arguing that similar or better student performance than in-person courses was achieved [4], while others reported the opposite [5]. As a matter of fact, the quality of online education depends on various factors such as structure, pedagogy, out-of-class interaction, and a portion of synchronous versus asynchronous interactions [6], [7].

Unforeseen challenges struck higher education in Spring 2020 when COVID-19 abruptly and forcefully exposed numerous college students to some form of online learning whether it was asynchronous or synchronous. From a recent study, Means and Neisler stated that the percentage of STEM college students who were very satisfied with the course dropped from 47% to 15%

after their in-person courses converted to fully online modality in Spring 2020 [8]. The students identified the difficulties in maintaining the motivation and getting help as major factors impacting their online learning experience. The fact that a large population of students took online classes regardless of their intention made online instruction during the pandemic exceptionally challenging and susceptible to being compromised.

This study leveraged "flipped classroom" as a pedagogical method to overcome the commonly encountered obstacles in online courses. In flipped classrooms, both the timing and function of at-home learning and learning in the classroom are reversed. Students first independently learn about a topic at home through pre-class assignments, and then the class time is used for activities and interactions with others to strengthen the learning [9]. Well-known benefits of the flipped classroom format include increased peer interactions through in-class group activities [10], more frequent and engaging faculty-student interactions[11], and flexibility that allows students to learn at their own pace through pre-recorded lectures [12]. Naturally, flipped classrooms are a great avenue for promoting collaborative learning [13], [14], active learning [15], and problem-based learning [16]. As a result, several studies have demonstrated enhanced student performance in courses offered as flipped classrooms compared to traditional lecture-based formats [17], [18].

Flipped classroom has been also implemented in online courses and found similarly effective [19]–[21]. At the same time, the use of flipped classroom format in full distance learning requires careful course design due to several limitations in the online environment. The absence of physical presence of peers and instructor, lack of immediate feedback, and technical difficulties can lead to feelings of isolation and hinder collaborative learning [22]. The requirement for a higher level of autonomy and independent learning in online courses can pose difficulties to some students, particularly undergraduate students [23]. Stohr observed polarized student performance in online flipped classrooms between students who regularly participated in synchronous sessions and those who skipped the synchronous activities [24]. This warns that the online flipped classroom is at risk of losing its benefits without a well-structured approach to promote regular attendance in synchronous sessions.

This paper presents the design and implementation of an online flipped classroom for a Fluid Mechanics course. Beyond simply inverting the class, the paper leveraged multi-stage assignments at incremental difficulties to enhance student performance through knowledge reinforcement. The paper also focuses on the use of technology to minimize the barriers in online communication and facilitate collaborative learning. Lastly, the paper provides a direct comparison in student performance between the students in online flipped classroom sections and those from in-person traditional lecture-based sections taught by the same instructor.

Course implementation

In Fall 2020, two sections of 3-unit ME 111 Fluid Mechanics were taught as a fully online course using flipped classroom format. It is a required course in both Mechanical Engineering (ME) and Civil and Environmental Engineering (CEE) departments at the author's university. Typically, students take this course in their junior years. The topics covered in this course include fluid properties, hydrostatics, dynamics of flow, energy and momentum analysis, and internal and external flows. The identical course structure, materials, and assignments were used for both online sections. The course used a bi-chronous online instruction mode that included both asynchronous lectures through recorded videos and synchronous 90-minute weekly class meetings at a designated day/time. For each topic, students followed the sequence below to learn about the materials, practice skills in solving engineering problems, and reinforce their knowledge.

1. Watch lecture videos of a total duration of 1 - 2 hours weekly.
2. Submit homework (HW) assignments by the day before the class.
3. Attend weekly synchronous class meetings and actively participate in group worksheet activities.
4. Submit worksheet (WS) write-ups by the next day of the class.
5. Before midterms and the final, submit a practice-problem set assignment that includes problems from multiple topics.
6. Test your knowledge through quizzes, midterms, and a final.

A total of 42 topic-by-topic lecture videos were recorded with 27 minute-length on average, and 2 to 5 of these were assigned each week. The total runtime of videos assigned each week was 104 min on average. In addition to watching the lecture videos, students submitted one homework and one worksheet assignment in typical weeks. The course grade weighting is shown in Table 1.

Table 1

Course grade weighting used in the online flipped Fluid Mechanics course

Component	Weighting
Homework (11 in total)	10%
Worksheet (11 in total)	10%
Practice problems (3 in total)	5%
Quizzes (4 occurrences)	20%
Midterms (2 occurrences)	30%
Final Exam	25%

Syncing the material delivery paces with assignment deadlines

The online flipped classroom was designed such that the learning takes place in a completely sequential way; lectures and assignments related to one topic were completed before moving on to the next topic. This is in drastic contrast to traditional lecture-based classes that inherently exhibit misalignment between the paces of lecture and assignment. In traditional classes, students submit a homework after roughly a week from attending the class teaching the related topics. As a result, students are usually still in the process of digesting the previous week's materials through homework assignments while the instructor starts covering the next topic in lectures. This can lead to students' unpreparedness for the next level and inefficient use of class time. Figure 1 is a schematic that compares representative timelines for a hypothetical T/Th traditional lecture-based class and a once-a-week flipped class. The first-row timeline indicates class times and the second row denotes due dates of assignments, which correlates with the instructor's interest and students' interest, respectively. The instructor's pace and students' pace are synchronized in the flipped class, whereas they are offset by 1 week in the traditional class.

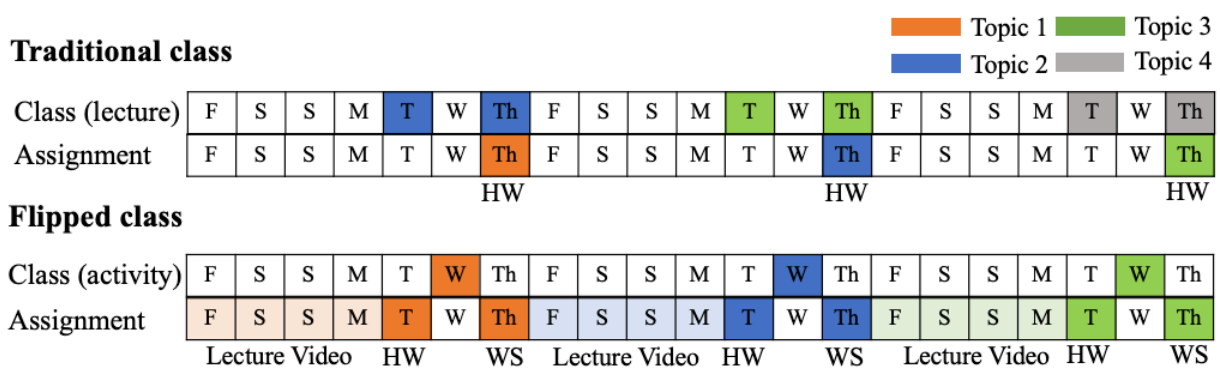

Figure 1. Class and assignment timelines for a hypothetical T/Th traditional class and the online flipped class. Each color represents a different topic. The first row indicates the days that the class meets to cover each topic in different colors. In the second row, the due dates for assignments associated with each topic are marked. The lighter color indicates the duration during which students watched lecture videos in online flipped classes (with no hard deadline).

In addition to syncing the pace, homework assignments were redesigned in a way that homework problems were directly linked to example problems presented in pre-recorded videos. Figure 2 demonstrates the high degree of correlation between an example problem from a lecture video and a homework problem in the same module. Homework problems were essentially the variants of the example problems, and they were produced by simple modifications of geometry, dimension, parameter values, materials, unknown variables, or unit systems. Homework also included concept problems, simple calculations of important parameters such as Reynolds number, and sometimes the same example problems that were partially solved in the lecture videos. Students were encouraged to work on homework problems while watching or immediately after watching the lecture videos. This structure allows lecture videos to serve as guidance for homework problems, which provides additional motivation for students to watch the lecture videos on time.

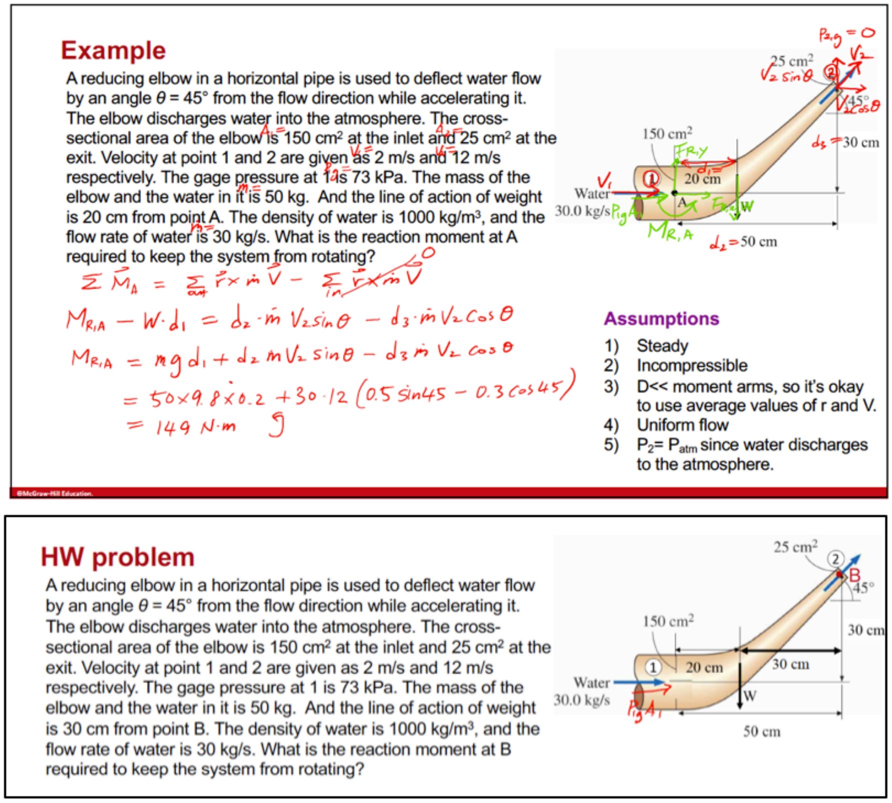

Figure 2. Comparison of an example problem solved in a lecture video (top) and a homework problem (bottom) included in the angular momentum analysis module.

Web-friendly in-class group activities to facilitate collaborative learning online

Weekly synchronous online class meetings took place through Zoom platform for guided group problem-solving activities. During each class, students worked on 2 to 4 problems called worksheet problems that were at a higher difficulty level and complexity than homework problems. For each of the problems, the class proceeded with the following sequence: comprehension of the problem, group discussion in breakout rooms, and wrap-up discussion. Each step took approximately 5 to 15 minutes. During the comprehension step, the instructor helped students understand the problem and reviewed the key concepts and equations related to the problem. Students were also reminded of the well-defined deliverables expected at the end of the breakout sessions.

During the group discussion in Zoom breakout rooms, students collaborated in stable groups of three students to analyze the problem. The pre-assigned breakout rooms were set up using students' preferred email addresses collected at the beginning of the semester. For the pre-assignment to work smoothly, the class zoom meetings had to require 'registration at each occurrence.' Students were informed to always register using the same email address as the one they used in the first class. New group sets were formed after Midterm 1 and Midterm 2 based on the midterm results such that average midterm scores are similar between groups.

Figure 3 shows an example worksheet problem that includes both the full problem description in black font and group discussion questions in blue font. Due to limited class time, breakout sessions focused mostly on formulating the core analysis steps rather than solving the entire problem. Boxes and blue font were used as visual cues for the clear deliverables required. Students received 50% of the worksheet score through group submission for their answers to blue-font discussion questions. The other 50% of the score was awarded based on the individual submission of the complete analysis to the full problems. The individual submission offered an additional way for students to repeat and review the analysis independently.

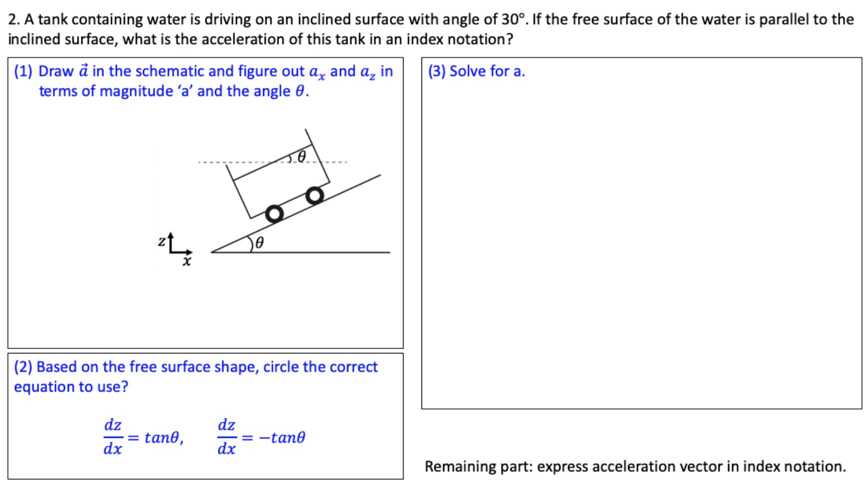

Figure 3. An example worksheet problem including the full problem description (black font) and the discussion questions (blue font). The problem was posted on Google Slide where students collaboratively worked on filling out answers to the blue-font questions during in-class worksheet activities.

Google Slides and Zoom annotation were used to facilitate smooth communications. Google Slides allowed group members to simultaneously type equations while discussing. And students used Zoom annotation tools to draw schematics or engineering notations on the shared screen of the Google Slides. In the meantime, the instructor randomly visited roughly 5 groups per breakout session to gain feedback on students' progress, provide customized help for each group, and dynamically adjust the pace in real-time. Students were frequently reminded to use the 'call for help' button to bring the instructor into their breakout room for questions.

Followed by the breakout session, the instructor led a wrap-up discussion with the entire class. Students were encouraged to share their progress, questions, uncertain parts, and challenges they faced during the breakout session. Sometimes students screen-shared the group's Google Slides to present their approach and work in progress to gather feedback. In addition, Zoom chat was utilized to report and match intermediate answers between groups. Some groups finished the problem during class time, others finished by the next day of the class time.

Knowledge reinforcement through multi-stage assignments at incremental difficulty

The course was structured to reinforce the newly acquired knowledge through a series of three assignments due at different times. The three sets of assignments, namely homework, worksheet, and practice problem set, had varying difficulty levels and served different purposes. The homework assignment was at the basic level and it was used to build foundational understanding and confidence. These are problems that had to be independently solved before the class meetings, and the step-by-step analysis of resembling example problems in lecture videos served as guidance to the homework problems. The intermediate-level worksheet problems were solved as a group during synchronous Zoom meetings. Students received immediate support on obstacles through peer interaction or the instructor's assistance. A day before midterms or finals, students completed practice problem sets, which consisted of McGraw Hill Connect problems from multiple chapters within the scope of each exam. These problems were of the highest complexity and difficulty, giving students opportunities to challenge themselves and test their understanding and skills in preparation for the exam. The multi-stage assignment structure let students revisit each topic three times throughout the semester and allowed learning through repetition.

Assessment methodology

Two sections of the online flipped classroom were compared to two in-person traditional lecture-based sections previously taught. Section A and B represent the two sections taught identically in an online flipped classroom format in Fall 2020. Section C1 and C2 were taught respectively in Spring 2018 and Spring 2019 as traditional lecture-based courses. Although the term 'traditional' was used to emphasize that there were no pre-class assignments (not flipped), the section C1 and C2 included in-class problem solving to promote active engagement and collaborative learning. All four sections were taught by the same instructor and had the same grade weighting for homework, worksheet assignments, midterms, and the final. However, in the section C1 and C2, homework assignments were due one week after the in-person lecture covering the relevant topic, whereas the section A and B had homework assignments due a day before the class meetings. Also, the section C1 and C2 did not include practice problem set assignments. Table 2 below summarizes basic course information of the two online flipped classroom sections as well as two in-person traditional sections used as controls.

Student engagement was monitored throughout Fall 2020 for the two sections offered as online flipped classrooms (section A and B). The number of absent students in each synchronous class meeting was recorded based on the participant list of Zoom meetings. The data was used to generate the time course plot of attendance. For student performance, cumulative final exams were used as an assessment tool. Two sets of final exam problems at different difficulty levels were used for the study. The final exam version 1 included a total of 10 concept problems and 4 analytical problems, and it was used for the section A and C1. The final exam version 2 included 9 concept problems and 5 analytical problems, and it was used for the section B and C2. The final exam version 2 was at a higher difficulty level than version 1. The same grading rubric was used for each pair of sections administered with the same version of the final exam.

Table 2

Course information of the two online flipped classes and two in-person traditional sections used in the study

	Section A	Section B	Section C1	Section C2
Offering semester	Fall 2020	Fall 2020	Spring 2018	Spring 2019
Number of students who took the final exam	45	41	74	50
Number of students who did not take the final and received WU grade	2	0	0	2
Number of worksheets	11	11	5	19
Assignment weighting towards final grade	HW 10%, WS10%, PP5%	HW 10%, WS10%, PP5%	HW10% WS10%	HW10% WS10%
Final exam	Version 1	Version 2	Version 1	Version 2

A series of careful measures were taken to eliminate the possibility of cheating during the exams conducted in the online flipped classroom. The synchronous online final exam was proctored in real-time through Zoom videos. All students set up their cameras at an angle that captures their faces and both hands throughout the exam duration. The instructor closely watched the individual's activity and made sure no one touched prohibited resources such as cell phones or tablet PCs during the exam. In addition to the real-time proctoring, Zoom meetings were recorded during the entire duration of exams for any necessary post-exam investigation. The exam problems posted on Canvas were only accessible by the passcode given via Zoom at the start of the exam. Canvas Lockdown Browser was required to prohibit students from browsing any other web-based resources. In the syllabus and in the beginning of each exam, students were reminded of the consequences of violating the academic integrity: receiving a zero on the exam and being referred to the Student Conduct and Ethical Development office. In addition to entering the final answers to each problem on Canvas, hand-written analyses were scanned and uploaded within 15 min after the exam to allow the instructor to review and assign partial credits. The instructor cross-compared the Canvas-recorded answers and the hand-written analyses on the scanned document to check for any suspicious cases and found no evidence of cheating in any of the sections.

Results

As a result of assignment restructuring, the total number of graded assignment problems has increased in the online flipped classroom compared to the previous in-person traditional lecture-based classes. In Figure 4, the number of problems that belong to all graded assignments in the online flipped class (orange) is compared to control cases (gray and blue). The online flipped classes (section A and B) had an average of 28.7% more problems than the section C2, and 65.8% more problems than the section C1. This is mainly attributed to the newly added basic-level homework problems that carry high similarity to the example problems. Also shown in Figure 4 is the distribution of the number of assignment problems over different topics, which are conveniently labeled with the corresponding chapter numbers in the course textbook by Cengel and Cimbala, Fluid Mechanics, 4th ed. Table 3 summarizes the list of main topics associated with each chapter. For kinematics and energy analysis topics, a fewer number of problems were used for assignments in online flipped classes. This was due to shortened time dedicated to these chapters as a result of rearranging the materials to fit into week-long modules.

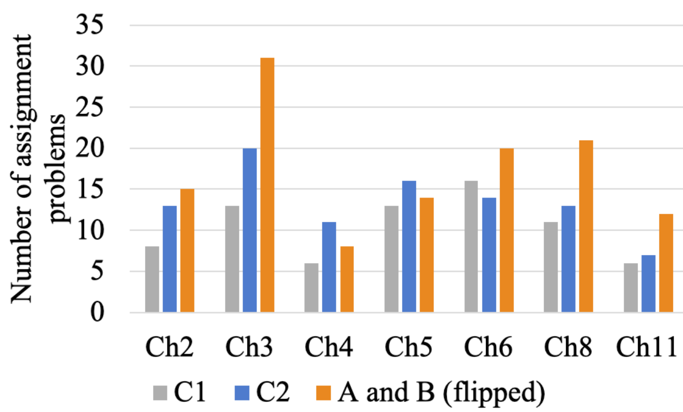

Figure 4. Comparison of the total number of problems used in assignments across sections. The data is presented based on the textbook chapters, whose topics are detailed in Table 3. The gray and blue bars indicate the total number of problems in the assignments (homework and worksheet) used in the in-person traditional sections C1 and C2, respectively. The orange bars indicate the total number of problems in the three assignments (homework, worksheet, practice problem sets) used in the online flipped classrooms (A and B).

Table 3

Topics covered in each chapter of the textbook, Cengel and Cimbala, Fluid Mechanics, 4th ed.

Chapter	Topic
Chapter 2	Properties of fluids
Chapter 3	Pressure and fluid statics
Chapter 4	Fluid kinematics

Chapter 5	Energy analysis
Chapter 6	Momentum analysis
Chapter 8	Internal flow
Chapter 11	External flow

Figure 5 presents the number of absent students in each synchronous class meeting, which is labeled with the corresponding worksheet number. The average student attendance in the online flipped classroom sections A and B were respectively 96.2% and 98.4%. Based on the data from the two sections combined, there were only 1.14 student absences on average in the online flipped classroom in Fall 2020. This excludes two students who received WU (withdrew unofficially) grades from the section A. Teaching the same course in two different formats, the instructor could see the clear difference not only in student attendance rate but also in the level of participation and engagement during classes. The instructor witnessed students discussing with classmates during every breakout session, and many students expressed their opinions during wrap-up sessions through chat, voice, or screen share.

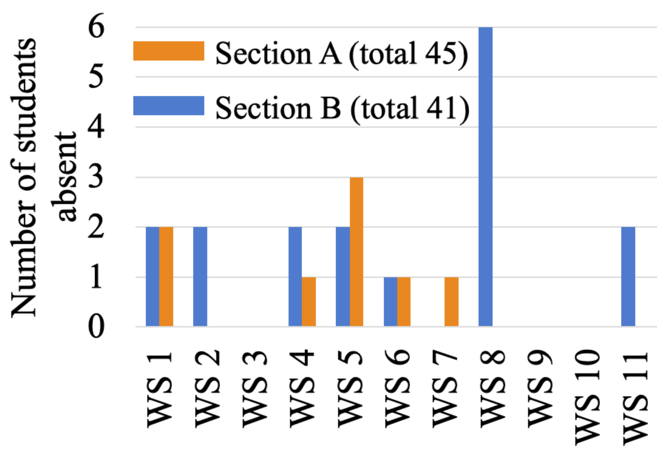

Figure 5. Student attendance over time among the students who participated in the final exam. The *x*-axis represents weekly assigned worksheet numbers. The figure does not include participation data on the first day of the semester and the midterm and final exam dates.

Regarding student performance, the average final exam score was higher in both online flipped classroom sections compared to traditional lecture-based sections. For the final exam version 1 at lower difficulty, the online flipped classroom section A had a 3.51% higher final average compared to the in-person traditional section C1. Likewise, for the final exam version 2 at a higher difficulty level, the online flipped classroom section B has shown a 3.47% increase in the final score compared to the section C2. Students who received WU grades did not take final exams and therefore not included in the analysis (two in section A and two in section C2). A similar increase in the student performance in both sections using two distinctively different difficulty levels of final exams implies that the pedagogy was effective for a wide range of students. Standard deviation slightly decreased for both online flipped classroom sections compared to in-person traditional sections.

Table 4
Learning outcome comparison between online flipped classroom sections and in-person lecture-based sections

	Final exam version 1		Final exam version 2	
Section	Section C1	Section A	Section C2	Section B
Teaching format	In-person traditional	Online flipped	In-person traditional	Online flipped
Average final exam score (out of 100)	80.1	82.9	71.1	73.6
Standard deviation	12.9	11.5	16.8	16.0

Limitations and improvement recommendations

Similar limitations generally applicable to flipped classrooms are the areas for improvement in the current implementation as well. First, the instructor's time commitment should be considered. In the first offering, a pre-semester time commitment is required by the instructor to record lecture videos. However, this is a one-time commitment that shortens the time spent on lecturing in future offerings. There are two kinds of additional work that an instructor should expect in the online flipped classroom compared to traditional courses: time to manage pre-assigned breakout groups and increased grading loads. During Fall 2020, student groups were shuffled twice during the semester, in which event the instructor re-grouped students manually to roughly match the average exam scores between groups. Potentially a custom-written software program can be developed to automate the grouping procedure. The use of multiple assignments for reinforcement increased the number of assignments to grade. Weekly, individual and group submissions of worksheets as well as homework had to be graded, excluding quizzes and exams. Worksheet grading was less intensive than homework grading because most students only had minor errors as a result of receiving interactive support during class time. In the future, self-grading or peer grading could be considered for worksheets for further reduction of grading workload.

Having students get fully prepared before arriving at class is a well-known challenge in using a flipped classroom format. As preventive measures to minimize the number of students unprepared for class, homework deadline was scheduled right before each class and no late submission was allowed. However, not all students watched lecture videos before attending classes. In the future, leveraging embedded quizzes in the lecture videos with 3-5% grade weighting is recommended. In addition, instructors are encouraged to regularly monitor the assignment submission to identify students falling behind the schedule. Reaching out to them individually via email and encouraging them to visit office hours for a 1-on-1 catch-up sessions can help some students get back on track.

Because flipped classrooms heavily involve group work, there is an inherent potential for conflicts among group members mainly due to uneven contributions to the group activities. To mitigate the issues, each member was asked to take distinct roles such as spokesperson, file manager, and quality inspector. To facilitate an early remedy, an anonymous survey on group activity-participation could be used in the future. Local rearrangement of group members among a few groups with the identified needs can be pursued in the event of a conflict. Although group sizes of 3 to 5 students have been recommended in promoting collaborative learning,[25] the effect of the size and lifetime of groups on student engagement during group activities in remote learning environments remains a future study.

Conclusions

Flipped classroom pedagogy has been implemented in an online 3-unit Fluid Mechanics course as a way to resolve common issues associated with online education such as students feeling isolated and not supported. The current study leveraged the bi-chronous model for an online flipped classroom where students asynchronously watched lecture videos and then attended 1.5-hour synchronous Zoom class meetings for collaborative activities once a week. Homework consisted of problems highly correlated to examples used in the lecture videos to increase support for independent learning. By having the homework and worksheet deadlines right before and after the class, respectively, the paces of lecture and assignment were synchronized. In addition, students were assigned various problems from the same topic three times throughout the semester, promoting the knowledge reinforcement by repetition. The two main areas of improvement with the current implementation were student participation and performance. An average of 97.3% of students attended synchronous online class meetings throughout the semester. The student performance based on section-averaged final scores increased by 3.5% compared to the data obtained from in-person traditional lecture-based sections using the same final exam problems. Overall, the paper demonstrates the effectiveness of a carefully designed online flipped classroom for enhancing student engagement and performance. The incremental multi-stage assignment and the synchronized course pace with assignments served as synergetic strategies in the online flipped classroom. However, the underlying principles, namely promoting knowledge reinforcement and increasing the correlation between assignments and lectures, will be generally applicable regardless of course modality and pedagogical methods.

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